Enhancing Belize's Resilience to Adapt to the Effects of Climate Change

Project Number 00083646

Contract Number: GCCA/PS/2013/01

In-Depth Final Report

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March 20, 2014

ACKNOWLEDGEMENTS

We would at first like to express our gratitude to the Government of Belize, Ministry of Forestry, Fisheries and Sustainable Development and UNDP Belize for giving us the opportunity to undertake this Consultancy on ‘Enhancing Belize’s Resilience to Adapt to the Effects of Climate Change’ **(**Project Number 00083646;Contract Number: GCCA/PS/2013/01).

We would also like to express our gratitude to Mrs. Ann Gordon, Ms. Safira Vasquez and Ms. Idé McKoy of the Belize National Climate Change Office, Ministry of Forestry, Fisheries and Sustainable Development for having facilitated the field work and the logistic arrangements for the project.

We are also thankful to Mrs. Diane Wade Moore and Ms. Stephanie Lozano of UNDP Belize for handling all the contract arrangements.

We are also grateful to INSMET (Mr. Abel Centella and Mr. Arnoldo Bezanilla) for having provided the ECHAM 5 and HadCM3-QUMP climate scenarios data and the Caribbean Community Climate Change Centre for facilitating the data transfer.

We also recognize the efforts of Ms. Stacey Cayetano in assisting in the data collection locally.

Finally, we are thankful to all participants and stakeholders who attended the Validation Workshop and who provided insightful comments on the In-Depth Draft Report.

LIST OF ACRONYMS

A1B	Median Emissions Scenario
AF5	IPCC Fifth Assessment Report
A-OGCM	Atmosphere-Ocean General Circulation Model
BEST	Belize Enterprise for Sustainable Technology
CCA	Climate Change Adaptation
CCSI	Climate Change Solutions International
CCCCC (5Cs)	Caribbean Community Climate Change Centre
CRFM	Caribbean Regional Fisheries Mechanism
CMIP3	Coupled Model Intercomparison Project phase 3
CPACC	Caribbean Planning for Adaptation to Climate Change
DRM	Disaster Risk Management
DSSAT	Decision Support System for Agrotechnology Transfer
FAO	Food and Agriculture Organization
ECHAM5	European/German General Circulation Model (version 5)
ENSO	El Nino Southern Oscillation
HadCM3	Hadley Centre General Circulation Model (version 3)
HadCM3Q11	Hadley Centre General Circulation Model (QUMP)
INSMET	Instituto de Meteorologia de Cuba
IPCC	Intergovernmental Panel on Climate Change
INC	Initial National Communication
IP	Implementation Plan
ITCZ	Inter Tropical Convergence Zone
JSDF	Japan Social Development Fund
MACC	Mainstreaming Adaptation to Climate Change
MPI-M	Max-Planck-Institute for Meteorology
NAPs	National Adaptation Plans

NMHS	National Meteorological and Hydrological Service of Belize
PAHO	Pan American Health Organization
PCMDI	Program for Climate Model Diagnosis and Inter-comparison
PGIA	Philip Goldson International Airport
PRECIS	Providing REgional Climates for Impacts Studies
QUMP	Quantifying Uncertainties in Model Projections
SSF	Small-Scale Fisheries
SNC	Second National Communications
TNC	Third National Communications
SRES	Special Report Emissions Scenarios
SNRL	Sustainable Natural Resources Based Livelihoods
UNDP	United Nations Development Programme
UNFCCC	United Nations Framework Convention on Climate Change
V&A	Vulnerability and Adaptation
WB	World Bank
WCRP	World Climate Research Programme
WHO	World Health Organization
WWF	World Wildlife Federation

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EXECUTIVE SUMMARY

This Consultancy Project focused on 'Enhancing Belize's Resilience to Adapt to the Effects of Climate Change: Project Number 00083646; Contract Number: GCCA/PS/2013/01)'.

The project undertakes an Integrated Vulnerability and Adaptation (V&A) Assessment consisting of: 1) Enhancing Belize's resilience to adapt to the effects of climate change and 2) Enabling Activities for the Preparation of Belize's Third National Communication to the UNFCCC.

The objective of the Third National Communication (TNC) project is to strengthen Belize's technical and institutional capacity to assist the mainstreaming of Climate Change activities into sectoral and national developmental planning priorities. In addition, it is expected to further build on the work done on the First and Second National Communications of Belize.

The V&A (vulnerability and adaptation) component aims to support more detailed assessments within priority development sectors, namely coastal development, water, agriculture, tourism, human health and fisheries.

The scope of the Integrated Assessment was to design a strategy, as applicable, to link the V&A studies with previous and on-going related projects/activities, such as the First (NC1, 2002) and Second (NC2, 2011) National Communications of Belize and National Adaptation Strategy (2008; 2009) for the water sector.

The Consultant, Professor Bhawan Singh of Climate Change Solutions International (CCSI), together with his Research Associates lead a multi-sectoral team from Belize in the preparation of this Final In-Depth Report on climate change adaptation requirements and measures based on an assessment of possible impacts of climate change and variability and including sea level rise and storm surges in Belize.

The multi-sector team of Consultants, led by Professor Bhawan Singh of CCSI, and consisting of Dr. Calin Obretin and Ms. Marylène Savoie provided an assessment of possible impacts of climate change on the natural and human resources of Belize based on projected changes in regional and global climate. Regional downscaled Climate Change scenarios data of climate variables including air temperature, rainfall, solar radiation and evaporation, on an annual, monthly and daily basis for Belize for the period 1961 to 2100 was provided by INSMET (Instituto de Meteorologia de Cuba) via the 5Cs (Caribbean Community Climate Change Centre). The data that was provided was PRECIS-downscaled scenarios of a version of the

HadCM3 and ECHAM5 climate models forced by the SRES A1B forcing scenario and recast on a 25 x 25 km grid spacing. Other climate scenarios data were accessed from The Climate Research Unit: University of East Anglia/Oxford University (McSweeney et al. 2009. 2010) and the National Meteorological Service of Belize (Gonguez, 2012).

The global climate models were downscaled by PRECIS (Providing REgional Climates for Impacts Studies) for the pertinent climate variables, namely maximum and minimum near-surface air temperature, rainfall, solar radiation and evaporation for a current 10-year period (2003-2012) and a future 10-year period (2060-2069).

The sea level rise scenarios selected were based on estimates provided by the IPCC (2013).

As for the climate change scenarios, both the ECHAM5 and HadCM3Q11 climate models consistently project an increase in temperature (^{0}C) for all Districts of Belize and for all seasons in the future (2060-2069) compared to the present (!961-1990). Though the HadCM3Q11 projections are slightly higher, both models project increases in seasonal temperature (^{0}C) that ranges from 2 to 4 ^{0}C and that display sometimes a fair level of spatial variation.

However, in the case of rainfall, both the ECHAM5 and HadCM3Q11 climate models generally project an overall decrease in seasonal rainfall in all seasons, especially the June-July-August rainy season. Furthermore, wide temporal and spatial variations in seasonal rainfall (mm/season) are projected for Belize. But in a zone centered over Stann Creek District and covering parts of Cayo, Toledo and Belize Districts and the offshore Cayes and atolls, the decreases in seasonal rainfall are most significant.

For the coastal zone sector, we at first examined the vulnerabilities to existing weather and climate variability, including sea level rise and storm surge scenarios (IPCC, 2007). These included low-lying coastal areas currently (2003-2012) affected by inundation, erosion and saline intrusions.

As for the vulnerabilities of the coastal zone to projected future (2060-2069) climate change and sea levels, this was done through data on sea level rise and storm surges gleaned from climate models (A-OGCM: Atmosphere-Ocean General Circulation Models) (IPCC,2013) and the Caribbean disaster mitigation project (2005).

Furthermore for the coastal zone of Belize under threat to sea level rise and storm surges we coupled current (2003-2012) and future (2060-2069) sea levels and storm surges to digital terrain mapping (DTM) using GIS techniques. These analyses allowed us to identify ecosystems (mangroves, sea grass, coral reefs...) and communities (fishing villages) that are likely to be at high risk to climate change and variability.

The total land area of the selected narrow coastal zone (10 km wide) at risk to inundation varied from ~ 210 km^2 for a sea level rise of 0.47 m (2040-2065) to ~ 1,754 km^2 for a sea level rise of 0.91 m coupled with a storm surge for a category 5 hurricane (2081-2100).

Furthermore, the landuse categories most affected by inundation are seagrasses, coastal wetlands mangroves and coastal forests, not to mention coral reefs.

We also focussed on the city of Belize. The coastal protection works that are highly uncoordinated and only about 1 meter or less high would only protect against slow-onset sea level rise but not against storm surges during tropical storms and hurricanes.

Based on these analyses, we identified adaptations options and barriers to adaptation to climate change (economic resources, technical knowledge, adaptive capacity, land availability for displaced peoples...) for the coastal zone sector. This component also addressed possible opportunities and priorities (coastal infrastructure and development, coastal zoning changes, setback limits...) for enabling effective and proactive adaptation to climate change and sea level rise in the coastal zone of Belize.

For the water resources sector we focussed on the increase (excess water and flooding) or decrease (more extreme droughts) in rainfall based on the relationship between Precipitation(P) and Evaporation (E), namely (P-E) for the future climate (2060-2069) compared to the current climate (1961-1990) for the stations with good quality data within the major hydrological regions of Belize, namely Tower Hill in Hydrological Region 7 representing the northern districts (Orange Walk and Corozal); Central Farm in Hydrological Region 9 representing central (Cayo and part of Belize); Melinda in Hydrological Region 11 representing the central and southern mountainous districts (Stann Creek and Toledo) and Punta Gorda, close to Hydrological Region 13, representing the extreme southern district (Toledo).

The results of the two climate models, namely ECHAM 5 and HadCM3Q11 show that all of the regions/stations examined will generally suffer increasing water deficits in the future (2060-2069) due to a combination of slight decreases in rainfall and moderate increases in temperature and evaporation.

The impacts of Climate Change on the water resources sector show that there are going to be challenges to Belize's capacity to respond. A priority then would be the further development of the Water Sector Adaptation Strategy to Climate Change in the Water Sector of Belize. These Strategies and Action Plans point to critical areas in need of further development and strengthening. These areas have to be pursued if the country is to sustain its abundant supply and preserve a sufficiently high quality of water for all users. For instance there should be a push towards greater water conservancy measures in agriculture and hydropower production and more efficient use of water in industry and domestic households.

As for the agriculture sector, we at first examine the current vulnerabilities of the agriculture sector to current climate conditions through a review of existing and through focus group meetings with technical experts in the Ministry of Agriculture and Famers Associations. We then coupled the future (2060-2069) climate scenarios (ECHAM5 and HadCM3Q11) outputs, namely daily air temperature, rainfall and solar radiation with different crop models to evaluate changing yields of the major crops, namely, sugarcane, rice and beans using the DSSAT (Decision Support System for Agrotechnology Transfer) and CROPWAT (Crop Water) models.

Based on discussions with the relevant stakeholders (Ministry of Natural Resources and Agriculture, it was agreed that for the crop simulations will be for the following /locations stations and the crops: Sugarcane: Richmond Hill or Tower Hill in Orange Walk District; Rice: Blue Creek or Richmond Hill in Orange Walk District; Citrus: Melinda Forest Station in Stann Creek District; Banana: Maya King in Stann Creek District and RK Beans: Central Farm in Cayo District.

The results show that the agricultural sector of Belize would suffer mainly negative impacts from future (2060-2069) climate change. Yields of the major crops, namely sugarcane, rice, bananas, citrus and RK beans, are all expected to decrease. These decreases in crop yields would result from an increase in air temperature accompanied by higher evaporation rates, variable rainfall and increases or decreases in rainfall, depending upon the location in Belize.

In the case where there will be excess water in the soil, due to higher rainfall, production costs will also likely increase because new drainage infrastructure will be necessary, especially for crops such as bananas.

Rainfed agricultural production systems will also be affected by the adverse impacts of changing climate on the rainfall pattern. This would place a high demand on management techniques for agricultural production and extra inputs into agriculture thereby resulting in an increase in cost of production. This creates the need to carry out adaptations in the sector, industry and markets, in producer strategies and in rural development strategies, with the objective of reducing social and economic costs.

The fisheries sector of Belize consists mainly of wild capture fisheries and is comprised of commodities such as spiny lobster, queen conch, pink shrimp, finfish, aquarium fish, aquatic invertebrates and stone crab. The spiny lobster, queen conch and pink shrimp (penaeus dourarum) are the most important ones with respect to production and economic value.

More recently aquaculture in Belize has become an important economic industry, most notably the culture of the Pacific White Shrimp (Litopenaeus vanammei). The aquaculture sector is now

firmly established as a significant contributor to the Belizean economy in terms of generating foreign exchange earnings.
Although aquaculture in Belize has been almost exclusively based on the farming of penaeid shrimps, the culturing of other species has been attempted in the past. These include the husbandry of: the Nile Tilapia (Oreochromis niloticus), the freshwater Australian Red Claw Lobster (Cherax quadricarinatus), the Redfish (Sciaenops ocellatus), and a number of African Rift Lake ornamental finfish species such as Haplochromis sp., Labeochromis sp., Melanochromis sp., Tropheus sp., Psuedotropheus sp. and Awlenocara sp. However, with the exception of Tilapia, the culturing of these species met with commercial failure, except for the Tilapia. There has been a recent interest in marine cage culture of other viable species such as the Florida Pompano (Trichinous carolinus) and the Cobia (Rachycentron canadum).

The effect of climate change and sea level rise on the fisheries sector of Belize will be mostly indirect. Fisheries require healthy habitats to survive and reproduce. Essential fisheries habitats in Belize include all types of aquatic habitats, namely wetlands, coral reefs and seagrasses where fish spawn, breed, feed, or grow to maturity. Rising sea levels could lead to partial or complete disappearance of these habitats through inundation. On the other hand rising near-surface water temperature and increasing acidification may cause massive bleaching and dieback of corals.

Another non-climate factor affecting fisheries stocks in Belize is overexploitation. The largest pressure on Belize’s fisheries stocks are from overfishing, including illegal fishing and this has caused a large-scale decline in fisheries production and exports in recent years.

However, the Belize Fisheries Department has taken the necessary steps to stop this practice. The Nassau Grouper has been regulated by imposing a closed season and limitations of fish size. Furthermore Parrotfish and other grazers have been fully protected since 2009 by government legislation regarding fishing seasons and sizes of catch.

Adaptive responses to climate change in fisheries could include: management approaches and policies that strengthen the livelihood asset base, improved understanding of the existing response mechanisms to climate variability to assist in planning adaptation; recognizing and responding to new opportunities brought about by climate change; monitoring biophysical, social and economic indicators linked to management and policy responses and adoption of multi-sector adaptive strategies to minimize negative impacts such as instituting Government regulations on fishing seasons.

The tourism industry in Belize is developing at a fairly fast rate, engaging a wide range of tourism operators and employment of significant numbers of Belize’s population. In fact, Belize’s tourism industry is the largest contributor to the gross domestic product and the largest source of foreign exchange.

Climate change, along with sea level rise, would result in loss of beaches, properties and public infrastructure and will make Belize less attractive as a tourist destination. The loss of beaches and coastline due to erosion, inundation and coastal flooding and loss of tourism infrastructure, natural and cultural heritage would reduce the amenity value for coastal users. Furthermore, some coastal areas in Belize will experience high levels of saltwater intrusion and rising water tables, thereby reducing water quality. Decline in water quality due to salinization of aquifers would lead to higher costs of water because Cayes and other coastal areas would need to invest in desalinization plants to provide fresh water for tourism. The overall effect of changing climate on Belize's tourism industry would be a loss of employment and higher insurance costs for properties in vulnerable area.

An assessment of the economic vulnerability of Belize's tourism industry to climate change mentioned that reef-based activities attract more than 80 percent of foreign tourists. Coral mortality from climate change and other human-induced impacts may reduce the appeal of visitors that would like to participate in underwater recreational activities. The assessment further suggested that perceptions of reef quality may be an important factor in the assessment of the vulnerability of tourism demand to climate change in Belize.

Climate change and climate-driven sea level rise will, in most likelihood, have important and severe impacts on the tourism industry of Belize. Increases in air temperature (2 ^{0}C to 4 ^{0} C) towards the end of the century may make conditions unbearable, especially for the elder retired tourist population, the major age group of tourists. Variability in precipitation that is also projected will very likely lead to extreme conditions, namely increasing drought in the dry season and torrential rains and flooding in the rainy season and to water and food shortages or higher prices if imported. Tropical storms and hurricanes, compounded by sea level rise, are also likely to increase in numbers and intensity, and apart from flooding and erosion of recreational beaches they will also very likely cause flooding and damage to transport and other infrastructure.

These projected changes in climate will have indirect secondary and tertiary effects on supply-based and demand-based systems upon which the tourism industry of Belize is dependent. Supply-based systems include: loss of beaches, loss of coral reefs due to temperature-induced bleaching, loss of food supply chains and loss of coastal infrastructure. Demand-based systems on the other hand include weather conditions in country of origin of tourists (mainly North America and Europe), perception issues such as security from extreme weather events and pricing policies for transport lodging and entertainment.

Climate change also has wide ranging consequences for human health. Public health depends on sufficient food, safe drinking water, secure shelter, good social conditions and a suitable environment for controlling infectious diseases. All of these factors can be affected by climate. Climate change is expected to exacerbate this condition. The basic requirements for good health are clean air and water, sufficient food and adequate shelter and each of these conditions are very likely to be affected by future climate changes.

Climate change will lead to higher levels of some air pollutants, will lead to an increasing number of extreme weather events and increased outbreaks and transmission of diseases through unclean water and through contaminated food, will threaten agricultural production in some of the poorest countries such as Belize. Furthermore, climate change will also bring new challenges to the control of infectious diseases. Many of the major killer diseases are highly sensitive to temperature and rainfall, including cholera and diarrhoeal diseases, as well as vector borne diseases including malaria, dengue and schistosomiasis.

Malaria and dengue fever, two diseases linked to climate change, have become major public health problems in Belize in the recent past, although malaria seems now to be controlled.

However, we focus attention on the two most common vector-borne diseases, namely dengue and malaria. Based on available data (2004-2012) for all districts of Belize, it appears that in the case of malaria, the trend for all of Belize is downward so much so that the disease is under control or eliminated in all districts except Stann Creek 2012. On the other hand the incidence of dengue has been increasing overall in Belize in all districts, except Orange Walk.

Adaptation options for the health sector in Belize include both climate and non-climatic factors. These adaptation measures are likely to include: current and future incidence of diseases; control of vectors (mosquitoes) for diseases (malaria, dengue); stagnant water control measures and sanitation improvements in areas where houses are built in swampy locations; looking after the most vulnerable population at risk such as the elderly, infants and young children and the economically disadvantaged groups; lifestyle changes such as eating healthier foods to maintain good health and improved health care and access, such as health alerts, more ambulances with more rapid response times and more health care centers and hospitals and professional staff.

Finally, in regards to Cross-cutting Issues, climate change impacts and vulnerabilities are not expected to occur in isolation. Non-climate factors such as population centers, linkages between sectors, as for instance the link between sea level rise and excessive rainfall and flooding in the low-lying coastal zone and the subsequent impacts on agriculture, tourism and human health and settlements should also be taken into consideration.

It is evident from the above sections that adaptation to climate change and sea level rise has to follow a holistic path by integrating adaptation measures across sectors. Adaptation policies should as a consequence be designed to link the various sectors of concern. It is evident that by addressing adaptation measures in regards to coastal protection works, that adaptation of the agriculture and water and tourism sectors, in particular, will be greatly facilitated.

Another social component of adaptation to climate change and other stressors is the question of alternative livelihoods for vulnerable peoples such as fishermen. Project that promote viable and sustainable natural resource-based livelihoods for poor communities in Belize, thereby reducing anthropogenic pressures, such as climate change, on the key natural resources through (1) support for social mobilization, facilitation, and community co-management, (2) development of community-based sustainable livelihoods of non-timber forest products in and around the selected protected areas, (3) support for innovative models of green livelihoods of fishing communities through mariculture development, and (4) community-led natural resources vigilance and knowledge dissemination need to be promoted.

The next steps should include, amongst others: cumulative impacts of climate change and sea level rise and how certain vulnerable groups may be affected in the short and medium term and the development and implementation of policy instruments such as NAPs (National Adaptation Plans) to move this process forward.

1.0 Introduction Section

This project undertakes an Integrated Vulnerability and Adaptation (V&A) Assessment consisting of: 1) Enhancing Belize's resilience to adapt to the effects of climate change and 2) Enabling Activities for the Preparation of Belize's Third National Communication to the UNFCCC.

The Enabling Activities for the Preparation of Belize's Third National Communication will enable Belize to prepare its Third National Communication to the United Nations Framework Convention on Climate Change (UNFCCC). The objective of the Third National Communication (TNC) project is to strengthen Belize's technical and institutional capacity to assist the mainstreaming of Climate Change activities into sectoral and national developmental planning priorities. In addition, it will build on the work done on the First and Second National Communications.

The V&A (vulnerability and adaptation) component aims to support more detailed assessments within priority development sectors, namely coastal development, water, agriculture, tourism, human health and fisheries. These new assessments will utilize more accurate scenario predictions developed by the Caribbean Community Climate Change Centre (5Cs) and Cuba's Institute of Meteorology (INSMET) and the Climate Research Unit (CRU)/Universities of East Anglia and Oxford, UK to support informed decisions on adaptation action by policy-makers, business, resource managers and the community at large.

The scope of the Integrated Assessment is to design a strategy, as applicable, to link the V&A studies with previous and on-going related projects/activities, such as the First (NC1, 2002) and Second (NC2, 2011) National Communications of Belize and National Adaptation Strategy (2008; 2009) for the water sector.

The Consultant, Professor Bhawan Singh of CCSI, together with his Research Associates lead a multi-sectoral team from Belize in the preparation of a report on climate change adaptation requirements and measures based on an assessment of possible impacts of climate change and variability and including sea level rise and storm surges in Belize. Analyses and data for climate change will be based on the work of the IPCC (2007; 2013) as well as on other scientific and technical information from the literature.

The multi-sector team of Consultants, led by Professor Bhawan Singh of CCSI, and consisting of Dr. Calin Obretin and Ms. Marylène Savoie provide an assessment of possible impacts of climate change on the natural and human resources of Belize based on projected changes in regional and global climate. Regional downscaled Climate Change scenarios data of climate variables including air temperature, rainfall, solar radiation and evaporation, on an annual, monthly and daily basis for Belize for the period 1961 to 2100 was provided by INSMET (Instituto de Meteorologia de Cuba) via the 5Cs (Caribbean Community Climate Change Centre). The data that was provided was PRECIS-downscaled scenarios of a version of the HadCM3 and ECHAM5 climate models forced by the SRES A1B forcing scenario and recast on a 25 x 25 km grid spacing. Other climate scenarios data were accessed from The Climate Research Unit: University of East Anglia/Oxford University (McSweeney et al. 2009. 2010) and the National Meteorological Service of Belize (Gonguez, 2012).

The sea level rise scenarios selected were based on estimates provided by the IPCC (2013).

The global climate models were downscaled by PRECIS (Providing REgional Climates for Impacts Studies) for the pertinent climate variables, namely maximum and minimum near-surface air temperature, rainfall, solar radiation and evaporation for a current 10-year period (2003-2012) and a future 10-year period (2060-2069).

The V&A assessments, based on the downscaled climate scenarios closely followed the methodology suggested by the UNFCC Secretariat (2008).

The sectors that are addressed in the V & A assessment are:

- Coastal Development
- Agriculture
- Water
- Tourism
- Fisheries
- Health

1.1 Coastal Development

For the coastal zone sector, we at first examined the vulnerabilities to existing weather and climate variability, including sea level rise and storm surge scenarios (IPCC, 2007). These included low-lying coastal areas currently (2003-2012) affected by inundation, erosion and saline intrusions.

As for the vulnerabilities of the coastal zone to projected future (2060-2069) climate change and sea levels, this was done through data on sea level rise and storm surges gleaned from climate models (A-OGCM: Atmosphere-Ocean General Circulation Models) (IPCC,2013) and the Caribbean disaster mitigation project (2005).

Furthermore for the coastal zone of Belize under threat to sea level rise and storm surges we coupled current (2003-2012) and future (2060-2069) sea levels and storm surges to digital terrain mapping (DTM) using GIS techniques (Singh and El Fouladi, 2005, 2007). These analyses allowed us to identify ecosystems (mangroves, sea grass, coral reefs...) and communities (fishing villages) that are likely to be at high risk to climate change and variability.

Finally, based on the foregoing analyses, we identified adaptations options and barriers to adaptation to climate change (economic resources, technical knowledge, adaptive capacity, land availability for displaced peoples...) for the coastal zone sector. This component also addressed possible opportunities and priorities (coastal infrastructure and development, coastal zoning changes, setback limits...) for enabling effective and proactive adaptation to climate change and sea level rise in the coastal zone of Belize.

1.2 Water Sector

For the water sector, we at first examined the vulnerabilities of the water sector (supply and demand) to current climate conditions. This was done through a review of existing documents (National Adaptation Strategy to address climate change in the water sector in Belize: Strategy and Action Plan: 2008, 2009; Second National Communications of Belize, 2009; CPACC (Caribbean Planning for Adaptation to Climate Change, 2001); MACC (Mainstreaming Adaptation to Climate Change, 2007) and IPCC (2007) and through focus group meetings with technical experts and stakeholders in the Ministries responsible for water resources.

We then examined how future climate change may affect future water resources, namely demand and supply, through the influence of changing seasonalities of rainfall and erratic weather patterns using observed (Belize Hydrometeorological Service) and downscaled scenarios data of climate variables including temperature, rainfall, solar radiation and evaporation, on an annual, monthly and daily basis for Belize for the period 1960 to 2100 that was provided by INSMET (Instituto de Meteorologia de Cuba) via the 5Cs (Caribbean Community Climate Change Centre). The data that was provided was PRECIS-downscaled scenarios of a version of the HadCM3 and ECHAM5 climate models forced by the SRES A1B SRES forcing scenario and recast on a 25 x 25 km grid spacing. Other climate scenarios data were accessed from The Climate Research Unit: University of East Anglia/Oxford University (McSweeney et al. 2009. 2010) and the National Meteorological Service of Belize (Gonguez, 2012).

The focus of the vulnerability assessment of the water sector was how climate change may lead to either water excesses or water deficits in the future. The methodology simply consisted of comparing values of precipitation (P), evaporation (E) calculated by the Priestly-Taylor ET method and water deficits or excess (P-E) for a selected current decadal (2000-2009) period against a future decadal period (2060-2069).

For the water sector calculations, at least one weather station was selected for each hydrological region (7, 9, 11 and 13). Furthermore, the choice of weather station was dictated by data availability for the current decadal period (2000-2010). Even as such, for certain stations missing data were filled in by choosing the mean value for the rest of the decadal period for the corresponding missing data.

Furthermore, we examined current and projected scenarios of socio-economic and environmental conditions (climate, population, shifting demands of competing sectors...) related to the water resources to evaluate impacts of, and vulnerability and adaptation to, climate change' (UNFCCC, 2008). These analyses will allowed us to identify sectors (potable water, agriculture, industry, including tourism) and communities that are likely to be at high risk to climate change and variability.

Finally, based on the foregoing analyses, we identified barriers to adaptation to climate change (economic resources, technical knowledge and adaptive capacity) in the water resources sector. This component also addressed possible opportunities and priorities (alternative water supply-desalination plants, water conservation measures) for enabling effective and proactive adaptation to climate change in the water resources sector.

1.3 Agriculture Sector

For the agriculture sector, we at first examined the vulnerabilities of the agriculture sector to current (2003-2012) climate conditions. This was be done through a review of existing documents (Bárcena et al. 2013, Ramirez et a. 2013, Belize Second National Communication, 2011) and through focus group meetings with technical experts in the Ministry of Agriculture and Famers Associations.

We also estimated changing yields of the major crops, namely, sugarcane, rice and beans using current (2003-2012) and future (2060-2069) climate scenarios data on temperature, rainfall, solar radiation and evaporation coupled with the DSSAT crop model, and possible impacts on citrus and bananas yields based on available data on climate and crop yields and trends from the literature of climate and non-climate factors. The sites for these experiments were chosen in consultation with the local/national authorities.

Finally, based on the foregoing analyses, we identified adaptation options and barriers to adaptation to climate change (economic resources, technical knowledge and adaptive capacity) in the agriculture sector. This component also addressed possible opportunities and priorities (modernization of agriculture) for enabling effective and proactive adaptation of agriculture to climate change.

1.4 Tourism Sector

For the tourism sector, we at first examined the vulnerabilities of the tourism sector of Belize, the major source of revenue for the country, to current (2000-2009) climate conditions.

This was done through a review of existing documents (Belize Tourism Board (BTZ): Travel and Tourism Statistics, 2011, 2012; Second National Communications of Belize, 2009; CPACC (Caribbean Planning for Adaptation to Climate Change, 2001); MACC (Mainstreaming Adaptation to Climate Change, 2007); National Sustainable Masterplan for Belize 2030: Project Implementation Manual (2011); CARIBSAVE Climate Change Risk Profile for Belize (2012) and IPCC (2007) and through focus group meetings with technical experts and stakeholders in the Ministry responsible for tourism in Belize (technical experts in the Ministry of tourism, hoteliers...).

We also examined and possible changing tourist arrival rates based on available data on climate (stations data on temperature, rainfall and sunshine hours), promotion and awareness campaigns and hotel occupancy and availability rates. We then addressed how future (2060-2069) climate change may affect the tourism sector in the future, through the influence of changing seasonalities of cloudiness and rainfall and erratic weather patterns using scenarios data that was provided by INSMET (Instituto de Meteorologia de Cuba) via the 5Cs (Caribbean Community Climate Change Centre). The data that was provided was PRECIS-downscaled scenarios of a version of the HadCM3 and ECHAM5 climate models forced by the SRES A1B SRES forcing scenario and recast on a 25 x 25 km grid spacing. Other climate scenarios data were accessed from The Climate Research Unit: University of East Anglia/Oxford University (McSweeney et al. 2009. 2010) and the National Meteorological Service of Belize (Gonguez, 2012).

These data enabled us to elaborate on climate and climate change factors affecting tourism, namely, rising air temperatures, sea-surface temperature, tropical storms and hurricanes intensity and frequency, sea level rise and storm surges and inundation and erosion of beaches and bleaching and destruction of coral reefs. Also, supply-based factors (beach loss, infrastructure destruction, pricing...) and demand-based factors (weather in host countries, perception of services and health and safety issues and prices and exchange rates) were also be examined. Results for these issues will be gleaned from Government of Belize documents and focus group meetings with pertinent stakeholders (technical experts in the Ministry of tourism, hoteliers...).

The chosen sites for these analytical studies are four typical tourist destinations in Belize, namely Belize City and Ambergris Caye in Belize District, Placencia in Stann Creek District and

Belmopan in Cayo District.

Furthermore, we examined current and projected scenarios of socio-economic and environmental conditions (tourist arrival rates, hotel occupancy rates, climate, quality of beaches and diving and snorkelling facilities ...) related to the tourism sector using information gleaned from the National Sustainable Masterplan for Belize 2030: Project Implementation Manual, 2011.

Finally, based on the foregoing analyses, we identified adaptation options and barriers to adaptation to climate change (economic resources, technical knowledge, adaptive capacity...) in the tourism sector of Belize. This component also addressed possible opportunities and priorities (diversification of tourism activities – beach, hiking...) for enabling effective and proactive adaptation to climate change in the tourism sector.

1.5 Fisheries Sector

For the fisheries sector, we at first examined the vulnerabilities of the fisheries sector of Belize to current (2000-2009) climate conditions. We also examined catches of the major fish categories (lobster, shrimp, conch and whole fish for data available between 1977 and 2013. This was accomplished through a review of existing documents (Ministry of Agriculture and Fisheries: FISHERIES STATISTICAL REPORT 2012; Belize Fisheries Department; Villanueva (2012): Fisheries Statistical Report, 2011; Wade, 2010; BELIZE FISHERY COUNTRY PROFILE AND INFORMATION FAO DIGITAL ATLAS; Belize Environment Outlook (2010): Ministry of Natural Resources and the Environment; Belize Coastal Threat Atlas (2005): Reefs at Risk in Belize: Improving the information base for better management of coral reefs; CARIBSAVE Climate Change Risk Profile for Belize (2012): Summary Document, and through focus group meetings with technical experts and stakeholders in the Ministry responsible for the fisheries sector.

We the compare current (2003-2012) and future (2060-2069) decadal temperature and rainfall for three locations in the major fishing zones of Belize, namely Ambergris Caye representing Zone 1 (the closest weather station to zone 1), Belize City representing Zones 2 and 3 and Placencia representing Zones 3 and 6 in order to decipher climate change impacts on fisheries, including aquaculture..

We then examined how future (2060-2069) climate change may affect the fisheries sector in the future, through rising air temperatures, sea-surface temperature, tropical storms and hurricanes intensity and frequency, sea level rise and storm surges and inundation and erosion of beaches that increase water acidity and turbidity and bleaching and destruction of coral reefs.

Furthermore, we examined current and projected scenarios of socio-economic and environmental conditions (catch rates, ability of boats and divers to withstand stormy weather ...) related to the fisheries sector. These analyses also allowed us to identify both climatic (rising air temperatures, sea-surface temperature, tropical storms and hurricanes intensity and frequency, sea level rise and storm surges and inundation and erosion of beaches and bleaching and destruction of coral reefs...) and non-climatic (pricing, exchange rates, global economic conditions, local employment rates, poverty alleviation...) that are likely to influence the fisheries industry of Belize in the future.

Finally, based on the foregoing analyses, we identified adaptation options and barriers to adaptation to climate change (economic resources, technical knowledge, adaptive capacity...) in the fisheries sector. This component also addressed possible opportunities and priorities (provide promotion for tourism, local food security...) for enabling effective and proactive adaptation to climate change in the fisheries sector.

1.6 Health Sector

For the health sector, we at first examined the vulnerabilities of the health sector of Belize to current (2004-2012) climate conditions. This was done through a review of existing documents (Amarakoon et al. 2003; Belize Millennium Development Goals and Post 2015 Report, 2013; CARIBSAVE Climate Change Risk Profile for Belize, 2012; Ministry of Health, Belize, 2013: Health Statistics of Belize 2008 – 2012; Vanzie, 2008; PAHO, 2012 and WHO, 2012 and through focus group meetings with technical experts and stakeholders in the Ministry responsible for the health sector of Belize.

We also examined the relationship between the incidence of the major tropical diseases that may proliferate with climate change, namely dengue fever and malaria, based on limited (annual and monthly) available data.

We then addressed how future (2060-2069) climate change may affect the health sector in the future, through the influence of changing seasonalities of rainfall, in particular, that encourages the proliferation of vectors (mosquitoes) responsible for the incidence of dengue fever and malaria.

We also elaborated on climate and climate change factors affecting health, namely (rising air temperatures, intense rainfalls, tropical storms and hurricanes...). Vulnerability of human health to climate change was also be assessed by taking into consideration such socio-economic factors as poverty and nutrition levels and health care delivery. Results for these issues were gleaned from Government of Belize documents and focus group meetings with pertinent stakeholders (technical experts in the Ministry of Health, health professionals and institutions...).

These analyses also allowed us to identify both climatic (rising air temperatures, more intense rainfalls, tropical storms and hurricanes intensity and frequency, sea level rise and storm surges...) and non-climatic (living and environmental conditions, health of the population, health delivery systems...) that are likely to influence the health sector of Belize in the future.

Finally, based on the foregoing analyses, we identified adaptation options and barriers to adaptation to climate change (economic resources, technical knowledge, adaptive capacity...) in the health sector. This component also addressed possible opportunities and priorities (provide and promote early warning systems regarding health risks, the creation of more health services centres...) for enabling effective and proactive adaptation to climate change in the health sector.

1.7 Cross-cutting Issues

This section focussed upon and discussed cross-linkages between sectors in terms of vulnerabilities and adaptation. For instance, changes in the water sector (excess rainfall, drought...) will have impacts on the agriculture sector and adaptations in the water sector will influence adaptation in the agriculture and other sectors.

For instance, for the coastal zone and the Cayes of Belize, climate change impacts and vulnerabilities are not expected to occur in isolation. Non-climate factors, linkages between sectors, as for instance the link between sea level rise and excessive rainfall and flooding in the low-lying coastal zone and the subsequent impacts on agriculture and human health and settlements would also be taken into consideration.

Moreover, it is evident from the separate sectors reports that climate change and sea level rise would affect all sectors considered, namely the coastal zone, water resources, agriculture, fisheries and human health. The potential threats of climate change and sea level rise and storm surges along the coastal belt will be particularly acute due to the fact that a large percentage of the population of Belize resides within the coastal zone, and this is the area where soils are most suitable for cultivation of crops and where the vital tourism activities take place.

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Section 2: Climate Sector

2.0 Introduction

This section presents future climate scenarios for Belize from three sources, namely the UNDP Country Profiles, the National Meteorological and Hydrological Service of Belize and ECHAM5/A1B and HadCM3Q11/A1B PRECIS-downscaled seasonal data on mean temperature and rainfall.

2.1 UNDP Country Profiles

The data sets and results reported in this section are extracted from the United Nations Development Programme (UNDP) Climate Change Country Profiles project (McSweeney *et al.* 2008; 2009) that provides country-scale data files and easily accessible analyses of up-to-date observed data and multi-model scenario-based projections for 52 developing countries in Africa, Asia the Caribbean and Central America, including Belize. The project facilitates the use of observed and modeled climate data in climate impact assessment and exploration by providing observed data and future climate projections modeled using the SRES (Nakicenovic, N., and Coauthors, 2000) scenarios in the IPCC Fourth Assessment Report for each country, including Belize in a standard format that is more manageable than the large global fields that are directly available from the Program for Climate Model Diagnosis and Inter-comparison (PCMDI) (McSweeney *et al*, 2008, 2010).

The data on current and future climates and climate scenarios (temperature and rainfall) together with time series climatologies (1961-2100) extracted from ensemble coupled Atmosphere-Ocean General Circulation Models (A-OGCMs) forced by three of the Special Report on Emissions Scenarios (SRES) marker scenarios used in the IPCC Fourth Assessment Report (2007), namely a high (A2), a low (B1) and a medium (A1B) emissions scenario that produce high, low and medium climate forcings and changes.

These country profiles and climate change scenarios were prepared by the University of Oxford in collaboration with the Tyndall Centre for Climate Change Studies (University of East Anglia) UNDP (McSweeney et al, 2008; 2009).The profiles were developed to address the climate change information gap in many developing countries by making use of existing climate data to generate country-level data plots from the most up-to-date climate observations and the multi-model projections from the WCRP CMIP3 archive (Meehl *et al.*, 2007).

The UNDP climate change profile report for Belize includes:

A set of maps and diagrams illustrating the observed and projected climates of Belize as:
An area-average time series for Belize showing observed climate combined with model-simulated recent and future climate under three SRES emissions scenarios (A2, A1B, and B1). For the models, the series depict the recent climate and future changes as a ‘plume’ that encompasses the range of the 15 model ensemble under each scenario to demonstrate the degree of model uncertainty;
Maps depicting projected changes for 10-year-average ‘time-slices’ for the 2030s, 2060s and 2090s under SRES emissions scenario A21 on a 2.5 x 2.5 ° grid demonstrating spatial variations in change across Belize. For each grid box the ensemble median change, and also the ensemble range is given.

A summary table of observed trends and projected change, averaged over the entire surface area of Belize: 2030s, 2060s and 2090s under SRES emissions scenarios A2, A1B, and B1 (McSweeney *et al*, 2008, 2010).

2.1.1 General Climate of Belize

Situated at latitude of 16-18°N, Belize has a typically moist tropical climate. There is little seasonal variation in temperature, but distinct ‘wet’ (May to October) and ‘dry’ (November to April) seasons. In the wet season, mean monthly rainfall can be 150 to 400 mm, with highest rainfall totals in the south. In the dry season, most of the country receives less than 100 mm of rainfall per month. The coastline of Belize is also vulnerable to Atlantic tropical cyclones and hurricanes from July through to October. Heavy rainfalls accompanying these storms contribute a significant fraction of the high wet-season rainfall totals.

Mean annual temperatures are 23-27°C, varying little with season through the year. The south-west, interior region of the country, due to its elevation (mountainous) tends to be a little cooler than regions in closer proximity to the coast.

Inter-annual variations in climate in southern Central America are caused by the El Niño Southern Oscillation (ENSO). El Niño events bring relatively warm and dry conditions between June and August, and decreased frequencies of Atlantic tropical cyclones, whilst La Niña episodes bring colder and wetter conditions at that time of year, and more frequent than average tropical cyclones (McSweeney et al, 2008, 2010).

2.1.2 Recent Climate Trends

2.1.3 Temperature

Mean annual temperature of Belize has increased by 0.45°C since 1960, an average rate of 0.10°C per, decade. The average rate of increase is most rapid in the wet seasons (MJJ: May-June-July and ASO: August-September-October) at 0.14-0.15°C per decade and slower in the dry seasons (NDJ: November-December-January and FMA: February-March-April) at 0.08-0.09°C per decade (McSweeney et al, 2008, 2010).

2.1.4 Precipitation

Mean annual rainfall over Belize has decreased at an average rate of 3.1mm per month per decade since 1960, but this trend is not statistically significant. Whilst all seasons appear to have shown decreasing precipitation trends since 1960, only the FMA season has a statistically significant trend.

The percentage of rainfall that falls in heavy events has not increased significantly since 1960. The observed maximum 1- and 5-day rainfalls generally show increasing trends, but are only statistically significant for 5-day rainfalls annually, and in the MAM season. Maximum 5-day rainfalls have increased by around 5.4mm per decade since 1960, annually, and by 2.7mm in the MAM season (McSweeney et al, 2008, 2010).

2.2. A-OGCM Projections of Future Climate and Sea Level

2.2.1 Temperature

For Belize overall, the mean annual air temperature is projected to increase in the 2030s by 0.4 °C to 1.3 °C according to the B1 scenario, by 0.4 °C to 1.7 °C according to the A1B scenario and by 0.7 °C to 1.5 °C according to the A2 scenario (Table 2.1 and Figure 2.1) (McSweeney *et al*, 2008, 2010).

In the 2060s, the mean annual air temperature is projected to increase by 0.8 °C to 2.0 °C according to the B1 scenario, by 1.2 °C to 2.9 °C according to the A1B scenario and by 1.7 °C to 2.9 °C according to the A2 scenario (Table 2.1 and Figure 2.1) (McSweeney *et al*, 2008; 2010).

Finally, by the 2090s, the mean annual air temperature of Belize is projected to increase by 1.3 °C to 2.7 °C according to the B1 scenario, by 2.0 °C to 3.8 °C according to the A1B scenario and by 2.8 °C to 4.6 °C according to the A2 scenario (Table 2.1 and Figure 2.1) (McSweeney *et al*, 2008; 2010).

Furthermore, the projected rate of warming is similar in all seasons, but more rapid in the southern (ASO) and western interior regions (MJJ) of the country than in the northern, coastal regions (McSweeney *et al*, 2008; 2010).

2.2.2 Precipitation

A-OGCM projections of mean annual rainfall from different models in the ensemble project a wide range of changes in precipitation for Belize. Ensemble minimum and median values of rainfall changes (mm/month and %) by the 2030s, 2060s and 2090s, however, are generally and consistently negative for all seasons and emissions scenarios

Overall, ensemble A-OGCM projections of mean annual rainfall decreases more and more from the 2030s to the 2090s. Furthermore, mean seasonal rainfall vary between a reduction of -26 % (A2: FMA) to an increase of +55 % (B1: ASO) by the 2090s, but with median values overall reductions of between -1 % (B1: NDJ) and -26 % (A2: FMA) (Table 2.1 and Figures 2.2 and 2.3) (McSweeney *et al*., 2008, 2010).

As for the changes in the spatial changes in rainfall into the future, it would seem, according to the A2 scenario, that generally, annual and seasonal rainfall would decrease slightly on average (~ -10 to - 20 %), especially in the 2090s and that these decreases in rainfall would mostly affect the southern half of Belize. Furthermore, the proportion of total rainfall that would fall in heavy events and maximum 1- and 5-day rainfalls, in the future (2060s and 2090s) does not show a consistent direction of change, but tends towards positive changes (increasing occurrences, except for the wet season months (MJJ) (Table 2.1) (McSweeney *et al*., 2008, 2010).

2.3. Other Regional Climate Changes

2.3.1 Tropical Storms and ENSO

Tropical cyclones are poorly captured by GCMs and thus potential changes in intensity and tracks of tropical cyclones in the future are very uncertain. Whilst evidence indicates that tropical cyclones are likely to become, on the whole, more intense under a warmer climate as a result of higher sea-surface temperatures, there is great uncertainty in changes in frequency, and changes to storm tracks and their interactions with other features of climate variability (such as the El Niño Southern Oscillation) which introduces uncertainty at the regional scale.

This uncertainty in potential changes in tropical cyclone contributes to uncertainties in future wet-season rainfall. Model simulations show wide disagreements in projected changes in the amplitude and frequency of future El Niño events. ENSO influences on the monsoon system in Central America and affects the position of the ITCZ, thus contributing to uncertainty in climate projections for this region (IPCC, 2007; Meehl et al, 2007; Gregory *et al*., 2004).

2.3.2 Sea level Rise

The coastal lowlands in northern Belize may be vulnerable to sea-level rise. Sea-level in this region is projected by climate models to rise by the following levels by the 2090s, relative to1980-1999 sea-level (IPCC, 2007):

0.18 to 0.43m under SRES B1;
0.21 to 0.53m under SRES A1B;
0.23 to 0.56m under SRES A2

But recent reports have claimed these sea level changes to be rather conservative. Regional variability in sea level change relative to the global average is projected to be higher in the North Atlantic in the region near Belize by the end of this century (Meehl *et al.*, 2007; Gregory *et al*., 2004). In fact other recent semi-empirical models estimate that sea level will rise more than 1 meter by 2100, at least double the IPCC (2007) estimates and even more than previously thought, largely due to increased mass loss from the ice sheets mainly in the Arctic regions (Rahmstorf, 2007 and 2010; Horton et al., 2008; Vermeer and Rahmstorf, 2009; Grinsted et al., 2009). Low-lying coastal areas as the coastal zone of Belize would therefore be particularly at risk to these higher projections of sea level rise (Meehl *et al.*, 2007; Jonathan *et al*., 2004).

Table 2.1: Summary of observed mean (1970-1999), observed trend (1960-2006) and projected changes for the 2030s, 2060s and 2090s of air temperature (°C) and precipitation (mm/month and %) on an annual basis and according to season for Belize (Source: McSweeney et al, 2008; 2009).

	Observed Mean 1970-99	Observed Trend 1960-2006		Projected changes by the 2030s			Projected changes by the 2060s			Projected changes by the 2090s		
				Min	Median	Max	Min	Median	Max	Min	Median	Max
Temperature												
	(°C)	(change in °C per decade)		Change in °C			Change in °C			Change in °C		
			A2	0.7	**1.2**	1.5	1.7	**2.2**	2.9	2.8	**3.6**	4.6
Annual	24.9	0.10*	A1B	0.4	**1.3**	1.7	1.2	**2.3**	2.9	2.0	**3.0**	3.8
			B1	0.4	**1.0**	1.3	0.8	**1.6**	2.0	1.3	**1.8**	2.7
			A2	0.6	**1.1**	1.4	1.5	**2.0**	2.9	2.4	**3.3**	4.7
NDJ	23.0	0.09	A1B	0.2	**1.2**	2.0	1.2	**2.0**	2.8	2.0	**2.6**	3.8
			B1	0.5	**0.9**	1.5	0.9	**1.4**	2.0	1.1	**1.5**	2.8
			A2	0.7	**1.1**	1.6	1.6	**2.1**	2.8	2.5	**3.5**	5.1
FMA	24.6	0.08	A1B	0.4	**1.1**	2.0	0.9	**2.2**	3.3	1.8	**3.0**	3.8
			B1	0.1	**0.9**	1.6	0.6	**1.6**	2.0	1.1	**1.8**	2.6
			A2	0.5	**1.3**	1.6	1.8	**2.4**	3.0	3.2	**3.8**	5.0
MJJ	26.3	0.14*	A1B	0.5	**1.3**	1.9	1.3	**2.3**	3.1	2.1	**3.1**	4.2
			B1	0.3	**1.0**	1.5	0.6	**1.7**	2.2	1.3	**2.0**	2.7
			A2	0.7	**1.2**	1.8	1.7	**2.4**	3.0	2.9	**4.0**	5.2
ASO	25.6	0.15*	A1B	0.5	**1.3**	1.8	1.3	**2.3**	3.1	2.2	**2.9**	4.0
			B1	0.5	**1.0**	1.5	0.9	**1.7**	2.3	1.4	**1.8**	2.8
Precipitation												
	(mm per month)	(change in mm per decade)		Change in mm per month			Change in mm per month			Change in mm per month		
			A2	-20	**-5**	9	-18	**-8**	8	-37	**-13**	0
Annual	172.7	-3.1	A1B	-20	**-5**	5	-25	**-9**	11	-33	**-10**	6
			B1	-15	**-2**	10	-22	**-5**	9	-20	**-5**	20
			A2	-20	**0**	6	-15	**-4**	9	-20	**-5**	10
NDJ	151.2	-0.3	A1B	-17	**-2**	5	-20	**-3**	22	-14	**-4**	12
			B1	-7	**-2**	15	-14	**-2**	3	-11	**-1**	12
			A2	-14	**-3**	5	-17	**-2**	15	-19	**-7**	6
FMA	58.6	-4.0*	A1B	-17	**-5**	26	-15	**-4**	0	-20	**-7**	1
			B1	-12	**0**	5	-16	**-2**	7	-16	**-1**	12
			A2	-22	**-6**	15	-50	**-17**	29	-55	**-26**	-4
MJJ	220.2	-3.0	A1B	-40	**-9**	0	-50	**-19**	24	-41	**-22**	21
			B1	-28	**-8**	14	-30	**-8**	18	-30	**-9**	11
			A2	-68	**-2**	54	-34	**0**	60	-94	**-15**	29
ASO	258.5	-4.8	A1B	-34	**0**	46	-28	**-11**	30	-78	**-8**	33
			B1	-34	**-2**	50	-51	**-3**	28	-60	**-9**	55
Precipitation (%)												
	(mm per month)	(change in % per decade)		% Change			% Change			% Change		
			A2	-22	**-7**	13	-47	**-12**	10	-64	**-22**	0
Annual	172.7	-1.8	A1B	-34	**-7**	7	-47	**-12**	15	-55	**-17**	8
			B1	-21	**-3**	15	-40	**-5**	13	-51	**-11**	26
			A2	-17	**-2**	9	-40	**-7**	12	-47	**-10**	15
NDJ	151.2	-0.2	A1B	-19	**-5**	14	-33	**-7**	32	-36	**-3**	17
			B1	-20	**-1**	19	-16	**-5**	8	-22	**-1**	17
			A2	-36	**-16**	5	-31	**-8**	29	-58	**-24**	9
FMA	58.6	-6.9*	A1B	-36	**-11**	30	-31	**-14**	3	-53	**-20**	7
			B1	-38	**0**	20	-30	**-7**	10	-39	**-9**	25
			A2	-34	**-12**	16	-67	**-33**	12	-83	**-43**	-4
MJJ	220.2	-1.4	A1B	-54	**-18**	1	-72	**-23**	10	-80	**-33**	9
			B1	-48	**-18**	14	-68	**-13**	41	-77	**-14**	20
			A2	-40	**-1**	40	-51	**0**	39	-70	**-16**	19
ASO	258.5	-1.8	A1B	-37	**0**	35	-62	**-9**	19	-65	**-12**	21
			B1	-31	**-3**	37	-58	**-9**	21	-77	**-9**	36

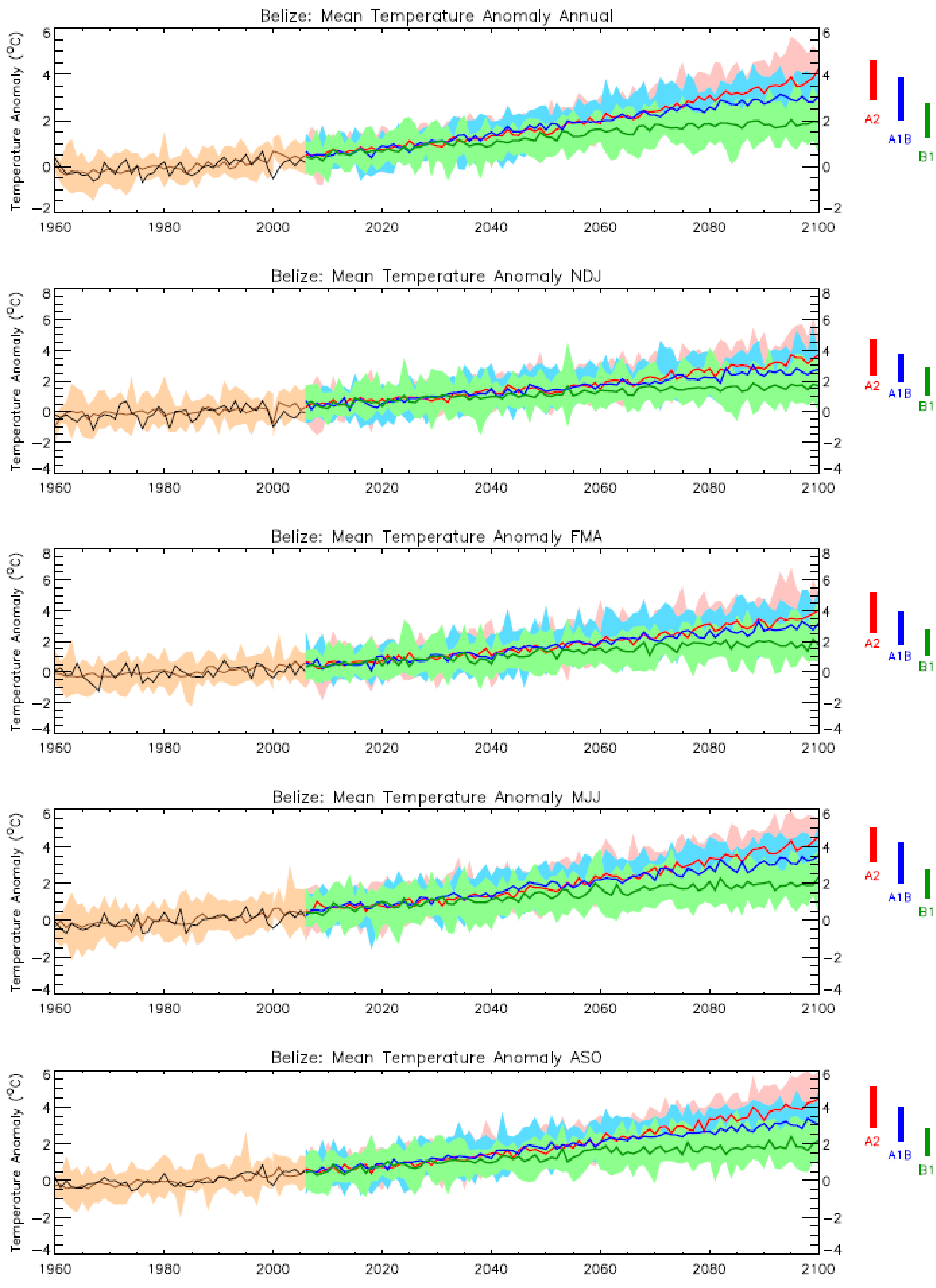

Figure 2.1: Observed (1960-2006) and projected (to 2100) annual and seasonal air temperature anomalies for Belize (referenced to 1970-1999 (McSweeney et al, 2008; 2009)

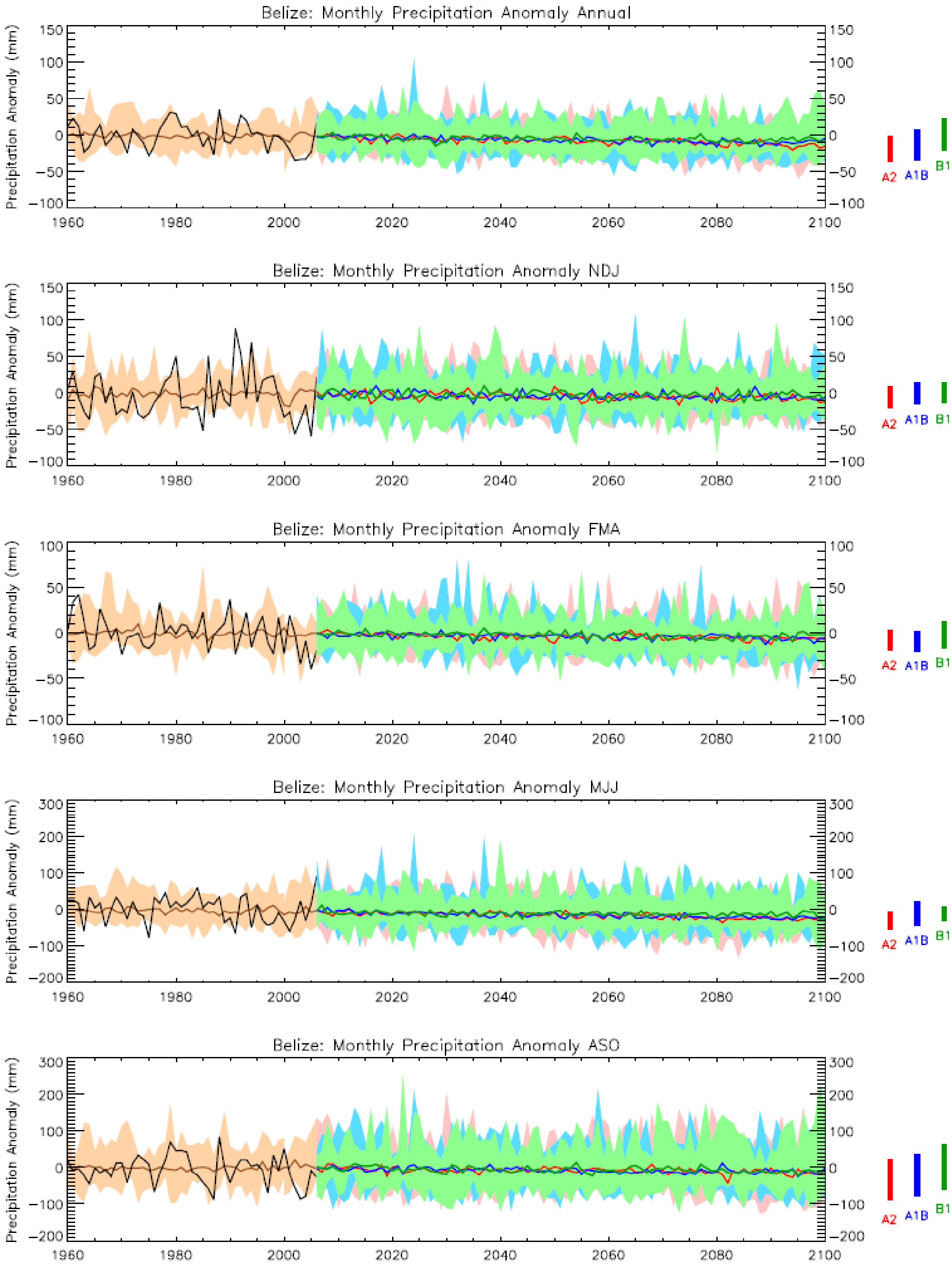

Figure 2.2: Observed (1960-2006) and projected (to 2100) annual and seasonal air precipitation anomalies (mm) for Belize (referenced to 1970-1999) (McSweeney et al, 2008; 2009)

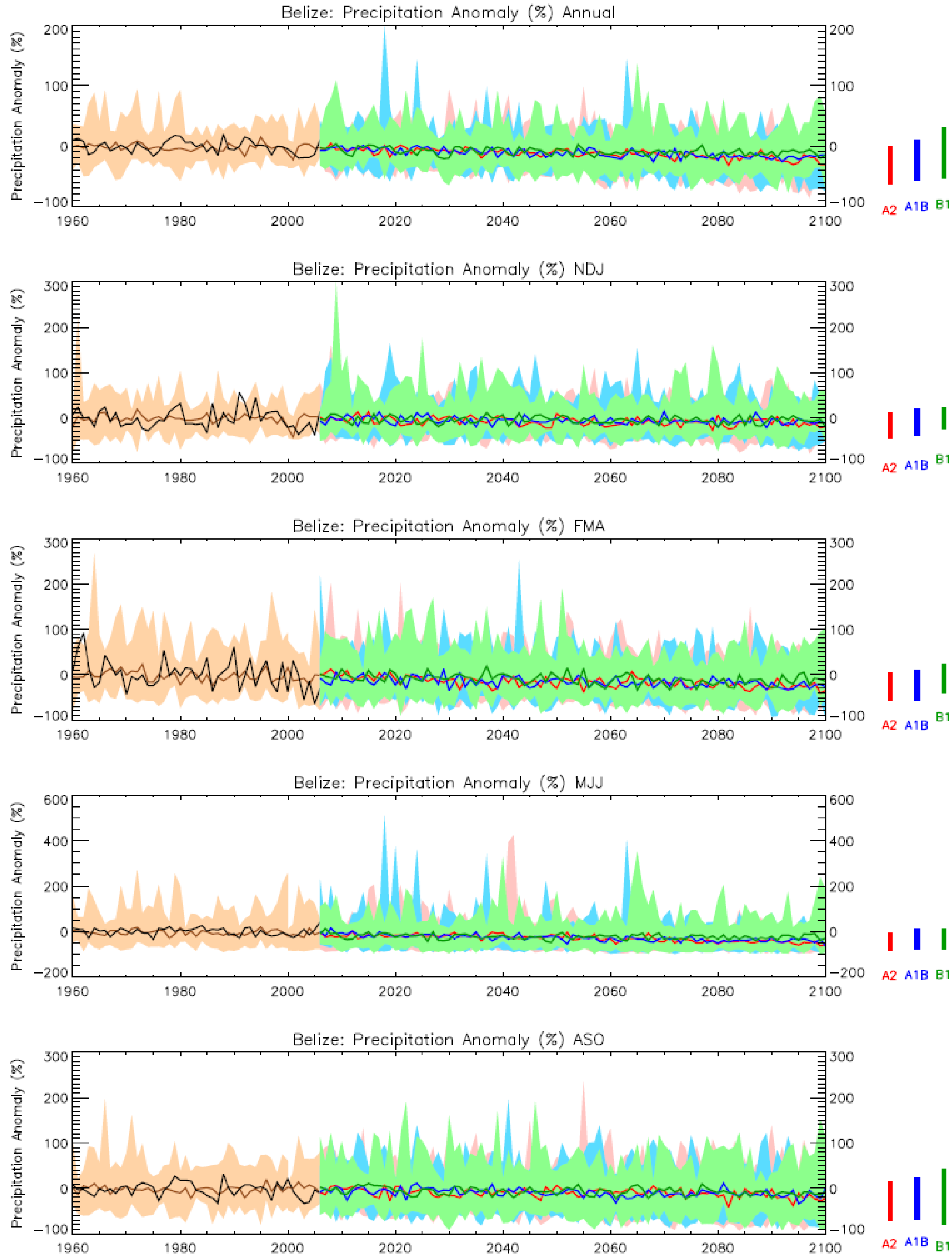

Figure 2.3: Observed (1960-2006) and projected (to 2100) annual and seasonal air precipitation anomalies (%) for Belize (referenced to 1970-1999) (McSweeney et al, 2008; 2009).

2.3.3 INSMET: National Meteorological and Hydrological Service of Belize

Climatological data from the National Meteorological and Hydrological Service of Belize (NMHS) database were used in identifying the trends in average rainfall and temperatures for 9 stations, namely: 1) Philip Goldson International Airport (PGIA); 2) Central Farm (CFM); 3) Belmopan (BMP); 4) Melinda Forest Station (MEL); 5) Punta Gorda (PG); 6) Libertad (LIB); 7) Pomona (POM) 8) Middlesex (MID) and 9) Savannah (SAV) (Gonguez, 2012).

Since all observation stations were not established at the same time no standard time period was used. However, the best or most consistent period for each station formed the database for the analysis. The data were subjected to strict quality control measures. In situations where large quantities were missing the month was simply deleted. No attempts were made at generating or interpolating information for missing data. Wherever climatological data were insufficient to identify trends, only projections were presented (Gonguez, 2012).

Future scenarios of air temperature and precipitation (rainfall) were generated by the British Meteorological Institute regional climate model PRECIS (Providing REgional Climates for Impact Studies). The climate variables outputs were generated by the Cuban Meteorological Institute (INSMET) by downscaling the ECHAM4 global climate model (50 km resolution) and forced by the (SRES A2) socio-economic scenario.

But for or this assessment we considered the following 4 stations, based on data quality and location in Belize:

1) Philip Goldson International Airport (PGIA) in Belize District: the capital city and a station representing coastal locations and Cayes;
2) Libertad (LIB) in Corozal District: a station representing the northern part of the country;
3) Belmopan (BMP) in Cayo District: a station representing the central part of the country;
4) Punta Gorda (PG): in Toledo District: a station representing the southern part of the country.

No station was available for the interior mountainous part of the country.

3.1 Philip Goldson International Airport (PGIA) in Belize District

The Philip Goldson International Airport (PGIA) in Belize District on the Caribbean coast is chosen to represent the eastern and coastal part of the Country.

3.1.2 Current Temperature

Figure 1 presents the monthly average temperature at Philip Goldson International Airport (PGIA) and it shows that the warmest temperatures occur in June (~ 28.5 ^{0}C) and the coolest temperatures occur in January (~ 24.0 ^{0}C) (See Figure 2.4).

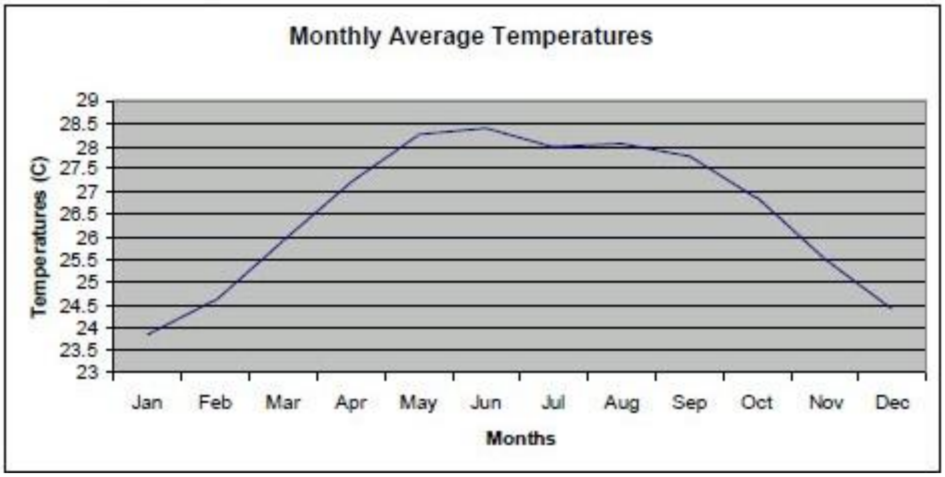

Figure 2.4: Average monthly temperatures (^{0}C) at the Philip Goldson International Airport (PGIA) (1960-2008) in Belize District (Source Gonguez, 2012)

On the other hand, Figure 2 presents the average yearly temperature at the Philip Goldson International Airport (PGIA) and it shows that he 1970's was the coolest decade (26.1 °C) and the 1990's the warmest (26.9 °C).

The linear trend (red) increase in average temperatures is about 0.9 °C for the years 1960 -2008) (See Figure 2.5).

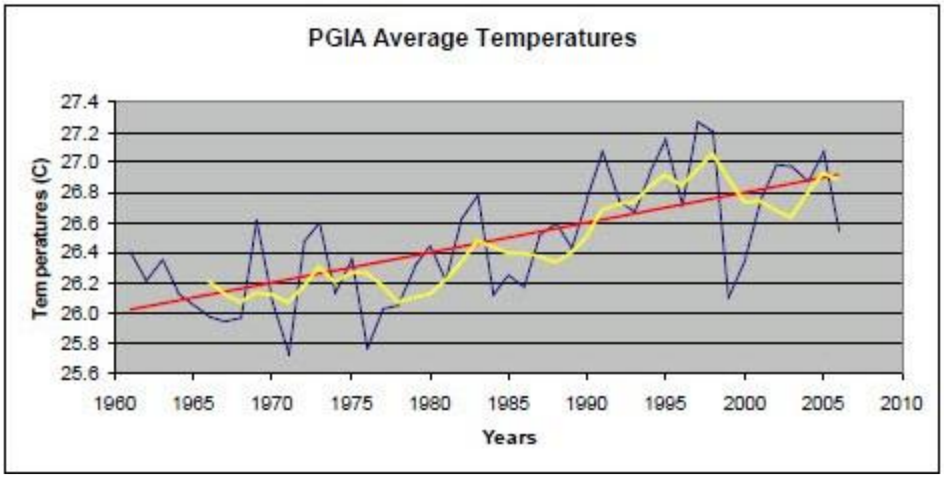

Figure 2.5: Time series plot of average temperatures at the Philip Goldson International Airport (PGIA) (1960-2008) together with linear trend (red) and 5-year moving average (yellow) (Source Gonguez, 2012)

Table 2.2 presents the average seasonal and decadal temperatures at the Philip Goldson International Airport (PGIA) (1960-2008) and its shows that the temperature has increased the most during the SON (September-October-November) months with the increase being ~ approximate to 1.1 °C (See Table 2.2).

Table 2.2: Average seasonal and decadal temperatures at the Philip Goldson International Airport (PGIA) (1960-2008) (Source Gonguez, 2012)

	DJF	MAM	JJA	SON
Average	24.2	27.0	28.0	26.6
1960's	24.0	26.7	27.8	26.3
1970's	23.9	26;9	27.8	26.2
1980's	24.2	26.9	27.8	26.5
1990's	24.6	27.4	28.2	26.9
2000's	24.5	27.3	28.3	27.1
Maximum	25.1 (1997)	28.3 (1997)	28.8 (2005)	27.6 (1998)

3.1.3 Current Rainfall

Figure 2.6 presents the monthly average rainfall at the Philip Goldson International Airport (PGIA) and it shows that the rainfall distribution is bi-modal with peaks near mid-June (~240 mm/month) and mid-October (~260 mm/month) during the rainy season and the minimum rainfall occurs in March (~50 mm/month) during the dry season (See Figure 2.6).

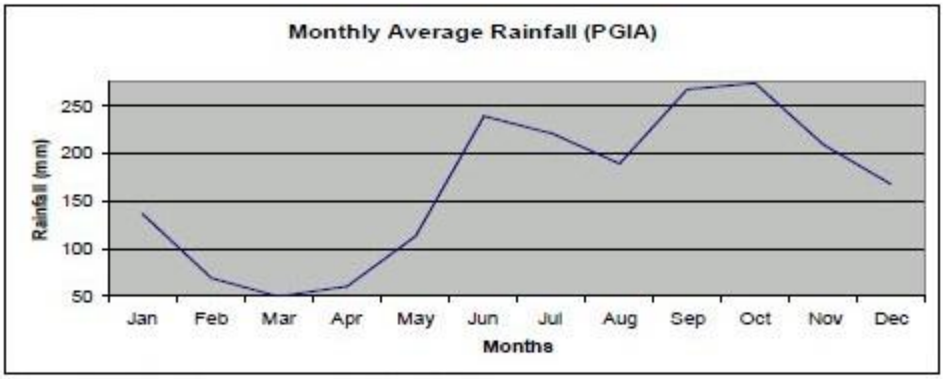

Figure 2.6: Monthly average rainfall at the Philip Goldson International Airport (PGIA) (1960-2008) (Source Gonguez, 2012)

Figure 2.7 presents the total annual rainfall and the trends at the Philip Goldson International Airport (PGIA) and the linear trend shows a 65 mm increase in annual total rainfall at between 1960 and 2008. The average annual total is for this time period 1,998 mm/year.

Furthermore, the wettest decade has been 2000's with an average annual total of 2,032 mm/year. On the other hand, 1963 was the driest year with 1,344 mm total annual rainfall (Figure 2.7).

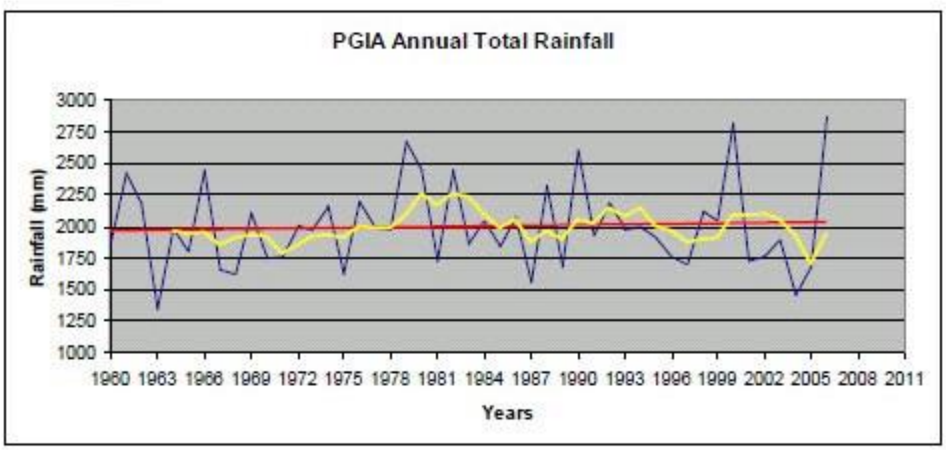

Figure 2.7: Time series plot of total annual rainfall (mm/year) at the Philip Goldson International Airport (PGIA) (1960-2008): linear trend (red); 5- year moving average (yellow) (Source Gonguez, 2012)

Table 2.3 presents the seasonal and decadal (average) and maximum and minimum (total annual) rainfall (mm) at at the Philip Goldson International Airport (PGIA) (1960-2008). It shows, in general the wettest seasons are SON (September-October-November) followed by JJZ (June-July-August) and the driest seasons are DJF (December-January-February) followed by MAM (March-April-May).

Furthermore, there have been extremes of rainfall in each of the seasons. For DJF there was an average seasonal maximum of 278.8 mm in 2006 and an average seasonal minimum of 42.6 mm in 1964. For MAM there was an average seasonal maximum of 239.3 mm in 1986 and an average seasonal minimum of 9.2 mm in 1975. Similarly, for JJA there was an average seasonal maximum of 359.3 mm in 2006 and an average seasonal minimum of 66.1 mm in 1995. Finally, for SON there was an average seasonal maximum of 534.2 mm in 2000 and an average seasonal minimum of 112.1 mm in 1987.

It is apparent then that both year to year and season to season variations in rainfall are common at the Philip Goldson International Airport (PGIA) (1960-2008) (Table 2.3).

Table 2.3: Seasonal and Decadal (average) and maximum and minimum total annual rainfall (mm) at the Philip Goldson International Airport (PGIA) (Source Gonguez, 2012)

	DJF	MAM	JJA	SON
Average	124.7	74.9	216.7	250.2
1960's	112.6	71.7	242.4	227.9
1970's	123.0	68.6	212.2	254.3
1980's	136.4	73.9	226.3	240.5
1990's	137.5	76.6	188.6	270.1
2000's	107.5	87.5	212.6	261.6
Maximum	227.8 (2006)	239.3 (1986)	359.3 (2006)	534.2 (2000)
Minimum	42.6 (1964)	9.2 (1975)	66.1 (1995)	112.1 (1987)

3.1.4 Future Scenarios/Projections of Temperature and Rainfall

Future scenarios of air temperature and precipitation (rainfall) (2010-2100) for the Philip Goldson International Airport (PGIA) were generated by the British Meteorological Institute regional climate model PRECIS (Providing REgional Climates for Impact Studies). The climate variables outputs were generated by the Cuban Meteorological Institute (INSMET) that downscaled the ECHAM4 global climate model (50 km resolution), forced by the (SRES A2) socio-economic scenario.

3.1.5 Future Scenarios/Projections of Temperature

Figure 2.8 presents the yearly trend in annual temperature (°C) at the Philip Goldson International Airport (PGIA) (2010-2100 and the trend analysis reveals a 3.5 °C increase in average temperatures over the 90-year period for this location (See Figure 2.8).

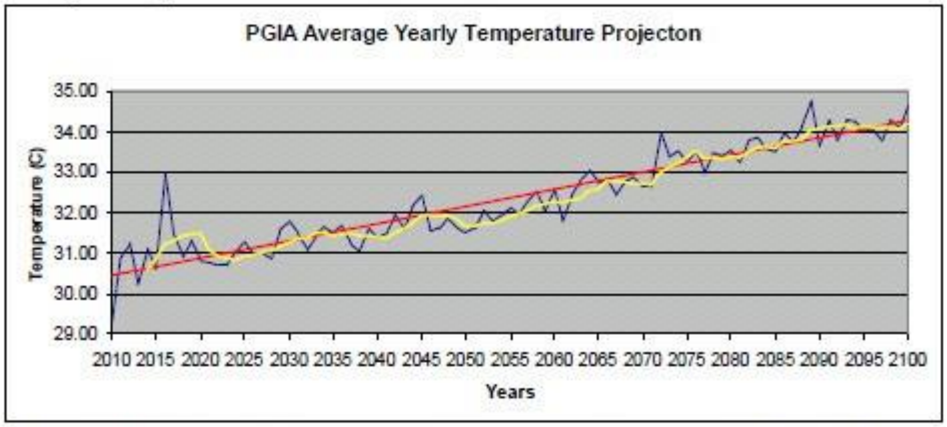

Figure 2.8: Future scenario time series plot of average yearly temperature (^{0}C) at the Philip Goldson International Airport (PGIA) (2010-2100): linear trend (red); 5- year moving average (yellow) (Source Gonguez, 2012)

Table 2.4 presents a decadal and seasonal breakdown of average temperatures at (^{0}C) at the Philip Goldson International Airport (PGIA) (2010-2100) and it shows that the highest projected seasonal increase in temperature will occur in the JJA (June-July-August) season: with the 90-year average being reaching 34 ^{0}C and climbing to 35.6 ^{0}C by the 2090's decade. On the other hand, the lowest projected seasonal increase in temperature will occur in the DJF (December-January-February) season: with the 90-year average being 29.5^{0}C and climbing to 31.0 ^{0}C by the 2090's decade (See Table 2.4).

Table 2.4: Decadal and seasonal projections of average temperatures at (^{0}C) at the Philip Goldson International Airport (PGIA) (2010-2100) (Source Gonguez, 2012)

	Average	DJF	MAM	JJA	SON
91 yr average	32.3	29.5	33.4	34.0	32.4
2010's	31.0	28.4	31.8	32.4	30.8
2020's	31.0	28.2	32.0	32.7	30.9
2030's	31.4	28.9	32.4	33.2	31.3
2040's	31.8	29.1	33.0	33.2	31.8
2050's	32.0	29.1	32.8	33.7	32.2
2060's	32.6	29.8	33.7	34.3	32.7
2070's	33.3	30.3	34.5	34.9	33.3
2080's	33.8	30.8	35.0	35.6	33.9
2090's	34.0	31.0	35.3	35.6	34.2

3.1.6 Future Scenarios/Projections of Precipitation/Rainfall

Figure 2.9 presents the future scenario time series plot of the projected total annual rainfall (mm/year) at the Philip Goldson International Airport (PGIA) (2010-2100) and the linear trend (red) shows that over the 91-year period (2010-2100), total annual rainfall will decrease by ~ 100 mm at this location (See Figure 2.9).

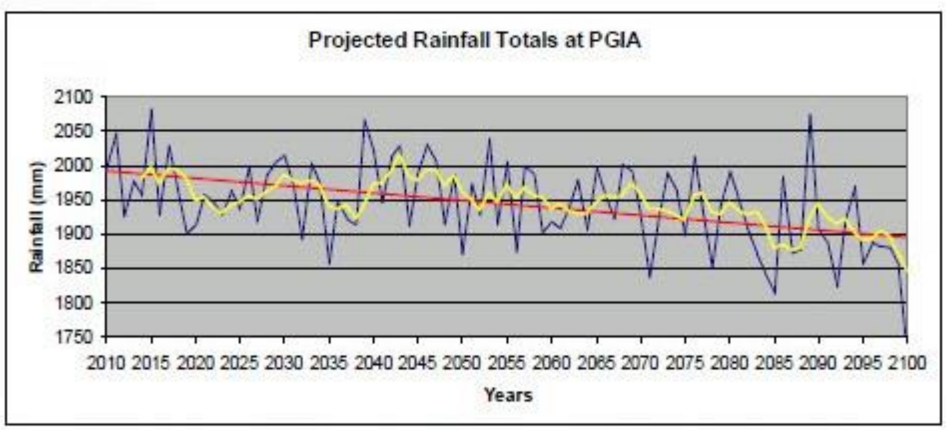

Figure 2.9: Future scenario time series plot of projected total annual rainfall (mm/year) at the Philip Goldson International Airport (PGIA) (2010-2100): linear trend (red); 5- year moving average (yellow) (Source Gonguez, 2012)

Table 2.5 presents a yearly, seasonal and decadal breakdown of total annual rainfall (mm) at the Philip Goldson International Airport (PGIA) (2010-2100) and it shows an overall decrease in precipitation in all periods and the yearly decreases were rather insignificant (-2.7 %) . However, the largest change in total seasonal rainfall is expected to occur in the early rainy season, namely JJA (June-July-August) (- 7.2 %) and MAM (March-April-May) (-7.3 %) periods, at this location (See Table 2.5).

Table 2.5: Decadal and seasonal projections of total annual rainfall at (mm) at the Philip Goldson International Airport (PGIA) (2010-2100) (Source Gonguez, 2012)

	Yearly Totals	DJF	MAM	JJA	SON
	1943	122.7	69.4	201.1	255.1
2010's	1981	127.3	68.4	203.7	261.2
2020's	1955.3	123.8	73.1	200.3	254.4
2030's	1956.2	124.1	73.9	200.2	254.7
2040's	1983.7	122	69.4	210.2	258.4
2050's	1949.6	122.1	71.8	201.8	255.1
2060's	1951.9	122	71.3	201.2	256.6
2070's	1927.2	125	66.4	199.5	251.3
2080's	1918.8	117.9	68.6	197.4	255.3
2090's	1887.2	120.2	63.0	196.3	249.5

3.2 Libertad in Corozal District

Libertad station in Corozal District is chosen to represent the northern and part of the Country.

3.2.1 Current Temperature

Figure 2.10 presents the monthly average temperature at Libertad and it shows that the warmest temperatures occur in June (~ 28.2 ^{0}C) and the coolest temperatures occur in January (~ 23.0 ^{0}C) (See Figure 2.10).

On account of missing data for the period 1966-2010, trends in annual and seasonal temperature trends could not be presented.

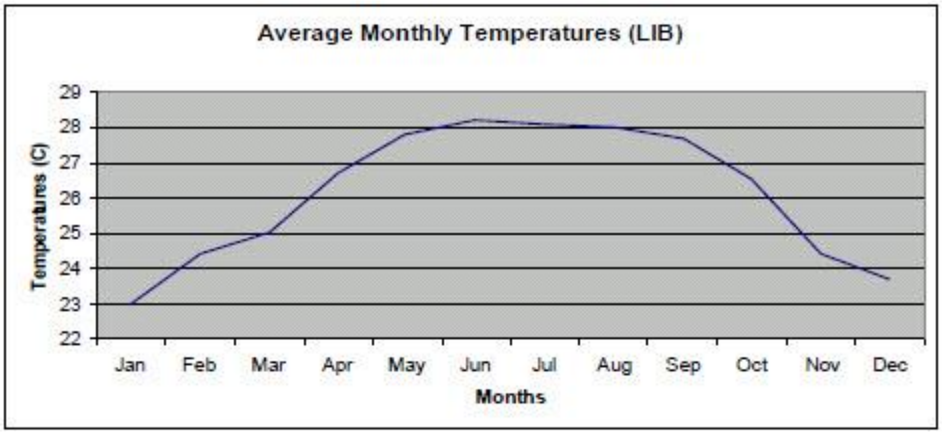

Figure 2.10: Average monthly temperatures (^{0}C) at Libertad (14 years of complete data between 1966 and 2010) in Corozal District (Source Gonguez, 2012)

3.2.2 Current Rainfall

Figure 2.11 presents the monthly average rainfall at the Libertad and it shows that the rainfall distribution is bi-modal with peaks near mid-June (~220 mm/month) and September-October (~225 mm/month) during the rainy season and the minimum rainfall occurs in February-March (~30 mm/month) during the dry season (See Figure 2.11).

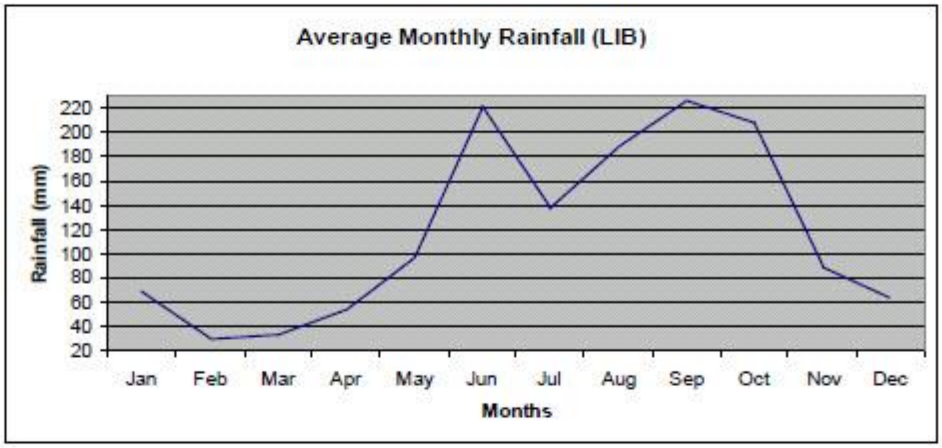

Figure 2.11: Average monthly rainfall (mm) at Libertad (14 years of complete data between 1966 and 2010) in Corozal District (Source Gonguez, 2012)

3.2.3 Future Scenarios/Projections of Temperature and Rainfall

Again, future scenarios of air temperature and precipitation (rainfall) (2010-2100) for Libertad were generated by the British Meteorological Institute regional climate model PRECIS (Providing REgional Climates for Impact Studies). The climate variables outputs were generated by the Cuban Meteorological Institute (INSMET) that downscaled the ECHAM4 global climate model (50 km resolution), forced by the (SRES A2) socio-economic scenario.

3.2.4 Future Scenarios/Projections of Temperature

Figure 2.12 presents the yearly trend in annual temperature (°C) at Libertad (2010-2100 and the trend analysis reveals a 3.8 °C increase in average temperatures over the 90-year period for this location (See Figure 2.12).

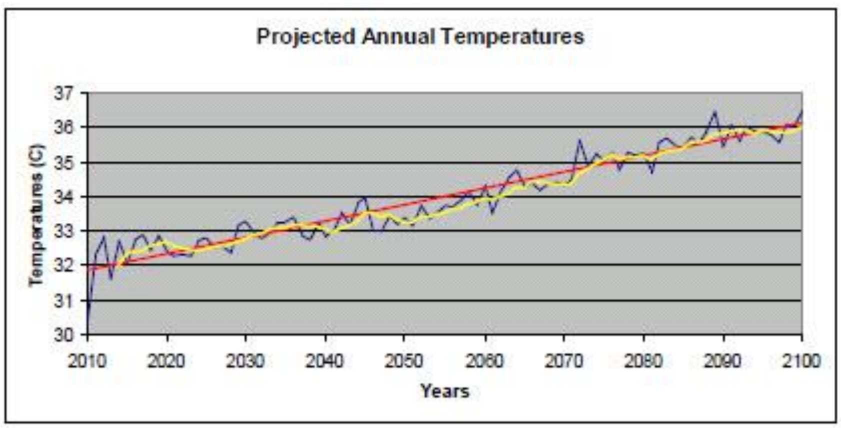

Figure 2.12: Future scenario time series plot of average yearly temperature (^{0}C) at Libertad (2010-2100): linear trend (red); 5- year moving average (yellow) (Source Gonguez, 2012)

Table 2.6 presents a decadal and seasonal breakdown of average temperatures at (^{0}C) at Libertad (2010-2100) and it shows that the highest projected seasonal increase in temperature will occur in the JJA (June-July-August) season: with the 90-year average being reaching 35.9^{0}C and climbing to 37.7 ^{0}C by the 2090's decade. On the other hand, the lowest projected seasonal increase in temperature will occur in the DJF (December-January-February) season: with the 90-year average being 30.9^{0}C and climbing to 32.5 ^{0}C by the 2090's decade (See Table 2.6).

Table 2.6: Decadal and seasonal projections of average temperatures at (^{0}C) at Libertad (2010-2100) (Source Gonguez, 2012)

	Average	DJF	MAM	JJA	SON
91-yr average	34.0	30.9	35.2	35.9	33.9
2010's	32.3	29.5	33.4	34.1	32.1
2020's	32.5	29.5	33.8	34.6	32.4
2030's	33.1	30.2	34.2	35.1	32.8
2040's	33.3	30.4	34.8	34.9	33.2
2050's	33.6	30.4	34.6	35.6	33.8
2060's	34.3	31.2	35.5	36.3	34.2
2070's	35.0	31.7	36.4	37.0	35.0
2080's	35.6	32.3	36.9	37.6	35.5
2090's	35.9	32.5	37.2	37.7	39.0

3.2.5 Future Scenarios/Projections of Precipitation/Rainfall

Figure 2.13 presents the future scenario time series plot of the projected total annual rainfall (mm/year) at Libertad (2010-2100) and the linear trend (red) shows that over the 91-year period (2010-2100), total annual rainfall will decrease by 145-150 mm at this location (See Figure 2.13).

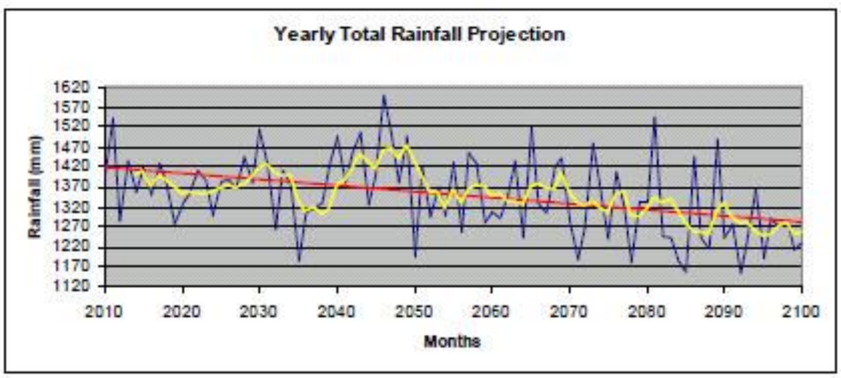

Figure 2.13: Future scenario time series plot of projected total annual rainfall (mm/year) at Libertad (2010-2100): linear trend (red); 5- year moving average (yellow) (Source Gonguez, 2012)

Table 2.7 presents a yearly, seasonal and decadal breakdown of total annual rainfall (mm) at Libertad (2010-2100) and it shows an overall decrease in precipitation in all periods and the yearly decreases were somewhat insignificant (-5.5 %) . However, the largest change in total seasonal rainfall is expected to occur in the late dry season, namely MAM (- 13.7 %) and the early dry season DJF (December-January-February) (- 15.3 %) periods, at this location (See Table 2.7).

Table 2.7: Decadal and seasonal projections of total annual rainfall at (mm) at Libertad (2010-2100) (Source Gonguez, 2012)

	Average	DJF	MAM	JJA	SON
91-yr average	1349.6	46.0	56.7	175.4	171.8
2010's	1386.5	47.9	56.7	180.6	177.5
2020's	1375.0	48.7	62.6	174.2	172.7
2030's	1354.4	47.5	57.7	173.9	172.1
2040's	1453.5	47.4	59.2	198.8	178.0
2050's	1342.9	45.8	55.7	179.1	168.8
2060's	1365.0	45.5	59.7	172.6	178.1
2070's	1305.0	48.6	49.1	172.3	165.0
2080's	1291.1	41	60.6	166.7	168.6
2090's	1281.3	42.3	49.2	162.6	164.2

3.3 Belmopan in Cayo District

Belmopan station in Cayo District is chosen to represent the central part of the Country.

3.3.1 Current Temperature

Figure 2.14 presents the monthly average temperature at Belmopan and it shows that the warmest temperatures occur in May (~ 28.0 ^{0}C) and the coolest temperatures occur in January (~ 23.0 ^{0}C) (See Figure 2.14).

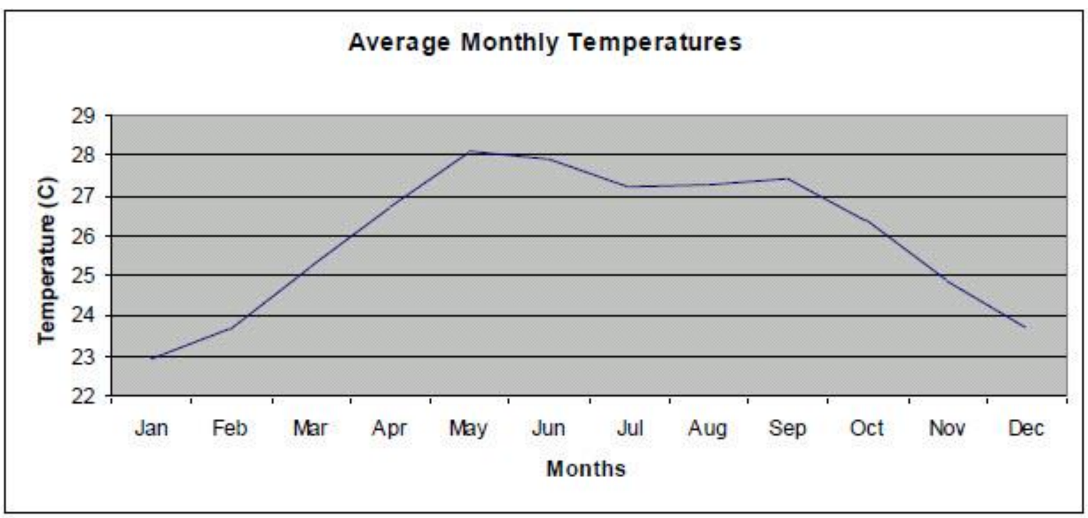

Figure 2.14: Average monthly temperatures (^{0}C) at the Belmopan station (1975-2005) in Belize District (Source Gonguez, 2012)

Due to the great quantity of missing data and the stringent quality control measures used in these analyses the data set was severely depleted. As a consequence trends and average seasonal and decadal temperatures in the Belmopan temperature data could not be determined. Less than half the 1975 to 2005 climatological data was deemed useful (Gonguez, 2012).

3.3.2 Current Rainfall

Figure 2.15 presents the monthly average rainfall at Belmopan and it shows that the rainfall distribution is somewhat bi-modal with the highest peak near mid-June (~290 mm/month) and a secondary peak mid-September (~240 mm/month) during the rainy season and the minimum rainfall occurs in March (~ 35 mm/month) during the dry season (See Figure 2.15).

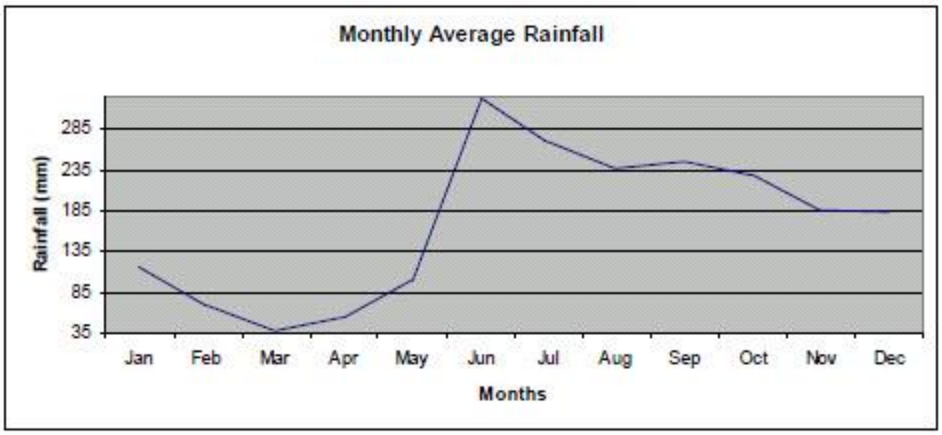

Figure 2.15: Monthly average rainfall at Belmopan (1975-2005) (Source Gonguez, 2012)

Figure 2.16 presents the total annual rainfall and the trends at Belmopan and the linear trend shows a 400 mm decrease in total annual rainfall at from 2200 (1975) to 1820 mm (2005) (See Figure 2.16).

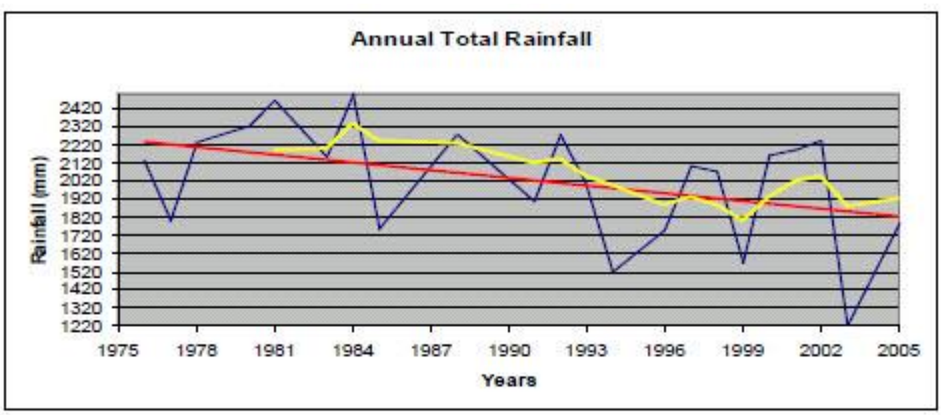

Figure 2.16: Time series plot of total annual rainfall (mm/year) at Belmopan (1975-2005): linear trend (red); 5- year moving average (yellow) (Source Gonguez, 2012)

Table 2.8 presents the seasonal and decadal (average) and maximum and minimum (total annual) rainfall (mm) at Belmopan (1975-2005). It shows, in general the wettest seasons are JJA (June-July-August) followed by SON (September-October-November) and the driest seasons are DJF (December-January-February) followed by MAM (March-April-May).

Furthermore, there have been extremes of rainfall in each of the seasons. For DJF there was an average seasonal maximum of 214.4 mm in 1988 and an average seasonal minimum of 79.0 mm in 2000. For MAM there was an average seasonal maximum of 120.1 mm in 1996 and an average seasonal minimum of 15.4 mm in 1976. Similarly, for JJA there was an average seasonal maximum of 564.7 mm in 1981 and an average seasonal minimum of 168.5 mm in 2003. Finally, for SON there was an average seasonal maximum of 353.3 mm in 1990 and an average seasonal minimum of 118.8 mm in 2002 (Table 2.8).

It is apparent then that both year to year and season to season variations in rainfall are common at the Belmopan station (1975-2005).

Furthermore, the 1980's was also the wettest decade.

Table 2.8: Seasonal and Decadal (average) and maximum and minimum total annual rainfall (mm) at Belmopan (Source Gonguez, 2012)

	DJF	MAM	JJA	SON
Average	118.9	59.5	267.8	223.1
1980's	141.7	60.3	284.0	227.9
1990's	108.9	52.1	259.4	238.7
2000's	79.0	73.7	272.9	207.7
Maximum	214.4 (1988)	120.1 (1996)	464.7 (1981)	335.3 (1990)
Minimum	50.1 (1987)	15.4 (1976)	168.5 (2003)	118.8 (2002)

3.3.3 Future Scenarios/Projections of Temperature and Rainfall

Future scenarios of air temperature and precipitation (rainfall) (2010-2100) for the Belmopan station were generated by the British Meteorological Institute regional climate model PRECIS (Providing REgional Climates for Impact Studies). The climate variables outputs were generated by the Cuban Meteorological Institute (INSMET) that downscaled the ECHAM4 global climate model (50 km resolution), forced by the (SRES A2) socio-economic scenario.

3.3.4 Future Scenarios/Projections of Temperature

Figure 2.17 presents the yearly trend in annual temperature (°C) at Belmopan (2010-2100 and the trend analysis reveals a 4.5 °C increase in average temperatures over the 90-year period for this location (See Figure 2.17).

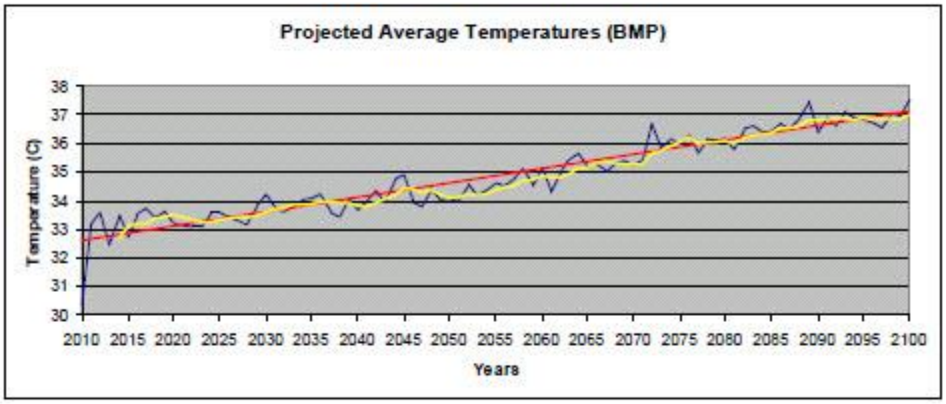

Figure 2.17: Future scenario time series plot of average yearly temperature (^{0}C) at Belmopan (2010-2100): linear trend (red); 5- year moving average (yellow) (Source Gonguez, 2012)

Table 2.9 presents a decadal and seasonal breakdown of average temperatures at (^{0}C) at Belmopan (2010-2100) and it shows that the highest projected seasonal increase in temperature will occur in the JJA (June-July-August) season: with the 91-year average being reaching 37^{0}C and climbing to 38.9 ^{0}C by the 2090's decade. On the other hand, the lowest projected seasonal increase in temperature will occur in the DJF (December-January-February) season: with the 91-year average being 31.5^{0}C and climbing to 33.2 ^{0}C by the 2090's decade (See Table 2.9).

Furthermore, by mid-century, the warmest month is projected to shift from May to June and this remains the trend through to the end of the century.

Table 2.9: Decadal and seasonal projections of average temperatures at (^{0}C) at Belmopan (2010-2100) (Source Gonguez, 2012)

	Averages	DJF (avg)	MAM (avg)	JJA (avg)	SON (avg)
91 yr	34.3	31.5	36.2	37	34.7
2010's	33.0	29.9	34.2	35.0	32.9
2020's	33.3	30	34.7	35.6	33.1
2030's	33.9	30.8	35.1	36.1	33.5
2040's	34.2	31	35.8	36.0	33.9
2050's	34.5	31	35.6	36.7	34.5
2060's	35.2	31.8	36.5	36.7	35.0
2070's	35.9	32.3	37.5	37.4	35.7
2080's	36.5	33.0	38.0	38.8	36.3
2090's	36.8	33.2	38.4	38.9	36.8

3.3.5 Future Scenarios/Projections of Precipitation/Rainfall

Figure 2.18 presents the future scenario time series plot of the projected total annual rainfall (mm/year) at Belmopan (2010-2100) and the linear trend (red) shows that over the 91-year period (2010-2100), total annual rainfall will decrease by ~ 110 mm at this location (See Figure 2.18).

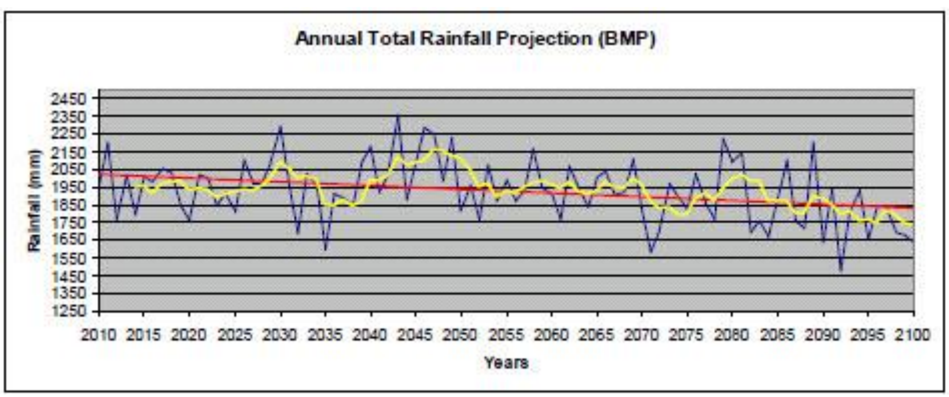

Figure 2.18: Future scenario time series plot of projected total annual rainfall (mm/year) at Belmopan (2010-2100): linear trend (red); 5- year moving average (yellow) (Source Gonguez, 2012)

Table 2.10 presents a yearly, seasonal and decadal breakdown of total annual rainfall (mm) at Belmopan (2010-2100) and it shows an overall decrease in precipitation in all periods and the yearly decreases were rather insignificant (-4.7 %) . However, the largest change in total seasonal rainfall is expected to occur in the early dry season, namely DJF (December-January-February) (- 11.2 %) and the early wet season, namely JJA (June-July-August) (-4.7 %), at this location (See Table 2.10).

Table 2.10: Decadal and seasonal projections of total annual rainfall at Belmopan (mm) (2010-2100) (Source Gonguez, 2012)

	Total	DJF (avg)	MAM (avg)	JJA (avg)	SON (avg)
91 yr avg	1927.9	105.6	60.4	255.3	224.7
2010's	1980.8	113.2	52.6	262.1	236.4
2020's	1925	111.4	63.7	254.7	227.8
2030's	1928	112.7	56.7	251.6	221.8
2040's	2139.8	107.5	64.7	294.7	233.7
2050's	1967.1	109.3	58.8	266.1	222.9
2060's	1935.8	102.6	71.2	251.4	232.5
2070's	1855.7	111.7	53.2	245.9	213.0
2080's	1846.4	91.7	74.7	240.5	223.4
2090's	1802.6	89.9	49.5	234.4	215.1

3.4 Punta Gorda in Toledo District

Punta Gorda station in Toledo District is chosen to represent the southern part of the Country.

3.4.1 Current Temperature

The Punta Gorda Station has a very long data record (1934-2011. However the station is plagued with large blocks of missing data.

Figure 2.19 presents the monthly average temperature at Punta Gorda and it shows that the warmest temperatures occur in May-June (~ 28.5 ^{0}C) and the coolest temperatures occur in January (~ 23.5 ^{0}C). The monthly average temperature is 26.6 °C (See Figure 2.19).

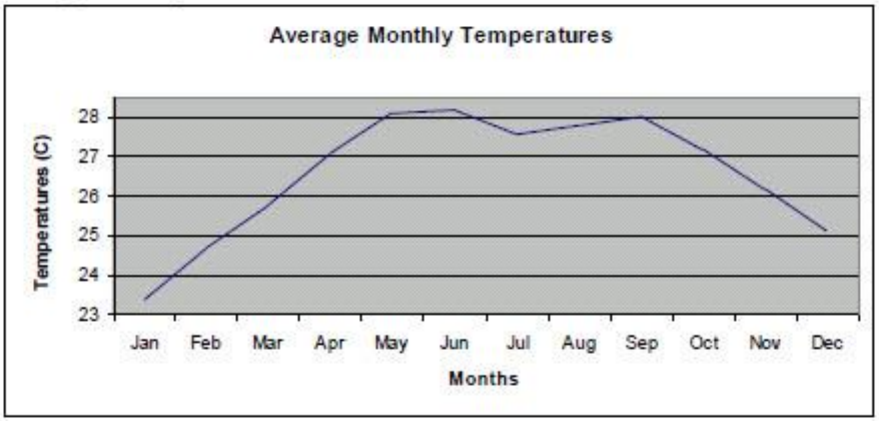

Figure 2.19: Average monthly temperatures (^{0}C) at the Punta Gorda station (1934-2011 and missing data) in Toledo District (Source Gonguez, 2012)

Since a consistent block of reliable data could not be found trends could not be adequately determined.

3.4.2 Current Rainfall

Figure 2.20 presents the monthly average rainfall at Punta Gorda and it shows that the rainfall distribution is generally unimodal with the highest peak in rainfall occurring in July (~750 mm/month) during the rainy season and the minimum rainfall occurs in March-April (~ 75 mm/month) during the dry season (See Figure 2.20).

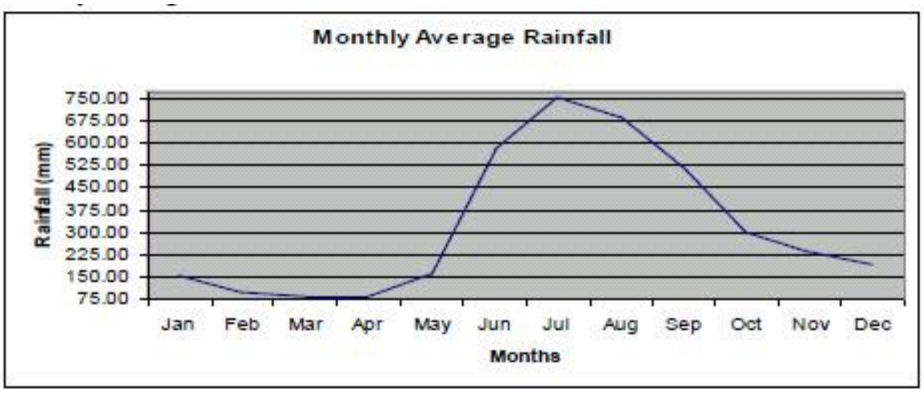

Figure 2.20: Monthly average rainfall at the Punta Gorda station (1934-2011 and missing data) in Toledo District (Source Gonguez, 2012)

On account of large chunks of missing data, no analyses could be done for total annual rainfall trends at Punta Gorda.

For the same reason, no analyses could be done the seasonal and decadal (average) and maximum and minimum (total annual) rainfall (mm) at Punta Gorda.

3.4.3 Future Scenarios/Projections of Temperature and Rainfall

Again, future scenarios of air temperature and precipitation (rainfall) (2010-2100) for the Punta Gorda station were generated by the British Meteorological Institute regional climate model PRECIS (Providing REgional Climates for Impact Studies). The climate variables outputs were generated by the Cuban Meteorological Institute (INSMET) that downscaled the ECHAM4 global climate model (50 km resolution), forced by the (SRES A2) socio-economic scenario.

3.4.4 Future Scenarios/Projections of Temperature

Figure 2.21 presents the yearly trend in annual temperature (°C) at Punta Gorda (2010-2100 and the trend analysis reveals a 4.5 °C increase in average temperatures over the 91-year period for this location (See Figure 2.21).

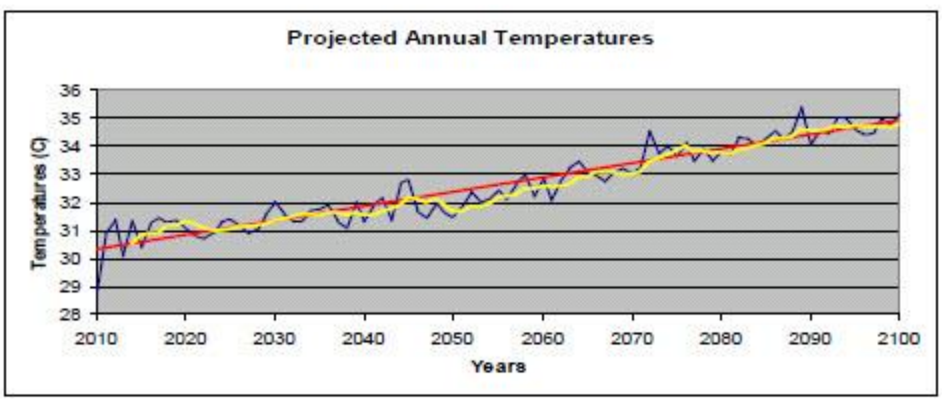

Figure 2.21: Future scenario time series plot of average yearly temperature (^{0}C) at the Punta Gorda station (2010-2100) in Toledo District (Source Gonguez, 2012)

Table 2.11 presents a decadal and seasonal breakdown of average temperatures at (^{0}C) at Punta Gorda (2010-2100) and it shows that the highest projected seasonal increase in temperature will occur in the JJA (June-July-August) season, with the 91-year average being reaching 33.7^{0}C and climbing to 35.8 ^{0}C by the 2090's decade. On the other hand, the lowest projected seasonal increase in temperature will occur in the DJF (December-January-February) season: with the 91-year average being 31.1^{0}C and climbing to 32.9 ^{0}C by the 2090's decade (See Table 2.11).

Table 2.11: Decadal and seasonal projections of average temperatures at (^{0}C) at the Punta Gorda station (2010-2100) in Toledo District (Source Gonguez, 2012)

	Average	DJF	MAM	JJA	SON
91-yr average	32.6	31.1	33.6	33.7	31.9
2010's	30.8	29.9	31.6	31.6	30.1
2020's	31.1	29.7	32.1	32.1	30.4
2030's	31.5	30.5	32.5	32.8	30.6
2040's	31.9	30.7	33.1	32.6	31.2
2050's	32.2	30.6	33.0	33.4	31.8
2060's	32.9	31.4	33.9	34.1	32.3
2070's	33.7	32.0	34.9	34.9	33.0
2080's	34.3	32.6	35.4	35.6	33.7
2090's	34.6	32.9	36.0	35.8	34.0

3.4.5 Future Scenarios/Projections of Precipitation/Rainfall

Figure 2.22 presents the future scenario time series plot of the projected total annual rainfall (mm/year) at Punta Gorda (2010-2100) and the linear trend (red) shows that over the 91-year period (2010-2100), total annual rainfall will decrease by ~ 70 mm at this location (See Figure 2.22).

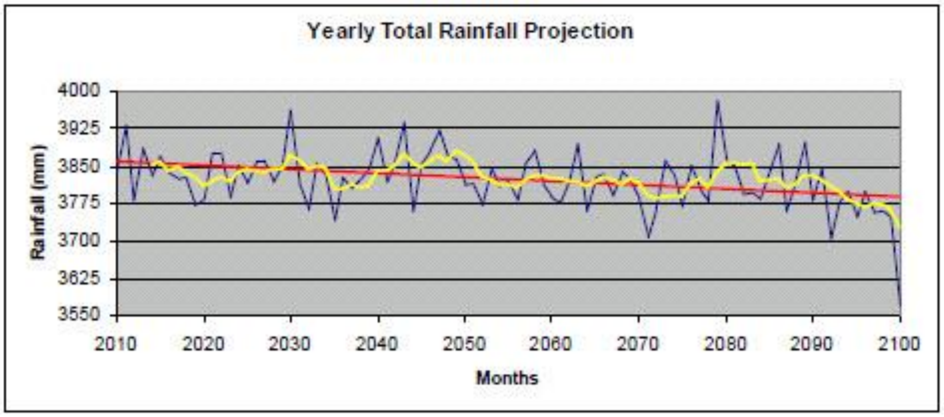

Figure 2.22: Future scenario time series plot of projected total annual rainfall (mm/year) at Punta Gorda (2010-2100): linear trend (red); 5- year moving average (yellow) (Source Gonguez, 2012)

Table 2.12 presents a yearly, seasonal and decadal breakdown of total annual rainfall (mm) at Punta Gorda (2010-2100). Projected changes in average rainfall are rather small and could possibly fall within the realm of observational or model computational error. However, it shows an overall insignificantly small decrease in precipitation in all periods with the yearly decreases being rather insignificant (-0.05 %). However, the largest decrease in total seasonal rainfall is expected to occur in the late dry season, namely MAM (March-April-May) (- 3.9 %) at this location (See Table 2.12).

Table 2.12: Decadal and seasonal projections of total annual rainfall at Punta Gorda (mm) (2010-2100) (Source Gonguez, 2012)

	Average	DJF	MAM	JJA	SON
91-yr average	3821.9	146.7	105.9	672.4	349.3
2010's	3839.7	148.7	103.1	675.8	352.7
2020's	3838.8	148.9	108.9	672.3	349.5
2030's	3826.6	147.2	104.5	672.7	350.9
2040's	3867.4	146.8	109.1	681.8	350.9
2050's	3820.7	147.3	102.2	675.1	349.6
2060's	3816.1	145.5	107.9	669.7	349.3
2070's	3813.5	147.2	106.2	671.2	346.4
2080's	3828.7	145.9	111.2	667.6	347.6
2090's	3771.9	143.3	101.0	666.1	347.1

3.5 Inland and Mountainous Stations

Inland stations tend to have more extreme temperatures than coastal stations where the sea breeze moderates the temperature. Average maximum and minimum temperatures at Cooma Cairn, as shown in Table 2.13 are ~ 5°C lower than at Philip Goldson International Airport and at Central Farm. Philip Goldson International Airport has an elevation of 5 meters above sea level and is located 5 miles from the coast; Cooma Cairn is located in the Mountain Pine Ridge Area and is 952 meters above sea level. The difference between the average temperatures between the two stations is about 4.8°C indicating a decrease of temperature with height (Gonguez, 2012).

Table 2.13: Differences in mean annual temperature between inland (Central Farm) coastal (Philip Goldson International Airport) and mountainous (Cooma Cairn) stations (Source: Gonguez, 2012)

	Stations	Average Maximum	Average Minimum
Inland	Central Farm	31.3°C	20.5°C
Coast	Philip Goldson International Airport	30.1°C	22.6°C
Mountain	Cooma Cairn	25.3°C	17.7°C

4.0 Mapping Seasonal Temperature and Rainfall Changes

In this section, changes in mean seasonal temperature (^{0}C) and rainfall (mm/day) are mapped using downscaled data for the ECHAM5/A1B and HadCM3/A1B climate models. The climate data was downscaled on a 25 x 25 km using PRECIS by the Instituto de Meteorologia (INSMET) of Cuba for the Caribbean Community Climate Change Centre (5Cs) and provided to us.

ECHAM5 is the 5th generation of the ECHAM general circulation model of the Max-Planck-Institute for Meteorology (MPI-M), initially developed by Roeckner et al., 2003.

HadCM3 is the model of the British Met Office Hadley Centre provides boundary data from a 17-member perturbed-physics ensemble (HadCM3Q0-Q16, known as ‘QUMP’) for use with

PRECIS in order to allow users to generate an ensemble of high-resolution regional simulations (McSweeney and Jones, 2010).

The Met Office Hadley Centre provides boundary data from a 17-member perturbed-physics ensemble (PPE) (HadCM3Q0-Q16, known as QUMP: Quantifying Uncertainties in Model Projections) for use with PRECIS in order to allow users to generate an ensemble of high-resolution regional simulations.

The Hadley Centre's PPE includes 17 members which are formulated to systematically sample parameter uncertainties under the A1B emissions scenario. Based on data availability and fit with observed data (1961-1990), we selected the HadCM3Q11, a moderately high sensitivity model from the QUMP ensemble data outputs

We examine seasonal (March, April and May; June, July and August; September October and November; December, January and February) changes in air temperature (^{0}C) and rainfall (mm/season) for the entire surface area of Belize. These seasonal changes in air temperature and rainfall are for the future decade of 2060-2070 when compared to the current climate period of 1961-1990.

4.1 ECHAM5 and HadCM3Q11

In this section, we present the mean seasonal temperature changes/anomalies according to the ECHAM5 and HadCM3Q11 climate models for Belize.

4.2 Air Temperature (^{0}C): ECHAM5

Figure 2.23 presents the changes in mean seasonal air temperature (^{0}C) (2060-2070 vs 1961-1990) for the March-April-May dry season for Belize according to the ECHAM5 climate model. It shows that during this season there is a significant change in mean seasonal air temperature (^{0}C) for the future decadal period of 2060-2070, with temperatures exceeding 2^{0}C for all of Belize and some of the larger Cayes except for the outer Turneffe Atoll and Bokel Caye. In fact the temperature increases are ~ 2.4 ^{0}C for Corozal, Orange Walk and Cayo Districts and most of Stann District (See Figure 2.23).

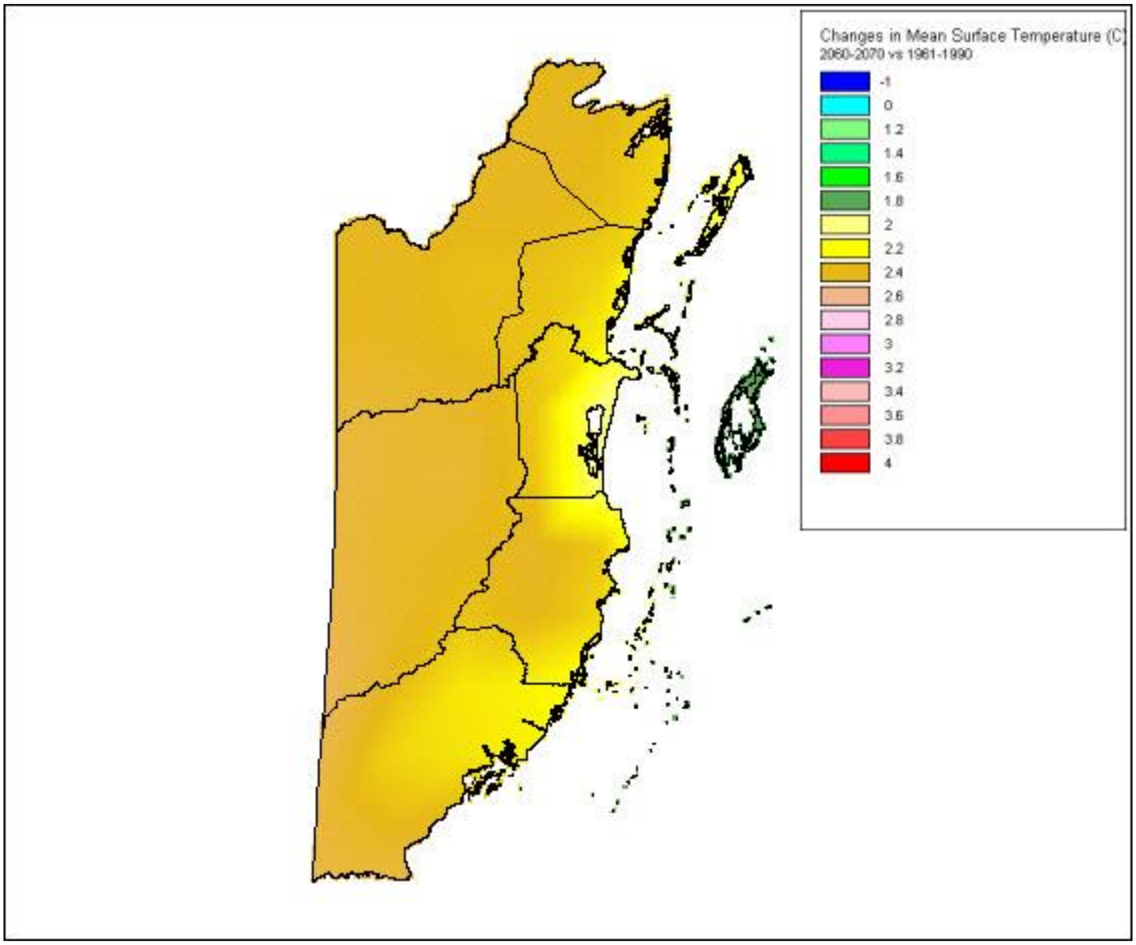

Figure 2.23: Changes in mean seasonal air temperature (^{0}C) (2060-2070 vs 1961-1990) for the March-April-May season according to the ECHAM5 climate model

On the other hand, Figure 2.24 presents the changes in mean seasonal air temperature (^{0}C) (2060-2070 vs 1961-1990) for the June-July-August rainy season for Belize according to the ECHAM5 climate model. It shows that during this wet season there is a more perceptible change in mean seasonal air temperature (^{0}C) for the future decadal period of 2060-2070. Increases in mean temperature during these months now approach ~ 3^{0}C. These future temperatures generally range from ~ 2.6 ^{0}C in Stann Creek and Corozal Districts to ~ 3^{0}C in western Corozal Districts. It is only along the central coast of Belize District and the Ambergris, Caulker and smaller Cayes that temperature increases are ~ 2.0 ^{0}C, most likely on account of marine influence (See Figure 2.24).

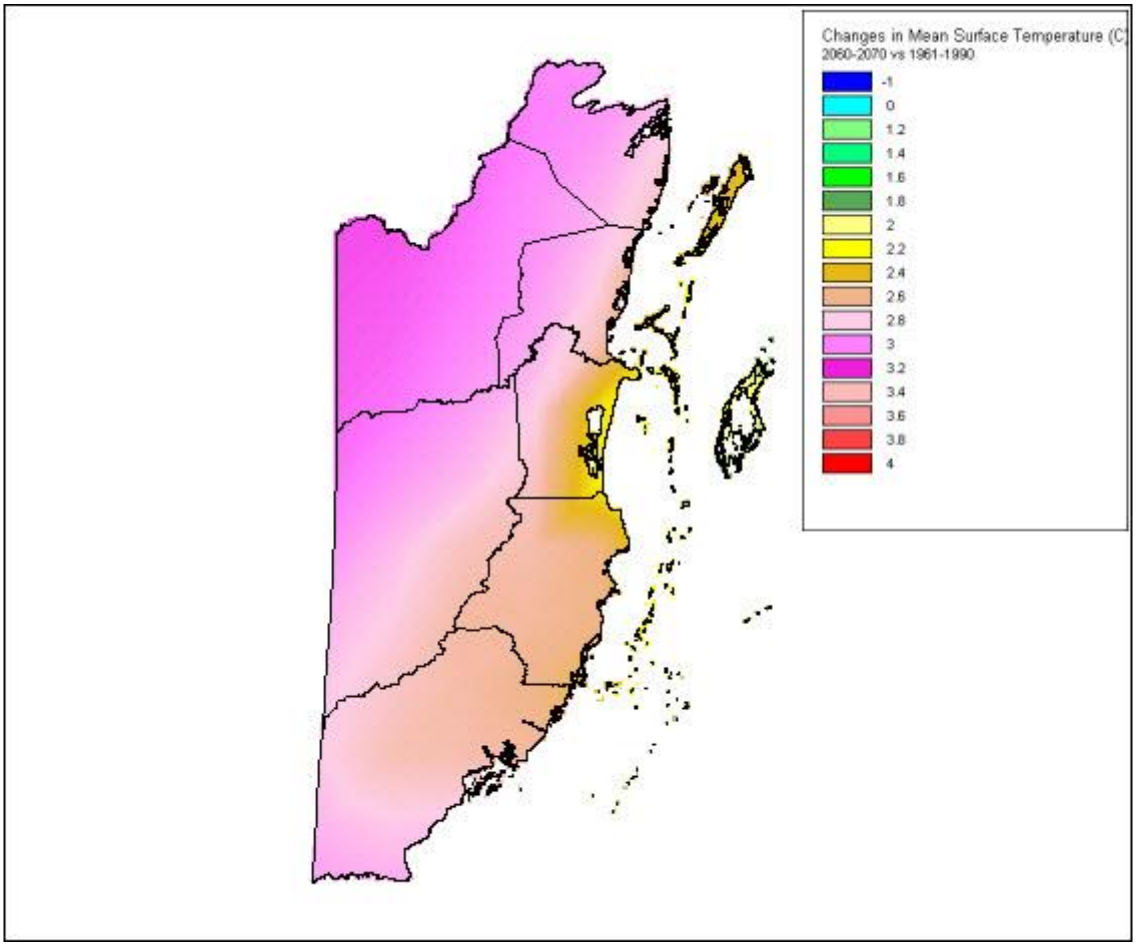

Figure 2.24 Changes in mean seasonal air temperature (^{0}C) (2060-2070 vs 1961-1990) for the June-July-August season according to the ECHAM5 climate model

As for Figure 2.25 which presents the changes in mean seasonal air temperature (^{0}C) (2060-2070 vs 1961-1990) according to the ECHAM5 climate model for the September-October-November season that currently (1961-1990) corresponds to the end of the rainy season in Belize. However, it shows that in general the increases in mean seasonal air temperature (^{0}C) for the future decadal period of 2060-2070 are of the order of 2.0 to 2.4 ^{0}C for all Districts of mainland Belize, except the northern Corozal and southern Toledo Districts where the temperature increases are > 2.4 ^{0}C. Also again, on account of the marine influence, the temperature increases are lower for the outer Cayes such as Ambergris Caye, where temperatures increase by < 2.0 ^{0}C (See Figure 2.25).

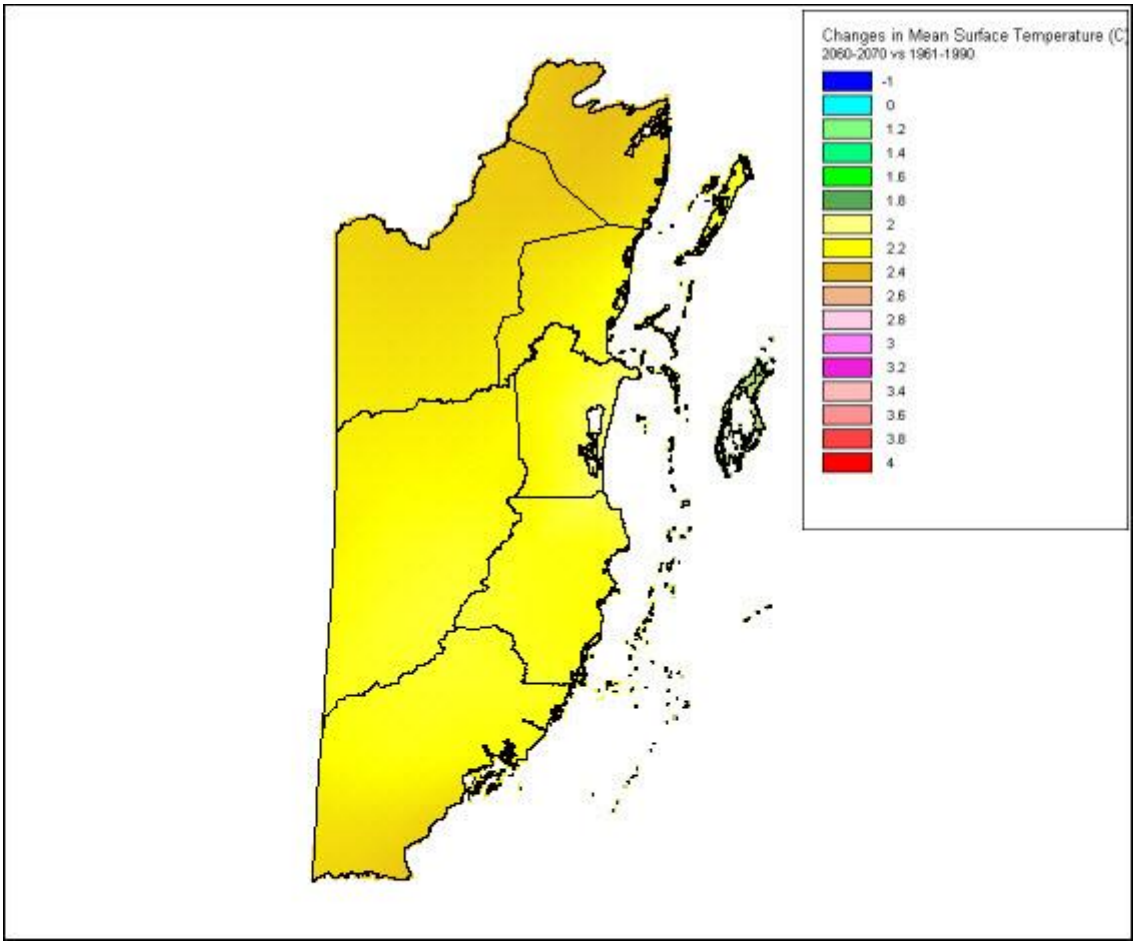

Figure 2.25 Changes in mean seasonal air temperature (^{0}C) (2060-2070 vs 1961-1990) for the September-October-November season according to the ECHAM5 climate model

Finally, Figure 2.26 presents the changes in mean seasonal air temperature (^{0}C) (2060-2070 vs 1961-1990) according to the ECHAM5 climate model for the December-January-February season that currently (1961-1990) corresponds to the winter dry season in Belize. It shows that during this season there is an overall increase in seasonal temperature of ~ 2 ^{0}C for the future decadal period of 2060-2070 in the northern Belize District, in the southern Orange Walk District, the western Cayo District and the southern Toledo District. But in the southern Belize District, the Stann Creek District and the northern Toledo Districts, the temperature increases are of ~ 1.8 ^{0}C. Again, on account of the marine influence, the temperature increases are lower for the outer Cayes such as Ambergris Caye, where temperatures increase by < 1.8 ^{0}C (See Figure 2.26).

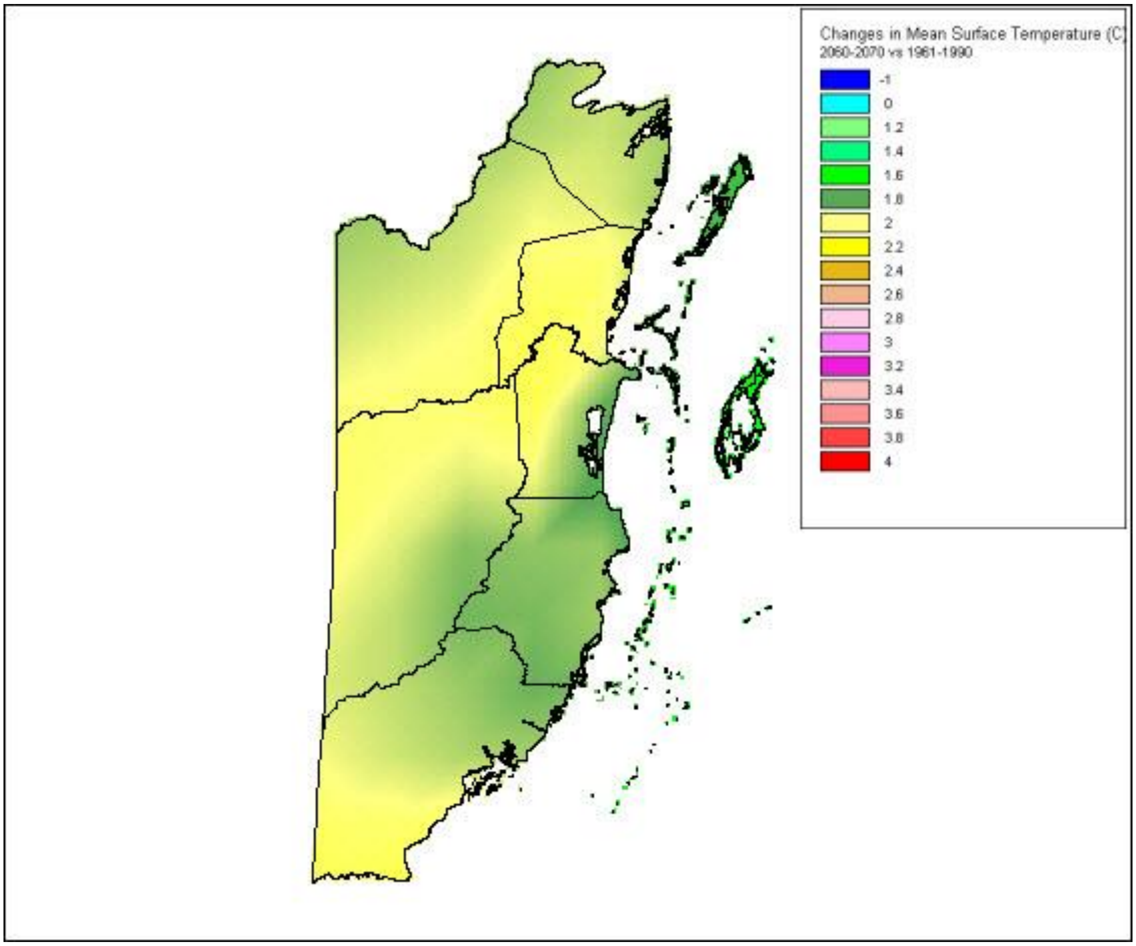

Figure 2.26 Changes in mean seasonal air temperature (^{0}C) (2060-2070 vs 1961-1990) for the December-January-February season according to the ECHAM5 climate model

4.3 Rainfall (mm/season): ECHAM5

Figure 2.27 presents the changes in mean seasonal rainfall (mm/season) (2060-2070 vs 1961-1990) for the March-April-May dry season for Belize according to the ECHAM5 climate model. It shows that during this season, generally, for most of Belize there little or no change in rainfall or a decrease of ~ 100 mm/season, except for a small zone in southern Stann Creek District and northern Toledo District where a seasonal decrease of rainfall ~ 150 mm/season, with isolated pockets of decreases in rainfall of ~ 200 mm/season are projected (See Figure 2.27).

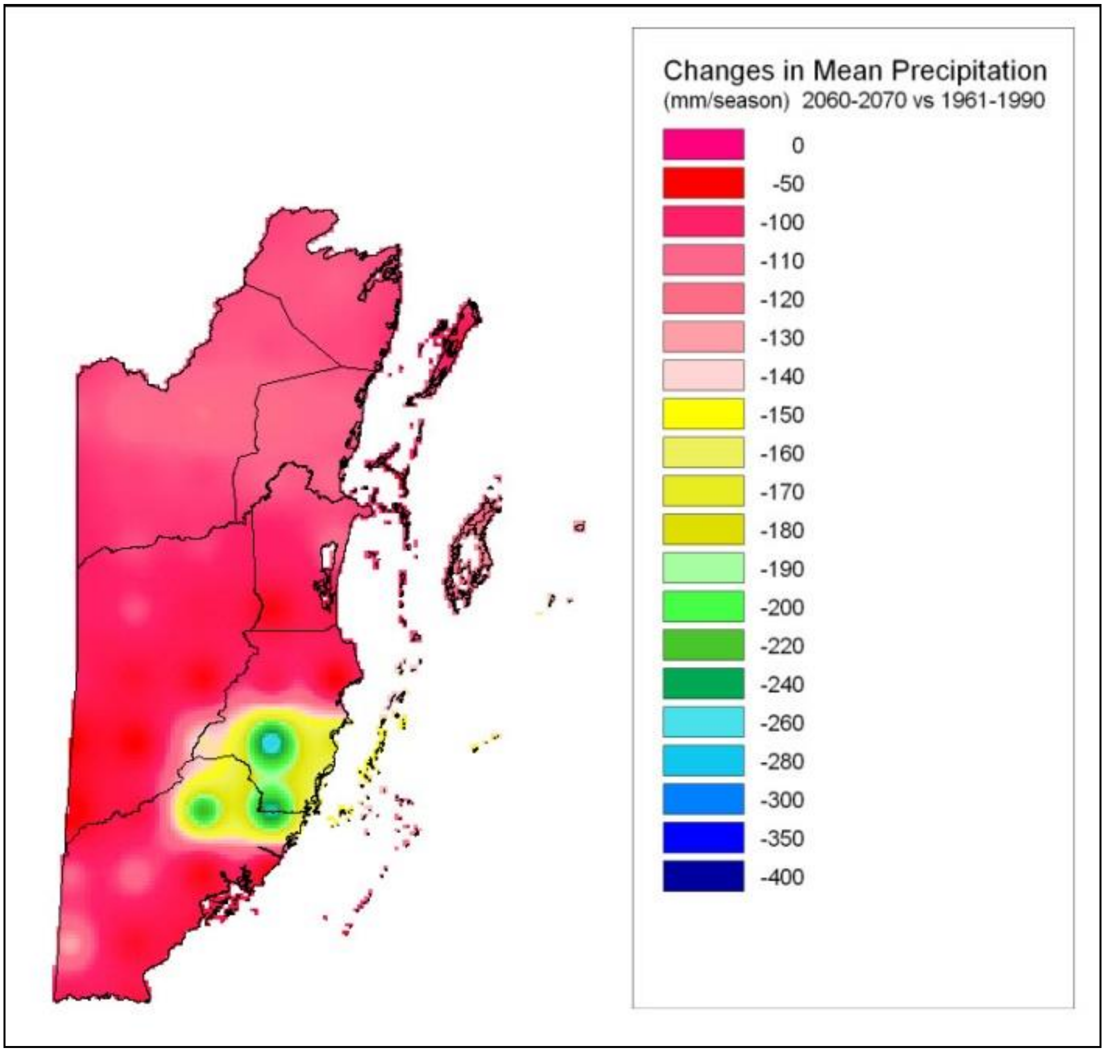

Figure 2.27: Changes in mean seasonal rainfall (mm/season) (2060-2070 vs 1961-1990) for the March-April-May season according to the ECHAM5 climate model

On the other hand, Figure 2.28 presents the changes in mean seasonal rainfall (mm/season) (2060-2070 vs 1961-1990) for the June-July-August wet season for Belize according to the ECHAM5 climate model. It shows that during this season there is, generally, an overall decrease in rainfall over all of Belize. For most of the country the decrease in seasonal rainfall is ~ 200 to ~ 220 mm/season. But in a zone in south-western Cayo and north-western Toledo, the decrease in seasonal rainfall is lesser being ~ 160 mm/season. But in a zone covering northern Toledo District and southern Stann Creek District and some of the Cayes, the decrease in seasonal rainfall is greatest, being ~ 350 mm/season (See Figure 2.28).

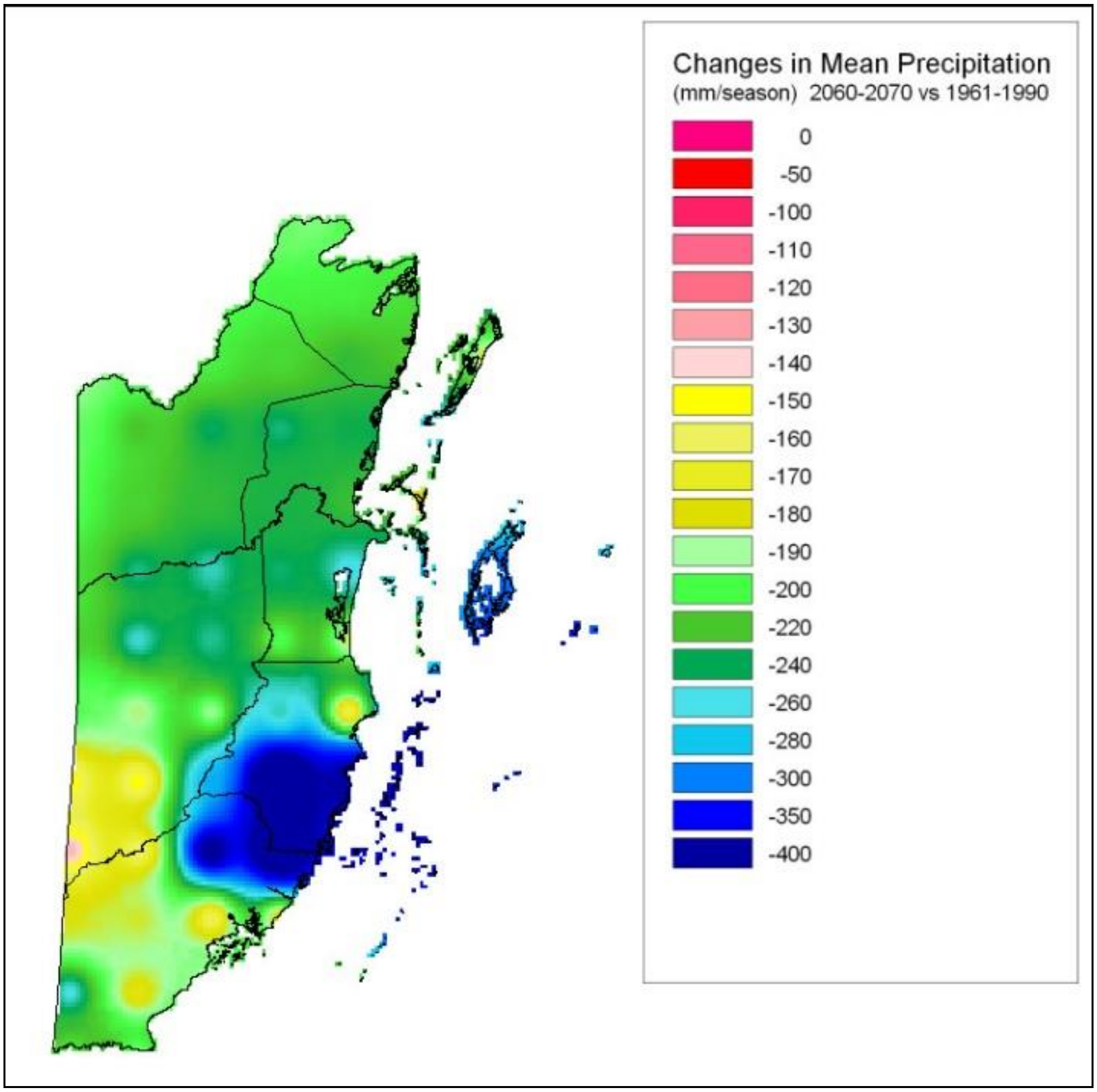

Figure 2.28 Changes in mean seasonal rainfall (mm/season) (2060-2070 vs 1961-1990) for the June-July-August season according to the ECHAM5 climate model

As for Figure 2.29, it presents the changes in mean seasonal rainfall (mm/season) (2060-2070 vs 1961-1990) for the September-October-November season for Belize according to the ECHAM5 climate model. It shows that during this season there is an overall decrease in rainfall over most of Belize of ~ 150 to ~ 160 mm/season. But, in a zone where the borders Stann Creek District and Toledo District converge, and for some of the Cayes, the decrease in seasonal rainfall is ~ 220 mm/season, with isolated pockets of decreases in seasonal rainfall approaching ~ 350 mm/season (See Figure 2.29).

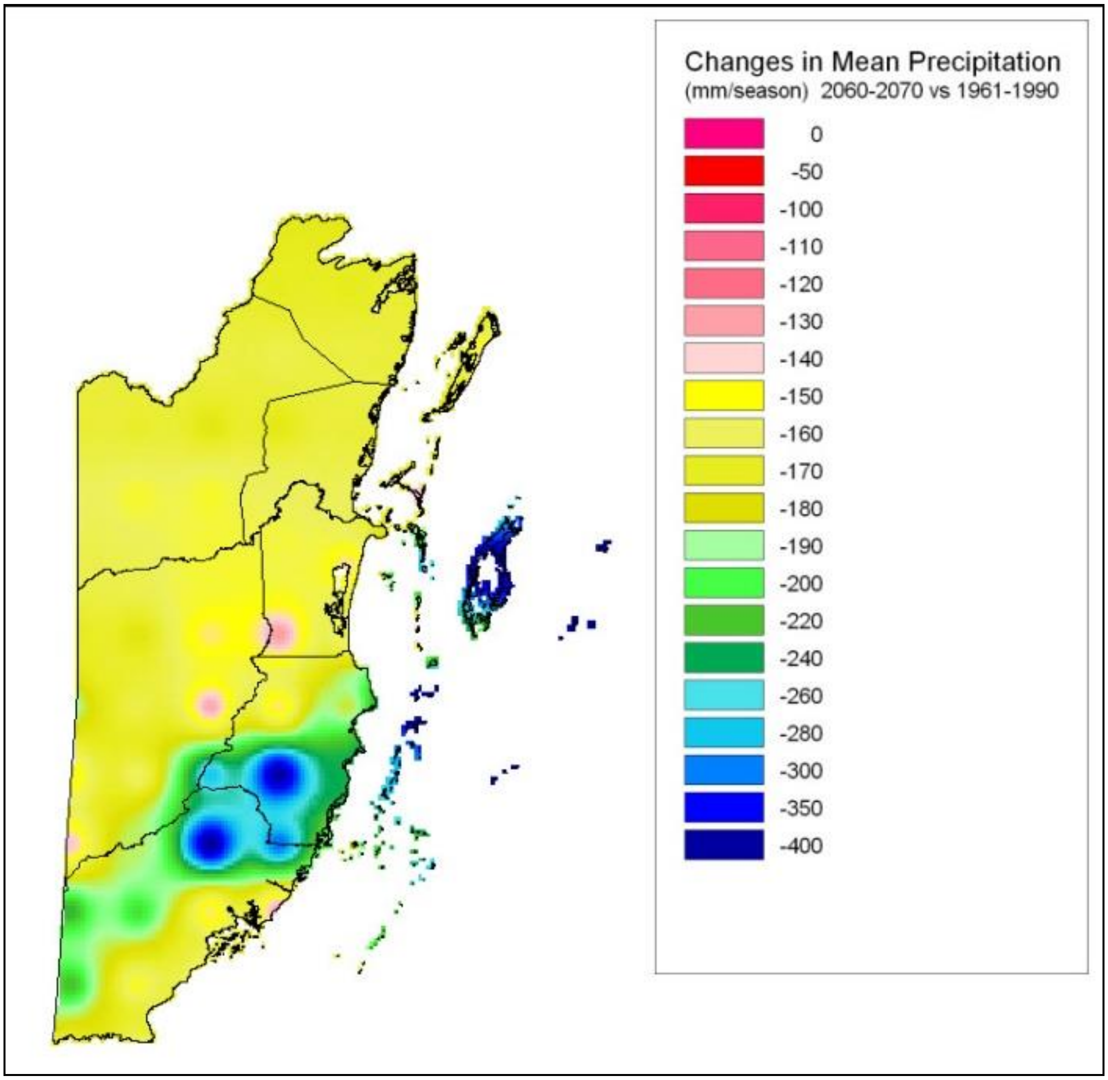

Figure 2.29: Changes in mean monthly rainfall (mm/season) (2060-2070 vs 1961-1990) for the September-October-November season according to the ECHAM5 climate model

Finally, Figure 2.30 presents the changes in mean seasonal rainfall (mm/season) (2060-2070 vs 1961-1990) for the December-January-February dry season for Belize according to the ECHAM5 climate model. It shows that during this season there is, generally, an overall decrease in rainfall of ~ 150 to ~ 160 mm/season for most of Belize. But in a zone covering northern Toledo District and most of Stann Creek District, and the Turneffe and nearby atolls, a decrease in seasonal rainfall of ~ 220 mm/season, with pockets of decreases in seasonal rainfall approaching ~ 350 mm/season are again projected (See Figure 2.30).

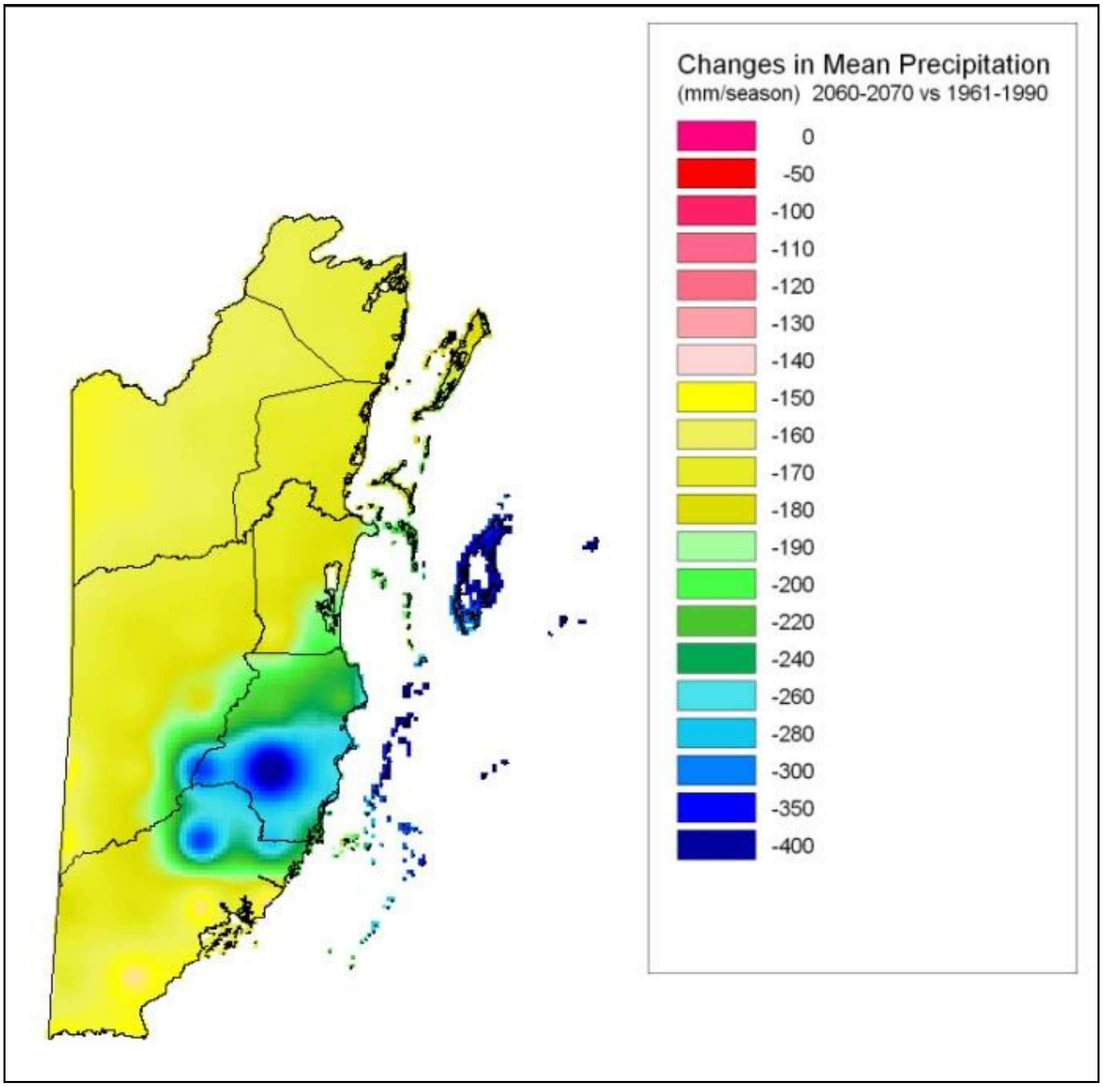

Figure 2.30: Changes in mean seasonal rainfall (mm/season) (2060-2070 vs 1961-1990) for the December-January-February season according to the ECHAM5 climate model

4.4 Air Temperature (^{0}C): HadCM3Q11

Figure 2.31 presents the changes in mean seasonal air temperature (^{0}C) (2060-2070 vs 1961-1990) for the March-April-May dry season for Belize according to the HadCM3Q11climate model. It shows that during this season, as was the case with the ECHAM5 model, there is a significant change in mean seasonal air temperature (^{0}C) for the future decadal period of 2060-2070, with temperatures increases exceeding ~ 2 to ~ 2.4 ^{0}C for all of Belize and even increasing by ~ 3.0 ^{0}C in some of the larger Cayes like Ambergris Caye and the coastal zone of southern Stann Creek and northern Toledo Districts. But in a small zone along the coast of southern Belize District and the outer Turneffe Atoll and Bokel Caye, a lower temperature increase of ~ 1.5 ^{0}C is projected, most likely due to oceanic influence (See Figure 2.31).

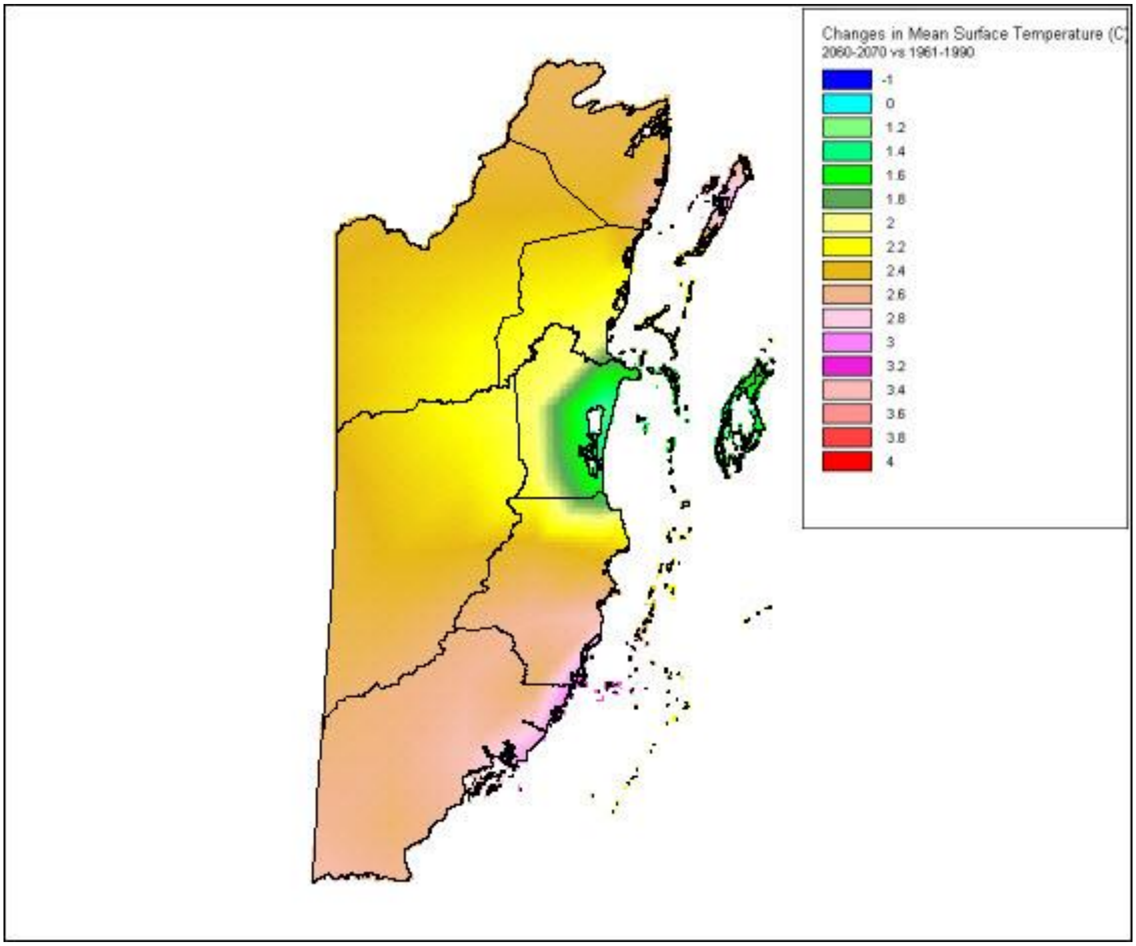

Figure 2.31: Changes in mean seasonal air temperature (^{0}C) (2060-2070 vs 1961-1990) for the March-April-May season according to the HadCM3Q11 climate model

On the other hand, Figure 2.32 presents the changes in mean seasonal air temperature (^{0}C) (2060-2070 vs 1961-1990) for the June-July-August rainy season for Belize according to the HadCM3Q11 climate model. It shows that during this wet season there is a more perceptible change in mean seasonal air temperature (^{0}C) for the future decadal period of 2060-2070. Increases in mean temperature during these months now generally range between ~ 2.6 and ~ 3^{0}C for most of Belize. But in a central zone stretching from northern Belize district through eastern Cayo District to southern Stann Creek District and northern Toledo district increases in seasonal temperature are > 3^{0}C. Also in northern Corozal district seasonal temperature increase approaches ~ 4^{0}C (See Figure 2.32).

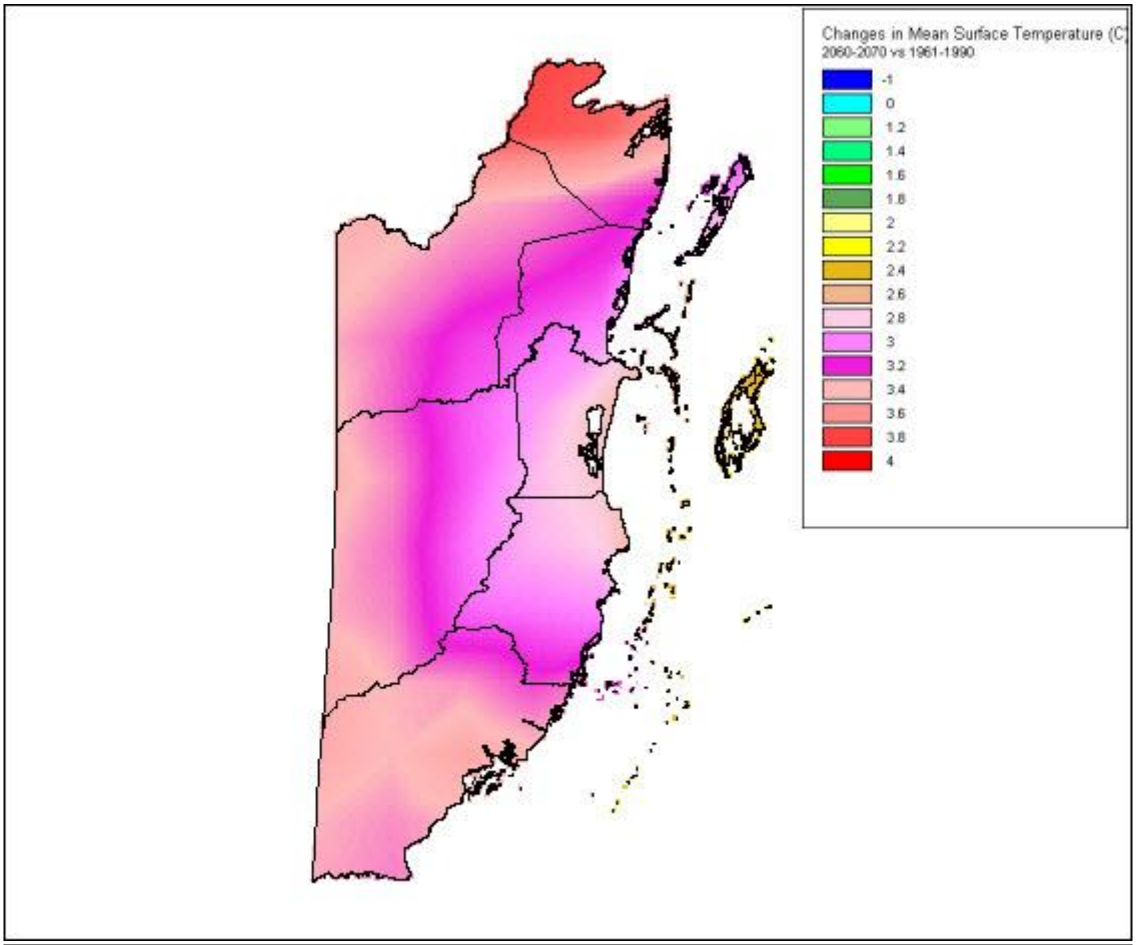

Figure 2.32: Changes in mean seasonal air temperature (^{0}C) (2060-2070 vs 1961-1990) for the June-July-August season according to the HadCM3Q11 climate model

Similarly, Figure 2.33 presents the changes in mean seasonal air temperature (^{0}C) (2060-2070 vs 1961-1990) for the September-October-November season for Belize according to the HadCM3Q11 climate model. It shows that during this wet season there is again a very perceptible change in mean seasonal air temperature (^{0}C) for the future decadal period of 2060-2070. Increases in mean temperature during these months again generally range between ~ 2.6 and ~ 3^{0}C for most of Belize. Again, in a narrow zone along the east coast stretching from Corozal District through Belize District and eastern Cayo District to Stann Creek District increases in seasonal temperature are > 3^{0}C (See Figure 2.33).

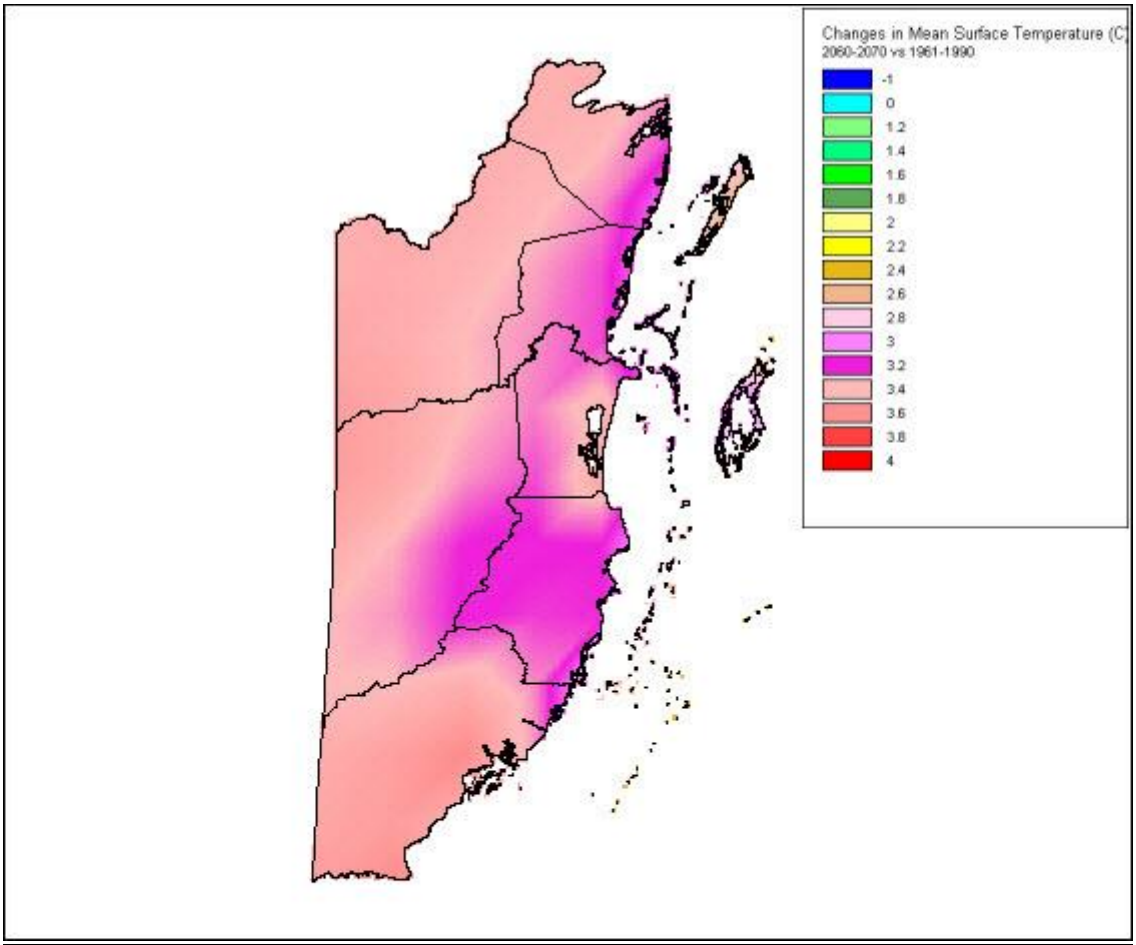

Figure 2.33: Changes in mean seasonal air temperature (^{0}C) (2060-2070 vs 1961-1990) for the September-October-November season according to the HadCM3Q11 climate model

Finally, Figure 2.34 presents the changes in mean seasonal air temperature (^{0}C) (2060-2070 vs 1961-1990) for the December-January-February dry season for Belize according to the HadCM3Q11 climate model. It shows that during this cool dry season there is again a very perceptible change in mean seasonal air temperature (^{0}C) for the future decadal period of 2060-2070. Increases in mean temperature during these months again generally range between ~ 2.8 and ~ 3.2 ^{0}C for most of Belize, except for parts of Belize district where the increase in temperature is ~ 2.6 ^{0}C. But in the extreme northern part of Belize, in most of Corozal District and part of Orange Walk District, increases in seasonal temperature are ~ 4^{0}C (See Figure 2.34).

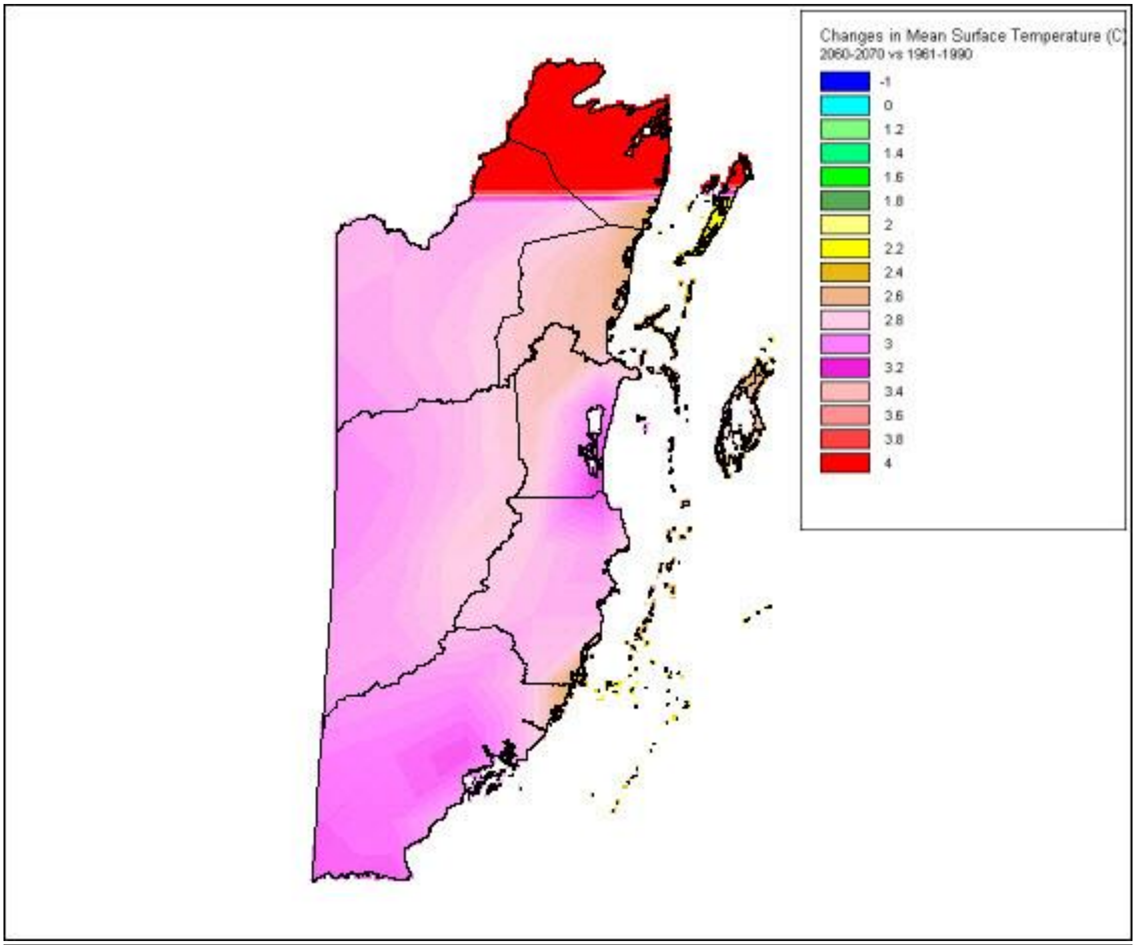

Figure 2.34: Changes in mean seasonal air temperature (^{0}C) (2060-2070 vs 1961-1990) for the December-January-February season according to the HadCM3Q11 climate model

4.5 Rainfall (mm/season): HadCM3Q11

Figure 2.35 presents the changes in mean seasonal rainfall (mm/season) (2060-2070 vs 1961-1990) for the March-April-May dry season for Belize according to the HadCM3Q11climate model. It shows that, in general, during this season there is an overall decrease in rainfall over almost the entire country. In a zone covering Western Cayo District, most of Orange Walk District and the northern tip of Corozal District the decrease in seasonal rainfall is ~ 160 mm/season. On the other hand, in a zone covering eastern Corozal District, most of Belize District and eastern Toledo District and most of the Cayes, the decrease in seasonal rainfall is ~ 190 to ~ 200 mm/season. But in a zone centered over all of Stann Creek District, the projected decrease in seasonal rainfall is even higher, namely ~ 240 mm/season with isolated pockets of decreases in seasonal rainfall approaching ~ 300 mm/season (See Figure 2.35).

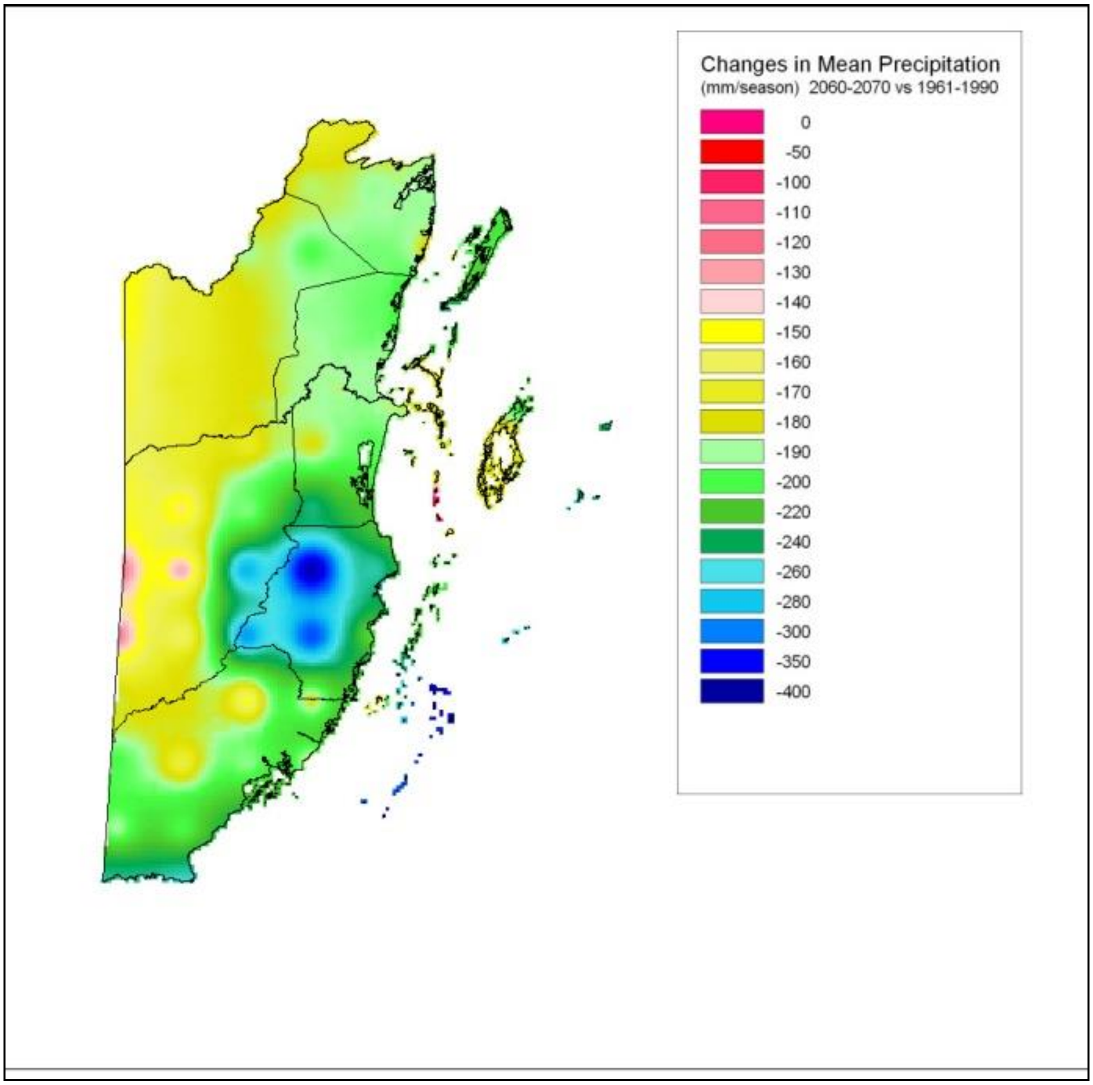

Figure 2.35: Changes in mean seasonal rainfall (mm/season) (2060-2070 vs 1961-1990) for the March-April-May season according to the HadCM3Q11 climate model

On the other hand, Figure 2.36 presents the changes in mean seasonal rainfall (mm/season) (2060-2070 vs 1961-1990) for the June-July-August rainy season for Belize according to the HadCM3Q11 climate model. It shows that during this season there is an overall and significant decrease in seasonal rainfall over most of Belize. In a zone located in western Cayo District the decrease in seasonal rainfall is ~ 150 to ~ 160 mm/season. On the other hand, in a zone covering western Orange Walk District, the northern tip of Corozal District and parts of Toledo and Cayo Districts the decrease in seasonal rainfall is ~ 220 mm/season. But for most of Corozal and Belize Districts, the northern tip of Orange Walk District and parts of Toledo District and the offshore Cayes and atolls the decrease in seasonal rainfall is ~ 260 mm/seasons and in a zone centered over most of Stann Creek and southern Toledo Districts, the decrease in seasonal rainfall approaches ~ 300 mm/season (See Figure 2.36).

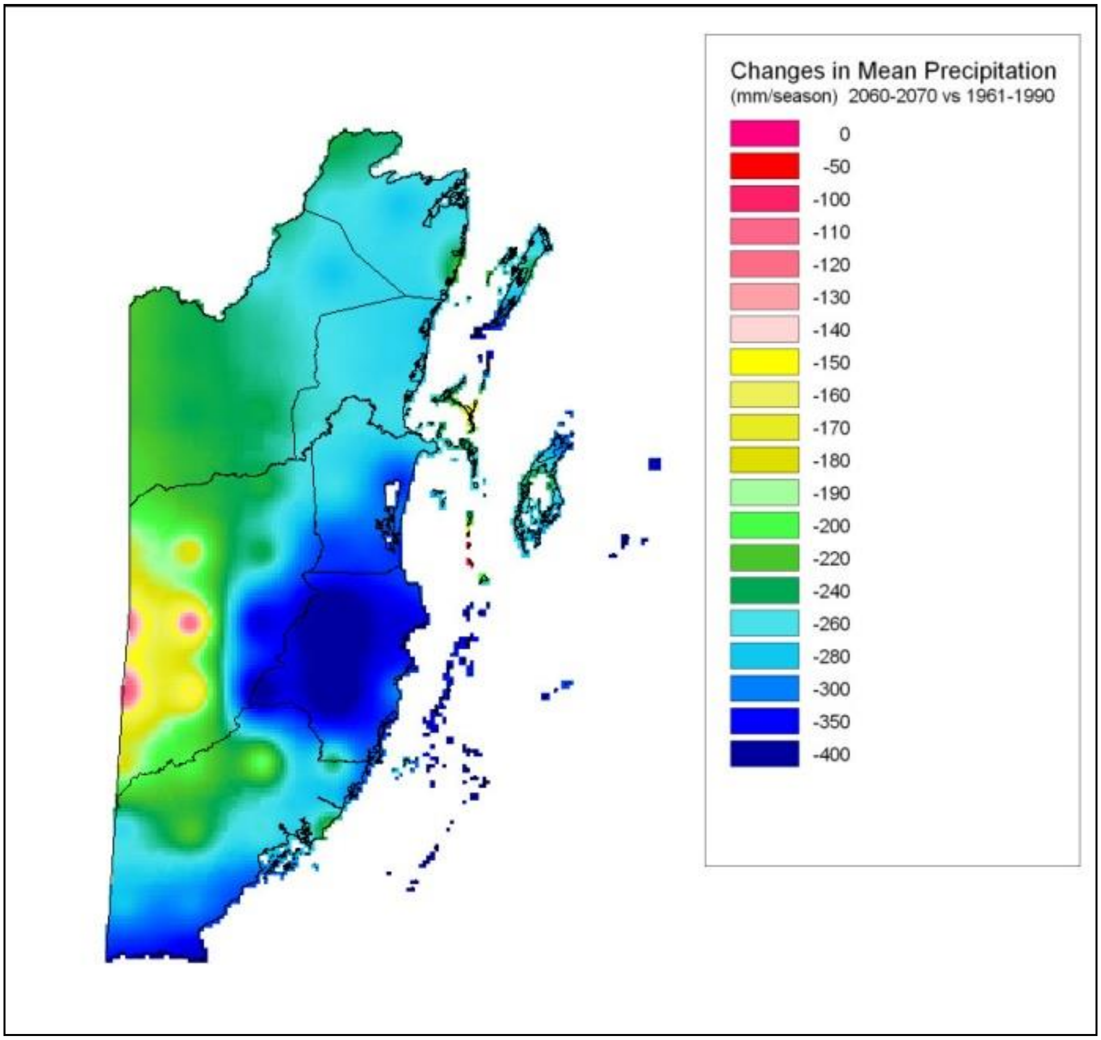

Figure 2.36: Changes in mean seasonal rainfall (mm/season) (2060-2070 vs 1961-1990) for the June-July-August season according to the HadCM3Q11 climate model

As for Figure 2.37, it presents the changes in mean seasonal rainfall (mm/season) (2060-2070 vs 1961-1990) for the September-October-November season for Belize according to the HadCM3Q11 climate model. It shows that during this season there is an overall decrease in rainfall of ~ 200 to ~ 220 mm/season for most of Belize. But in a zone centered over Stann Creek District and covering parts of Cayo and Belize Districts and the offshore Cayes and atolls, the changes in seasonal rainfall are ~ 260 mm/season with isolated pockets of seasonal rainfall decreases approaching 350 mm/season (See Figure 2.37).

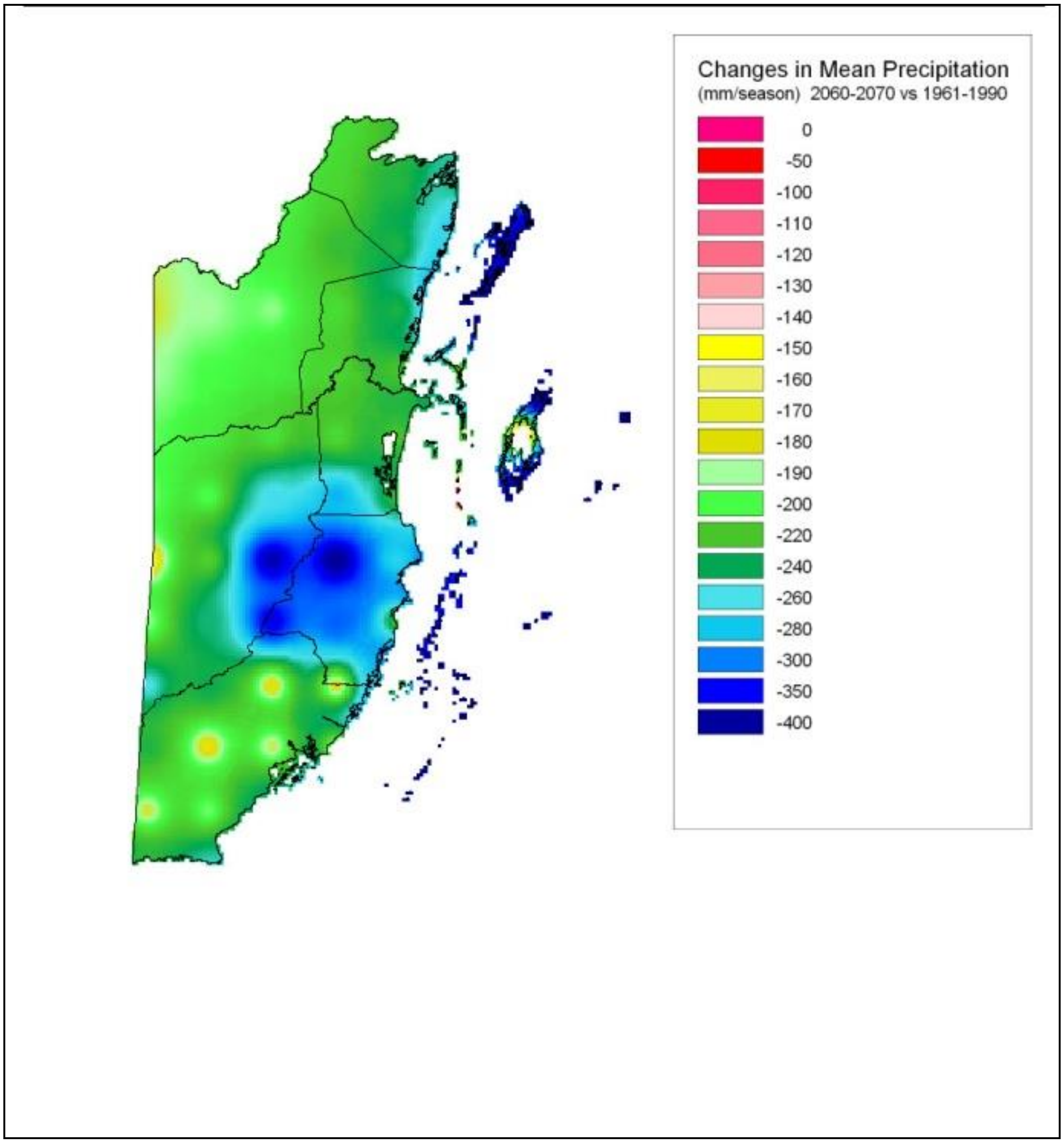

Figure 2.37: Changes in mean seasonal rainfall (mm/season) (2060-2070 vs 1961-1990) for the September-October-November season according to the HadCM3Q11 climate model

Finally, Figure 2.38 presents the changes in mean seasonal rainfall (mm/season) (2060-2070 vs 1961-1990) for the December-January-February dry season for Belize according to the HadCM3Q11 climate model. It shows that during this season there is little change or an overall decrease in rainfall of ~ 100 mm/season for most of Belize. But in a zone centered over Stann Creek District and covering parts of Cayo, Toledo and Belize Districts and the offshore Cayes and atolls, the changes in seasonal rainfall are ~ 150 to ~ 200 mm/season (See Figure 2.38).

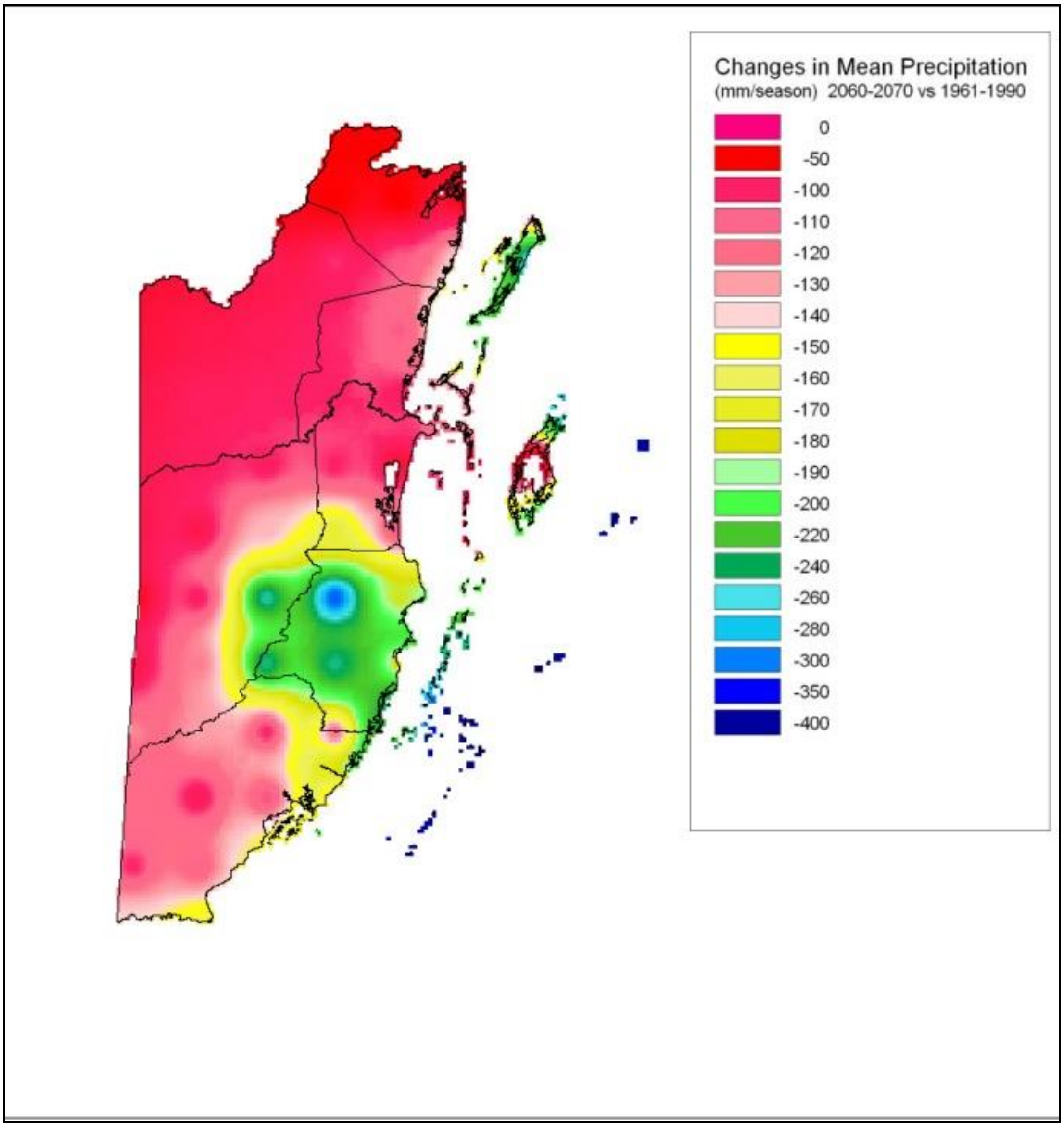

Figure 2.38: Changes in mean seasonal rainfall (mm/season) (2060-2070 vs 1961-1990) for the December-January-February season according to the HadCM3Q11 climate model

4.6 Summary and Conclusions

From the foregoing sections, both the ECHAM5 and HadCM3Q11 climate models consistently project an increase in temperature (^{0}C) for all Districts of Belize and for all seasons. Though the HadCM3Q11 projections are slightly higher, both models project increases in seasonal temperature (^{0}C) that ranges from 2 to 4 ^{0}C and that display sometimes a fair level of spatial variation.

However, in the case of rainfall, both the ECHAM5 and HadCM3Q11 climate models generally project an overall decrease in seasonal rainfall in all seasons, especially the June-July-August rainy season. Furthermore, wide temporal and spatial variations in seasonal rainfall (mm/season) are projected for Belize. But in a zone centered over Stann Creek District and covering parts of Cayo, Toledo and Belize Districts and the offshore Cayes and atolls, the decreases in seasonal rainfall are most significant.

5.0 Socio-economic Impacts Adaptation

All of the climate scenarios presented above, namely the Program for Climate Model Diagnosis and Inter-comparison (PCMDI), based on SRES A2, B1 and A1B forcing scenarios (McSweeney *et al*, 2008, 2010), the climatological data from the National Meteorological and Hydrological Service of Belize (NMHS) based on the downscaled ECHAM4 global climate model (50 km resolution), forced by the SRES A2 socio-economic scenario and the ECHAM5 and HadCM3Q11 global climate models (25 km resolution), forced by the SRES A1B socio-economic scenario all demonstrate that important climate changes will occur in Belize in the future. For the decadal period (2060-2069) of interest here, seasonal air temperatures are expected to increase by ~ 2^0 C. Also, the changes in seasonal rainfall are expected to decrease significantly, depending on the season and the area, in some cases according to both the ECHAM5 and the HadCM3Q11 climate models.

Furthermore, climate change will provoke a rise in mean sea level in excess of 0.5 m by the end of the century. Storm surges are also expected to increase in intensity as a result of increases in the intensity of tropical storms and hurricanes.

These changes in temperature and rainfall and sea levels will have significant impacts on Belize, especially the coastal zone, and the major socio-economic sectors of Belize, namely water resources, agriculture, tourism, fisheries and human health. These impacts and adaptation options will be elaborated upon in the sections to follow.

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Section 3: Coastal Zone/Development

1.0 Introduction

This Section deals with the **Coastal Zone** sector of vulnerability and adaptation (V&A) assessment component of the Third National Communication (TNC) of Belize.

The coast comprises the interface between land and sea. The coast therefore represents a highly dynamic nexus between land and sea, which is adjusting over time to a range of drivers, including climate change and sea level rise and storm surges.

Vulnerability may be defined as the degree of capability to cope with the consequences of climate change and sea level rise (Klein and Nicholls, 1999). As such the concept of vulnerability comprises:

- The susceptibility of the coastal zone to the physical and ecological changes imposed by sea level rise and storm surges;
- The potential impacts of these natural system changes on the socioeconomic system;
- The capacity to cope with the impacts, including the possibilities to prevent or reduce impacts through adaptation measures.

Climate change and climate-driven sea level rise impose additional threats to coastal systems already under pressure from population concentration and increasing population growth in the future. Human presence, including infrastructure facilities, is becoming a significant direct and indirect control on coastal ecosystem functions and coastal processes.

Increased coastal erosion and more extensive inundation are expected from rising sea levels; storm surges may flood greater areas than now, thereby impacting on primary production, and may cause saline intrusion up estuaries and into groundwater aquifers. These biophysical impacts may cause loss of coastal habitats, property damage, flooding and loss of life, as well as having economic consequences for rural production and urban lifestyles. In many cases the effect of a change in climate and sea level are going to exacerbate problems that already exist.

Furthermore, the adaptive capacities of local communities to cope with the effects of severe climate impacts decline if there is a lack of availability of physical, economic and institutional resources employed to combat the effects of the climate hazard, and to reduce the vulnerability of high-risk communities and groups exposed to them.

The last Intergovernmental Panel on Climate Change (IPCC) assessment report (IPCC, 2007) indicates that countries that contain extensive low-lying coastal zones, such as Belize, where a significant proportion of the population resides along the coast, are likely to be among the communities most vulnerable to the adverse impacts of climate change. In fact the low-lying coastal lowlands of Belize are already protected from sea levels by an uncoordinated system of sea walls. The IPCC (2007) and other similar reports point to a number of vulnerabilities that

Coastal Zones face with regards to climate change and variability, including their size and limited resource base, vulnerability to existing weather events such as heavy rainfall, dry-season drought, tropical storms and storm surges, and restricted economic opportunities that are being exacerbated by globalization and trade barriers. Though there is more than ample space in the interior of Belize, economic resources and poor and sometimes water-logged soils make displacement to the interior difficult. Other issues that would come under consideration would include the practical and ethical considerations of relocating a large part of the population, along with all the necessary infrastructure and developments, away from the coast, not to mention the issue of finding suitable areas to relocate to, and displacing its current land use.

Most of Belize's coastline is at or near sea level and more than 50% of the country's population reside on or near the coast. Most of the business operations are also near the coast. Belize City, the largest population centre in the country is on the coast at more or less sea level and between two major rivers; The Belize River and the Sibun River. Both are known to break their banks near Belize City during flood events.

2.0 Coastal Zone/Methodology

For the coastal zone sector of Belize, we at first examine the vulnerabilities to existing weather and climate variability, including sea level rise and storm surge scenarios (IPCC, 2007; Singh and El Fouladi 2005, 2007). These would include low-lying coastal areas currently affected by inundation, erosion and saline intrusions. This information will be extracted from published reports (First National Communication of Belize (NC1), 2002; Second National Communication of Belize (NC2), 2011; National Climate Resilience Investment Plan (NCRIP) 2013, Belize Integrated Coastal Zone Management Plan, 2013) and through consultations with the appropriate Ministerial stakeholders.

As for the vulnerabilities of the coastal zone to projected future climate change and sea levels, this will be done through data on sea level rise and storm surges gleaned from climate models (A-OGCM: Atmosphere-Ocean General Circulation Models) and the literature (NC1, 2002; NC2, 2011; IPCC, 2007; CPACC (Caribbean Planning for Adaptation to Climate Change), 2001; MACC (Mainstreaming Adaptation to Climate Change, Special Program on Adaptation to Climate Change (SPACC), 2011,Vulnerability Assessment of the Belize Coastal Zone, 2007). Furthermore for the coastal zone of Belize under threat to sea level rise and storm surges (~ 10 m elevation) we couple current (around 2012) and future (a decade centred on 2060) sea levels and storm surges to digital terrain mapping (DTM) using GIS techniques, as was performed in Trinidad and Tobago (Singh and El Fouladi, 2005, 2007).

In order to be able to highlight the susceptibility of floodplains along the coast of Belize, we use the following methodological approach.

2.1 Identification of the region of interest (ROI)

This zone covers an area of 3 481 km2 stretching from the northern area of the coastline of Belize and it extends southward to over 386 km of coastline. More specifically, the Area of Interest (ROI) is represented by a band of 10 km within the mainland and the islands of Turnelle, Chappel Cayo, Cayo Caye Corker and Caye.

2.2 Data

The data are represented by the Digital Surface Elevation Model (DSM) in a format "ArcGis.shp" with a spatial resolution of 4.1m absolute in vertical and a standard deviation of 25 cm. The Data projection is WGS84. The XY resolution is 30 meters.

In order to correct the DSM so as to derive a DTM (Digital Terrain Model), especially where tall vegetation is found, we used data from the Belize Ecosystem Shapefile (Biodiversity and Environmental Resource Data System of Belize (2013)

Data representing the projected sea level changes for the 2060s decade is derived from the latest IPCC (2013) Summary Report. However, sea level rise values of the IPCC (2013) are rather conservative when compared to other recent studies that integrate the land ice contribution to sea level rise (Rahmstorf, 2007, 2010; Horton et al., 2008; Vermeer and Rahmstorf, 2009; Grinsted et al., 2009). In view of this conservativeness, we selected the extreme values of the IPCC (2013): 0.38 m for the 2046-2065 period and 0.82 for the 2081-2100 period (See Table 3.1).

As for the effects of storm surges, we used the storm surge and hurricane categories data from the Caribbean Disaster Mitigation Project (2005) (Table 3.2). We used the storm surge projections for a category 2 and a category 5 hurricane. Furthermore, the final values of the storm surges were derived by incorporating the sea level rise and the highest tide level for the 2046-2065 and 2081-2100 future periods (See Table 3.3). These values are close to the storm surges caused by Hurricane Hattie, a Category 5 hurricane that hit Belize in 1961, with winds of approximately 255 km/hr and storm surge heights between 4.5 and 6 m (Terminal Report - Part 2, 1999).

In the final analysis, we superimposed the sea level rise and the storm surge categories on the Digital Elevation Map (DEM) of Belize together with the major land use categories for the 2046-2065 and the 2081-2100 periods (See Table 3.3).

2.3 Methodological steps: coastal inundation

The main methodological steps then for evaluating coastal inundation and land use changes from sea level rise in the future (centred around 2060) are:

1. Visualization of Digital Elevation Model (DEM) using ArcGIS software;
2. The evaluation of the model quality and data cleaning;
3. The creation of the layer containing the elevation values of the model;
4. The creation of the layer representing the current level of the ocean;
5. The creation of the layer from satellite imagery to identify flooding zones;
6. The integration of the layers into a single map;
7. The creation of the layer representing the level of the ocean in 2060;
8. Identification and calculation of flooding zones;
9. Based on the statistical results on flooding zones, we derived land use categories affected by inundation from sea level rise and storm surges.

Table 3.1: Global mean sea level rise for the 2046-2065 and 2081-2100 time periods (Source: IPCC Summary Report, 2013)

		2046–2065		2081–2100	
Variable	**Scenario**	mean	*likely* range [c]	mean	*likely* range [c]
Global Mean Surface Temperature Change (°C) [a]	RCP2.6	1.0	0.4 to 1.6	1.0	0.3 to 1.7
	RCP4.5	1.4	0.9 to 2.0	1.8	1.1 to 2.6
	RCP6.0	1.3	0.8 to 1.8	2.2	1.4 to 3.1
	RCP8.5	2.0	1.4 to 2.6	3.7	2.6 to 4.8
		mean	*likely* range [d]	mean	*likely* range [d]
Global Mean Sea Level Rise (m) [b]	RCP2.6	0.24	0.17 to 0.32	0.40	0.26 to 0.55
	RCP4.5	0.26	0.19 to 0.33	0.47	0.32 to 0.63
	RCP6.0	0.25	0.18 to 0.32	0.48	0.33 to 0.63
	RCP8.5	0.30	0.22 to 0.38	0.63	0.45 to 0.82

Table 3.2: Storm surge levels according to hurricane categories (Source: Caribbean Disaster Mitigation Project, 2005)

STORM SURGE AND HURRICANE CATEGORIES (SOURCE: CARIBBEAN DISASTER MITIGATION PROJECT, 2005).

Category	Pressure (mb)	Winds (km/hr)	Storm Surge (m)	Damage	Rounded Value of Relevant Storm Surges (m)
0: Tropical Storm	> 995	61-119	0.5-1.2	Some	
1: Hurricane	980-995	119-153	1.2-1-5	Minimal	
2.Hurricane	065-979	154-177	1.6-2.4	Moderate	2
3: Hurricane	945-964	178-209	2.5-3.6	Extensive	
4: Hurricane	920-944	210-250	3.7-5.4	Extreme	
5: Hurricane	<920	> 250	> 5.4	Catastrophic	5

Table 3.3: Final values of future sea level and storm surge scenarios: Belize

Sea Level Rise (RCP 8.5) (m)		Contribution of MHHW (Mean Higher High Water) (m)	**Final Values of Future Sea Levels (m)**	*Storm Surge Scenarios Category 2 Hurricane Mid Value (m)	**Final Storm Surge Scenarios Category 2 Hurricane: Mid Value plus Sea Level Rise (m)**	*Storm Surge Scenarios (m) Category 5 Hurricane Minimum Value (m)	**Final Storm Surge Scenarios Category 5 Hurricane: Minimum Value plus Sea Level Rise (m)**
2040-2065	0.38	0.9	**0.47**	2.00	**2.47**	5.4	**5.87**
2081-2100	0.82	0.9	**0.91**	2.00	**2.91**	5.4	**6.31**

*By adding the sea levels to the mid-value storm surges

3.0 Simulations Results

The major land use categories and their spatial distribution for Belize are presented in Figure 3.1. This land use map will be used as the base map for demonstrating the land use types and their respective areas that would be subjected to inundation following the scenarios of sea level rise and storm surges described in the previous section (Figure 3.1).

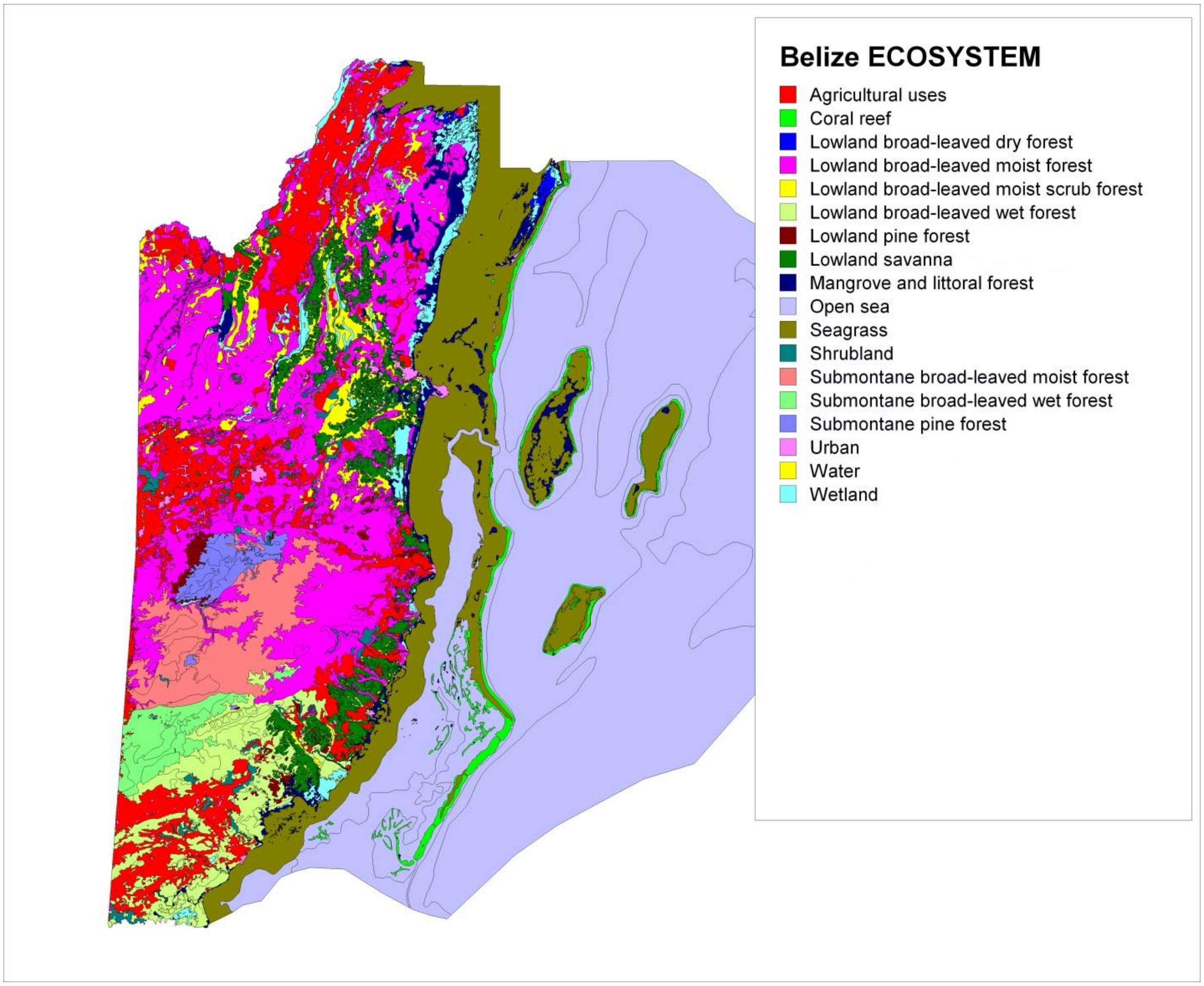


Figure 3.1: Major Land Use Classes of Belize

Figure 3.2 shows the Coastal Zone and Land Use categories inundated by a 0.47 m rise in sea level (Level 0.47 m) for Belize for the 2040-2065 period. Table 3.4 summarizes the landuse categories that are likely to be inundated in the event of a 0.47 rise in sea level by 2040-2065 (See Figure 3.2 and Table 3.4).

It is evident in Figure 3.2 and Table 3.4 that all of the coastal zone and a large portion of the Cayes, a total area of ~ 210 km^2 will be affected by inundation from a 0.47 rise in sea level by 2040-2065 (See Figure 3.2 and Table 3.4).

The landuse classes that would be most affected are Seagrass (~ 88 km^2/42 %), Wetland (~ 67 km^2/32 %) and Mangrove and littoral forest (~ 48 km^2/23 %) (See Figures 3.2 and 3.3 and Table 3.4).

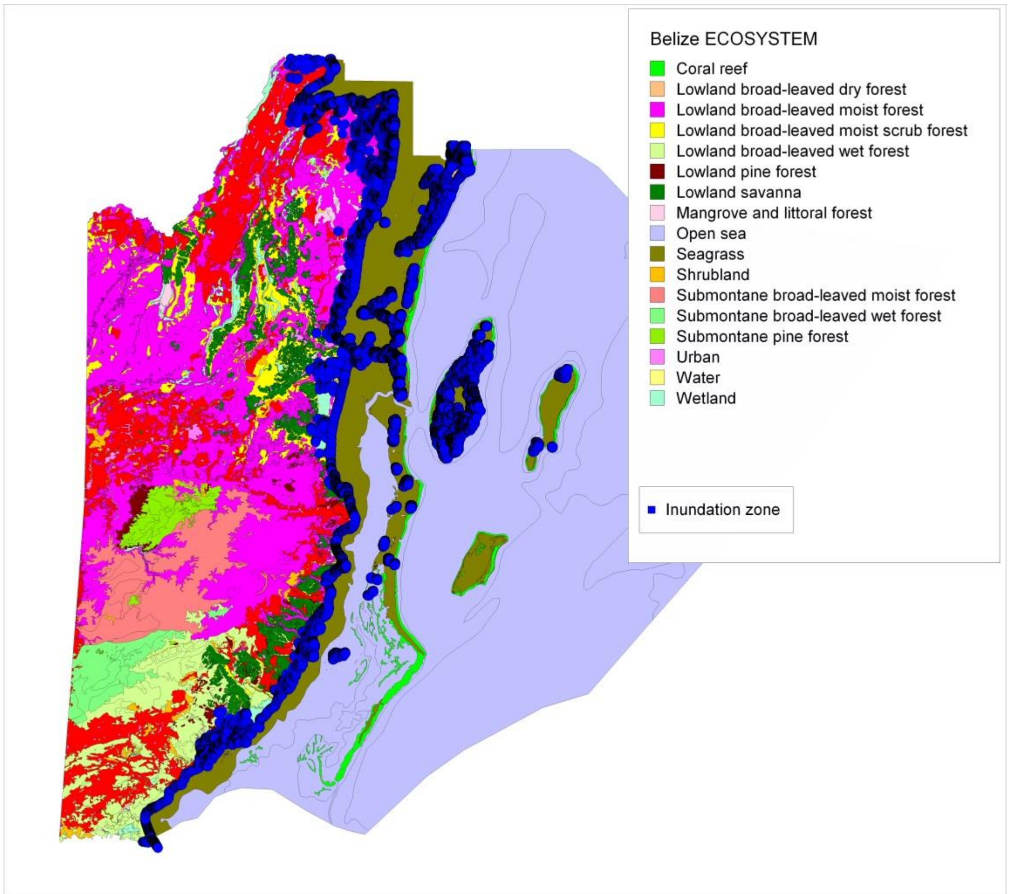


Figure 3.2: Coastal Zone and Land Use categories inundated by a 0.47 m rise in sea level (Level 0.47 m: 2040-2065)

Table 3.4: Land Use categories inundated by a 0.47 m rise in sea level (Level 0.47 m: 2040-2065)

Land Use Category	Areas inundated (km^2)
Agricultural uses	0.3096
Coral reef	1.1007
Lowland broad-leaved dry forest	1.4391
Lowland broad-leaved moist forest	0.2907
Lowland broad-leaved moist scrub forest	0.1035
Lowland broad-leaved wet forest	0.0018
Lowland pine forest	0
Lowland savanna	0.5697
Mangrove and littoral forest	48.3156
Seagrass	88.9164
Shrubland	0
Urban	1.0404
Water	0.8964
Wetland	67.3506
Total Area	210.335

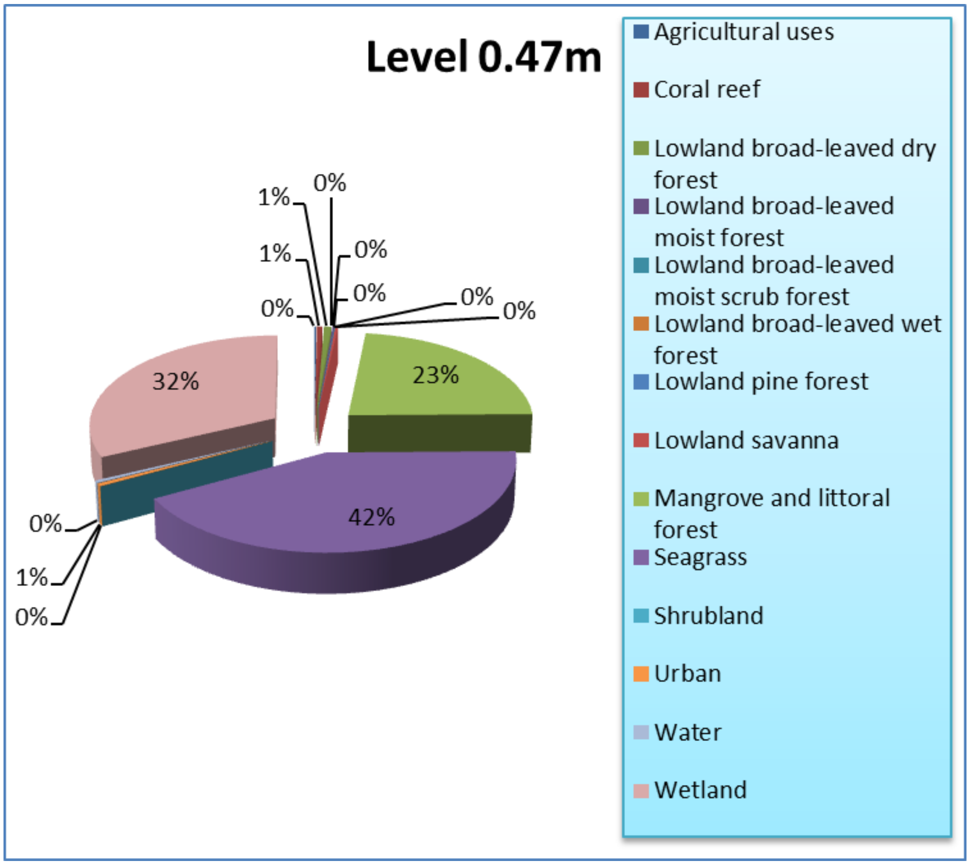


Figure 3.3: Percentage of Land Use categories inundated by a 0.47 m rise in sea level (Level 0.47 m: 2040-2065)

On the other hand, Figure 3.4 shows the Coastal Zone and Land Use categories inundated by a 0.91 m rise in sea level (Level 0.91 m) for Belize for the 2081-2100 period. Table 3.5 summarizes the landuse categories that are likely to be inundated in the event of a 0.91 rise in sea level by 2081-2100 (See Figure 3.4 and Table 3.5).

Again, it is evident in Figure 3.4 and Table 3.5 that all of the coastal zone and a large portion of the Cayes, a total area of ~ 291 km^2 will be affected by inundation from a 0.91 rise in sea level by 2081-2100 (See Figure 3.4 and Table 3.5).

Also, the landuse classes that would be most affected are Seagrass (~ 110 km^2/38 %), Wetland (~ 93 km^2/32 %) and Mangrove and littoral forest (~ 77 km^2/27 %) (See Figures 3.4 and 3.5 and Table 3.5).

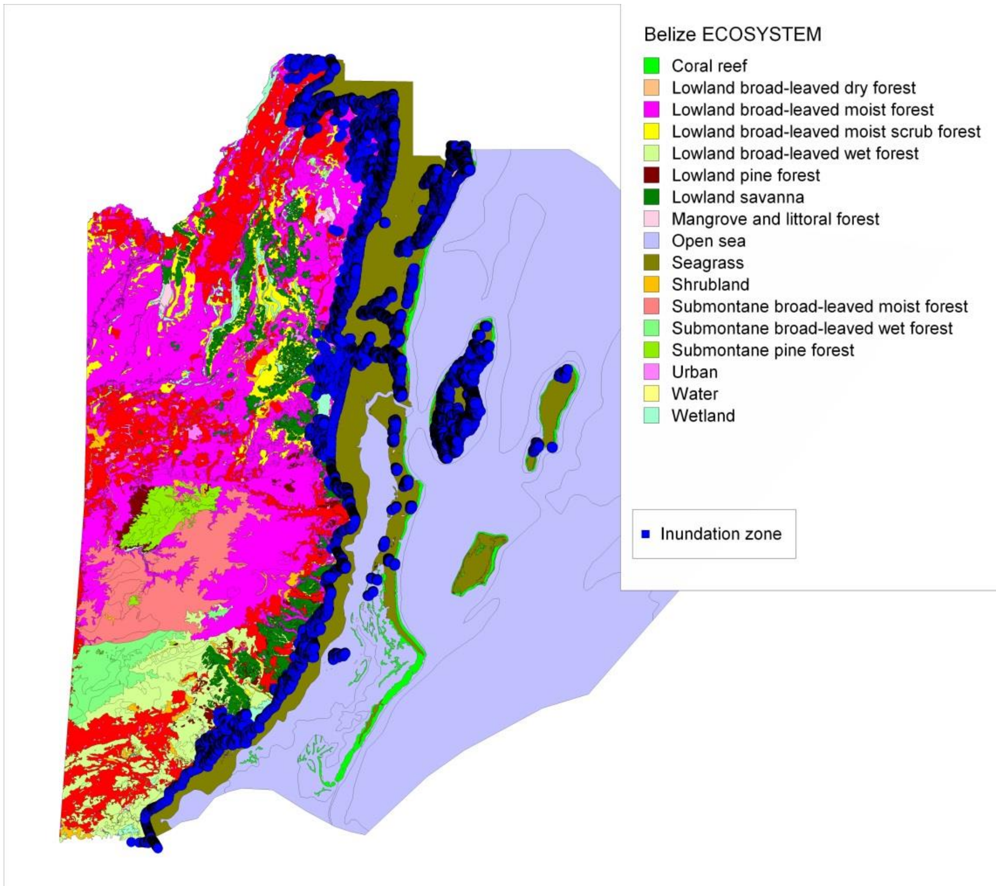


Figure 3.4: Coastal Zone and Land Use categories inundated by a 0.91 m rise in sea level (Level 0.91 m: 2081-2100)

Table 3.5: Land Use categories inundated by a 0.91 m rise in sea level (Level 0.91 m: 2081-2100)

Land Use Category	Areas inundated (km^2)
Agricultural uses	0.7551
Coral reef	1.3779
Lowland broad-leaved dry forest	2.0529
Lowland broad-leaved moist forest	0.5922
Lowland broad-leaved moist scrub forest	0.2088
Lowland broad-leaved wet forest	0.0036
Lowland pine forest	0
Lowland savanna	1.6956
Mangrove and littoral forest	77.5287
Seagrass	110.3589
Shrubland	0
Urban	2.2023
Water	1.5453
Wetland	93.5775
Total Area	291.899

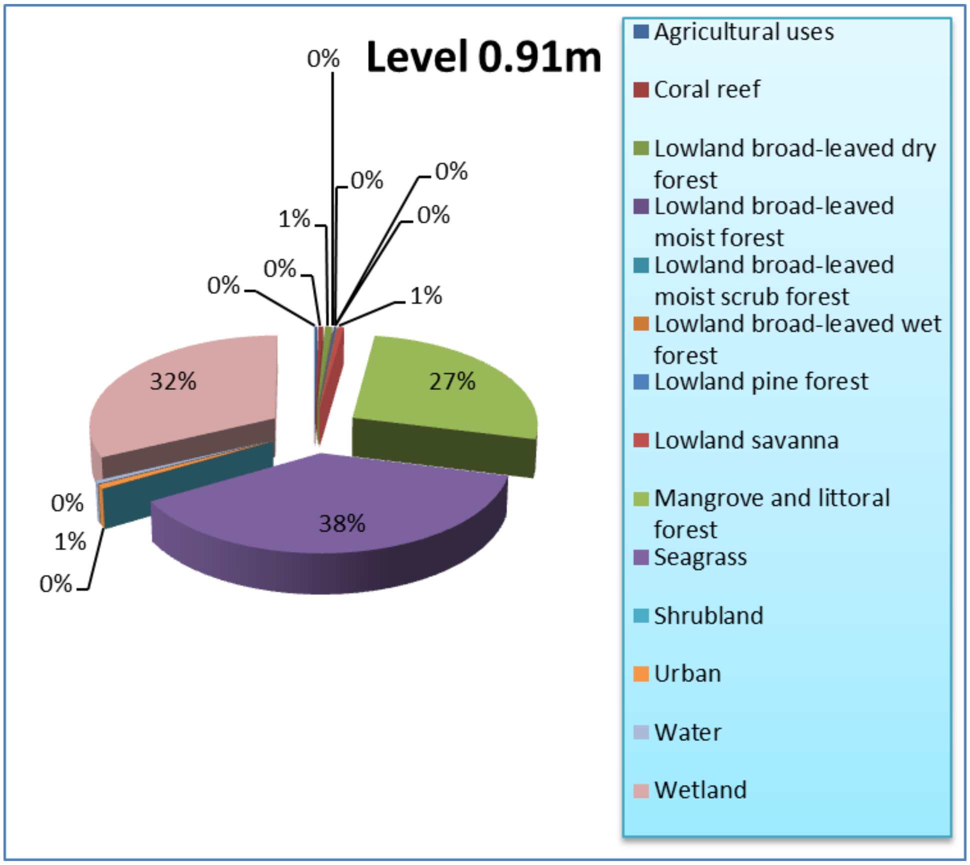


Figure 3.5: Percentage of Land Use categories inundated by a 0.91 m rise in sea level (Level 0.91 m: 2081-2100)

When a storm surge for a category 2 hurricane is considered, Figure 3.6 shows the Coastal Zone and Land Use categories inundated by a 2.47 m rise in sea level combined with the category 2 hurricane storm surge (Level 2.47 m) for Belize for the 2040-2065 period. Table 3.6 summarizes the landuse categories that are likely to be inundated in the event of a 2.47 storm surge coupled with a 0.47 rise in sea level by 2040-2065 (See Figure 3.6 and Table 3.6).

Furthermore, it is evident in Figure 3.6 and Table 3.6 that all of the coastal zone and a large portion of the Cayes, a total area of ~ 827 km^2 will be affected by inundation from a rise in sea level coupled with a storm surge, namely 2.47 m, by 2040-2065 (See Figure 3.6 and Table 3.6).

Also, the landuse classes that would be most affected are, in order of magnitude, Wetland (~ 323 km^2/39 %), and Mangrove and littoral forest (~ 284 km^2/34 %) and Seagrass (~ 153 km^2/19 %), (See Figures 3.6 and 3.7 and Table 3.6).

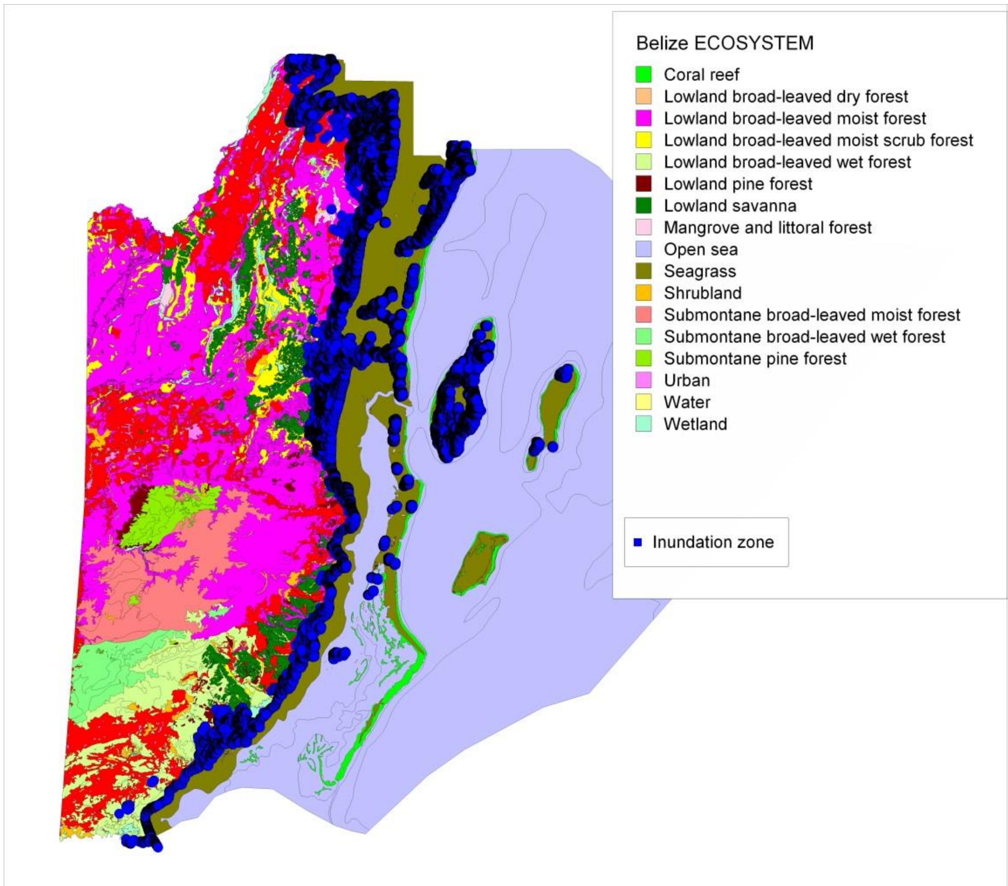


Figure 3.6: Coastal Zone and Land Use categories inundated by a combination of sea level rise and a storm surge for a category 2 hurricane and during highest tide level (Level 2.47 m: 2040-2065)

Table 3.6: Land Use categories inundated by a combination of sea level rise and a storm surge for a category 2 hurricane and during highest tide level (Level 2.47 m: 2040-2065)

Land Use Category	Areas inundated (km^2)
Agricultural uses	6.0021
Coral reef	1.8468
Lowland broad-leaved dry forest	6.3027
Lowland broad-leaved moist forest	5.5341
Lowland broad-leaved moist scrub forest	2.4615
Lowland broad-leaved wet forest	0.0531
Lowland pine forest	0
Lowland savanna	26.4762
Mangrove and littoral forest	284.229
Seagrass	153.9297
Shrubland	0.0045
Urban	11.5146
Water	5.6475
Wetland	323.1765
Total Area	827.178

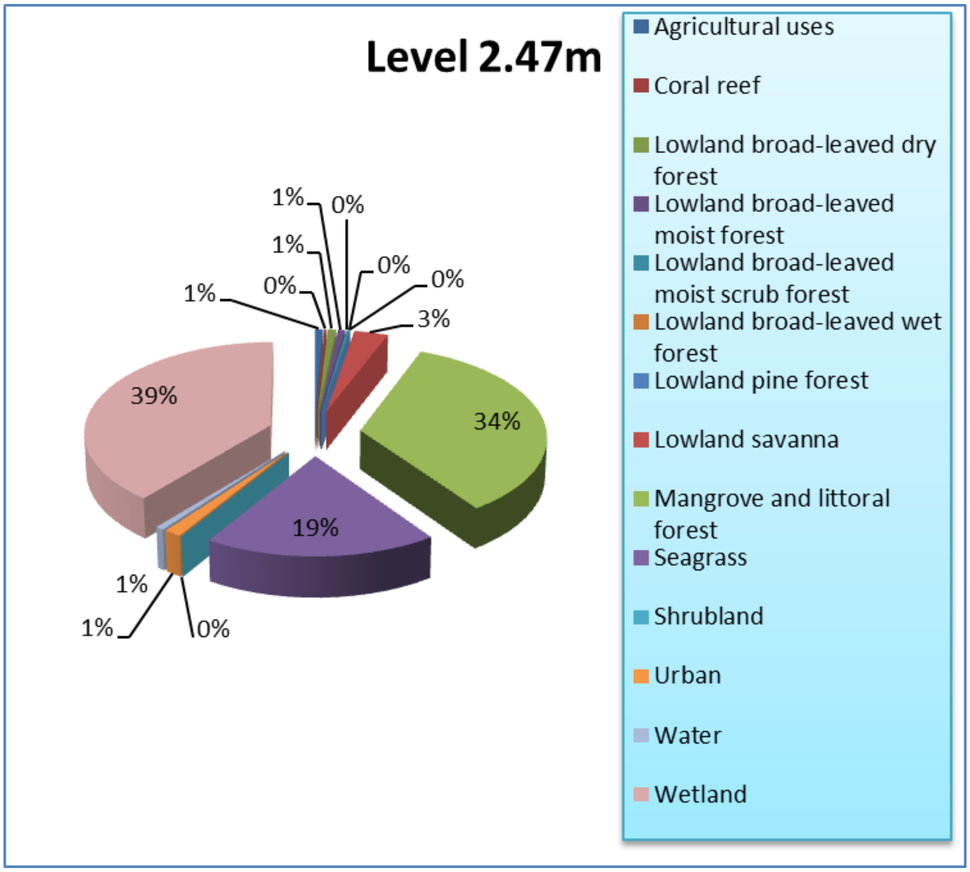


Figure 3.7: Percentage of Land Use categories inundated by a combination of sea level rise and a storm surge for a category 2 hurricane and during highest tide level (Level 2.47 m: 2040-2065)

However, when a storm surge for a category 2 hurricane is considered, Figure 3.8 shows the Coastal Zone and Land Use categories inundated by a 2.91 m rise in sea level combined with the category 2 hurricane storm surge (Level 2.91 m) for Belize for the 2081-2100 period. Table 3.7 summarizes the landuse categories that are likely to be inundated in the event of a 2.91 storm surge coupled with a 0.91 rise in sea level by 2081-2100 (See Figure 3.8 and Table 3.7).

Furthermore, it is evident in Figure 3.8 and Table 3.7 that all of the coastal zone and a large portion of the Cayes, a total area of ~ 941 km^2 will be affected by inundation from a rise in sea level coupled with a storm surge, namely 2.91 m, by 2081-2100 (See Figure 3.8 and Table 3.7).

Also, the landuse classes that would be most affected are, in order of magnitude, Wetland (~ 356 km^2/38%), and Mangrove and littoral forest (~ 335 km^2/36 %), Seagrass (~ 160 km^2/17 %) and Lowland savanna (~ 12 km^2/4 %) (See Figures 3.8 and 3.9 and Table 3.7).

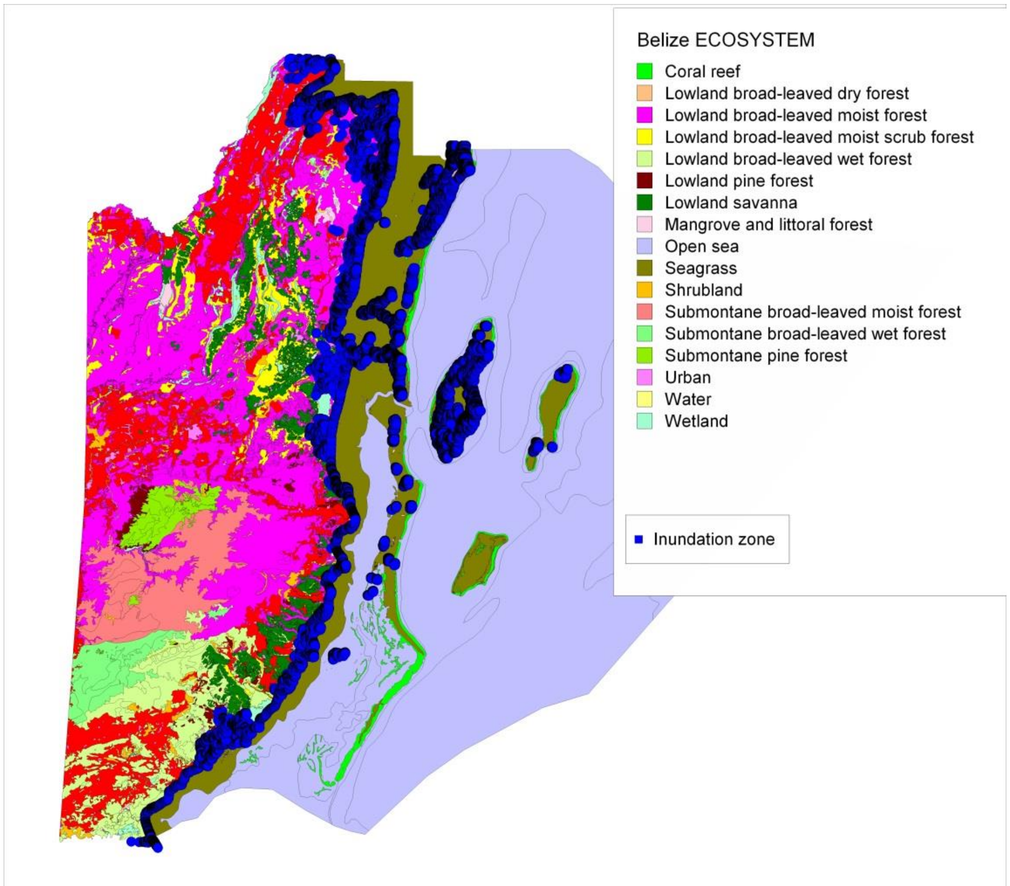


Figure 3.8: Coastal Zone and Land Use categories inundated by a combination of sea level rise and a storm surge for a category 2 hurricane and during highest tide level (Level 2.91 m: 2081-2100)

Table 3.7: Land Use categories inundated by a combination of sea level rise and a storm surge for a category 2 hurricane and during highest tide level (Level 2.91 m: 2081-2100)

Land Use Category	Areas inundated (km ^{2})
Agricultural uses	8.0262
Coral reef	1.8927
Lowland broad-leaved dry forest	7.65
Lowland broad-leaved moist forest	8.2827
Lowland broad-leaved moist scrub forest	3.6297
Lowland broad-leaved wet forest	0.099
Lowland pine forest	0.0009
Lowland savanna	38.5191
Mangrove and littoral forest	335.6352
Seagrass	160.0731
Shrubland	0.0108
Urban	15.0966
Water	6.1425
Wetland	356.3793
Total Area	941.438

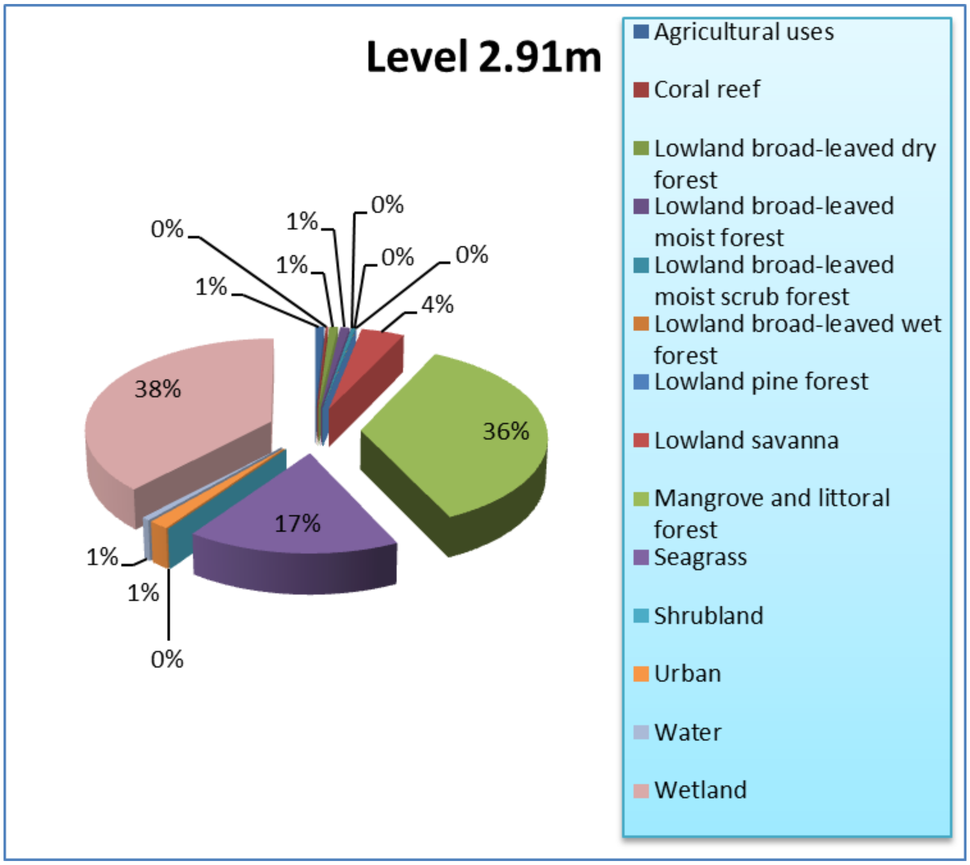


Figure 3.9: Percentage of Land Use categories inundated by a combination of sea level rise and a storm surge for a category 2 hurricane and during highest tide level (Level 2.91 m: 2081-2100)

But, when a storm surge for a category 5 hurricane is considered, Figure 3.10 displays the Coastal Zone and Land Use categories inundated by a 5.87 m rise in sea level combined with the category 5 hurricane storm surge (Level 5.87 m) for Belize for the 2040-2065 period. Table 3.8 summarizes the landuse categories that are likely to be inundated in the event of a 2.91 storm surge coupled with a 0.91 rise in sea level by 2081-2100 (See Figure 3.10 and Table 3.8).

Furthermore, it is evident in Figure 3.10 and Table 3.8 that all of the coastal zone and a large portion of the Cayes, a total area of ~ 1,651 km^2 will be affected by inundation from a rise in sea level coupled with a storm surge, namely 5.97 m, by 2040-2065 (See Figure 3.10 and Table 3.8).

Also, the landuse classes that would be most affected are, in order of magnitude, Mangrove and littoral forest (~ 606 km^2/37 %), Wetland (~ 486 km^2/29 %), Seagrass (~ 183 km^2/11 %) Lowland savanna (~ 162 km^2/10 %) and now urban (~ 52 km^2/3 %), Lowland broad-leaved moist forest (~ 51 km^2/8 %) and Agricultural land (~ 44 km^2/3 %) (See Figures 3.10 and 3.11 and Table 3.8).

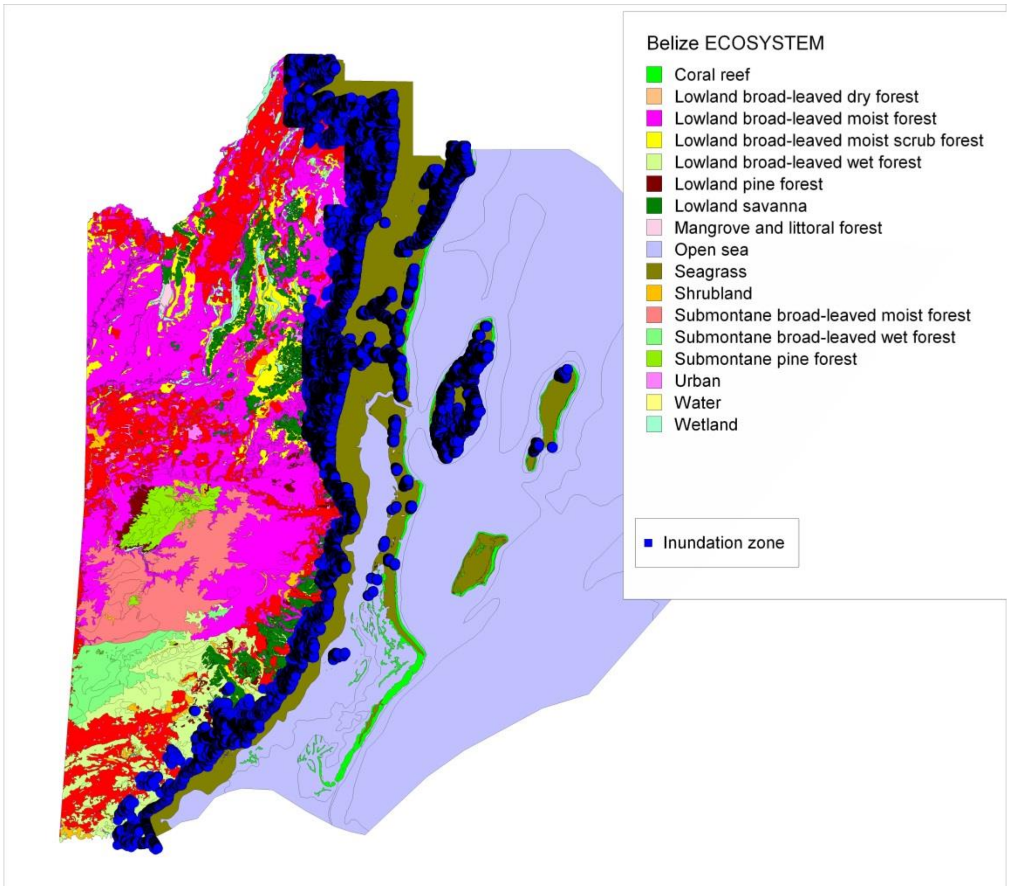


Figure 3.10: Coastal Zone and Land Use categories inundated by a combination of sea level rise and a storm surge for a category 5 hurricane and during highest tide level (Level 5.87 m: 2040-2065)

Table 3.8: Land Use categories inundated by a combination of sea level rise and a storm surge for a category 5 hurricane and during highest tide level (Level 5.87 m: 2040-2065)

Land Use Category	Areas inundated (km ^{2})
Agricultural uses	44.2755
Coral reef	2.0439
Lowland broad-leaved dry forest	24.0327
Lowland broad-leaved moist forest	51.8913
Lowland broad-leaved moist scrub forest	25.5159
Lowland broad-leaved wet forest	1.4445
Lowland pine forest	0.1854
Lowland savanna	162.2934
Mangrove and littoral forest	606.8493
Seagrass	183.8619
Shrubland	0.6318
Urban	52.2549
Water	9.8586
Wetland	486.2574
Total Area	1651.397

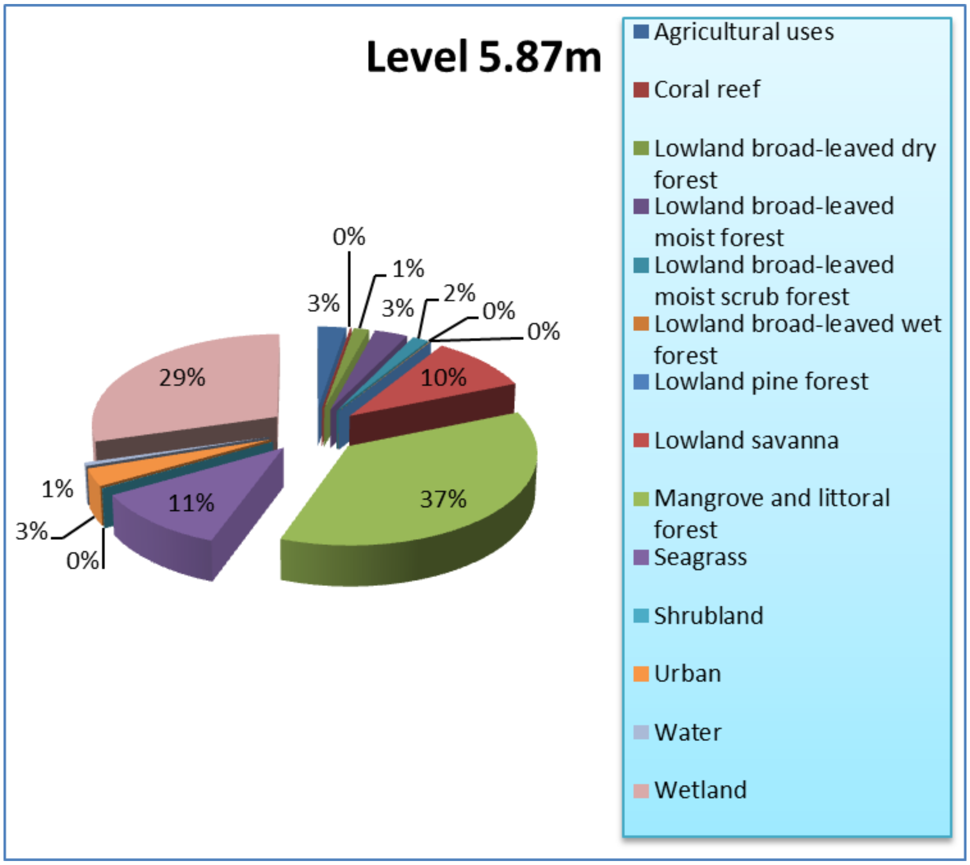


Figure 3.11: Percentage of Land Use categories inundated by a combination of sea level rise and a storm surge for a category 5 hurricane and during highest tide level (Level 5.87 m: 2040-2065)

Finally, when a storm surge for a category 5 hurricane is considered, Figure 3.12 shows the Coastal Zone and Land Use categories inundated by a 6.31 m rise in sea level combined with the category 5 hurricane storm surge (Level 6.31 m) for Belize for the 2081-2100 period. Table 3.9 summarizes the landuse categories that are likely to be inundated in the event of a 6.31 storm surge coupled with a 0.91 rise in sea level by 2081-2100 (See Figure 3.12 and Table 3.9).

Again, it is evident in Figure 3.12 and Table 3.9 that all of the coastal zone and a large portion of the Cayes, a total area of ~ 1,754 km^2 will be affected by inundation from a rise in sea level coupled with a storm surge, namely 5.97 m, by 2081-2100 (See Figure 3.12 and Table 3.9).

Furthermore, the landuse classes that would be most affected are, in order of magnitude, Mangrove and littoral forest (~ 631 km^2/36 %), Wetland (~ 502 km^2/29 %), Seagrass (~ 185 km^2/11 %) Lowland savanna (~ 184 km^2/10 %) and now Lowland broad-leaved moist forest (~ 63 km^2/4 %), urban (~ 57 km^2/3 %), and Agricultural land (~ 54 km^2/3 %) (See Figures 3.12 and 3.13 and Table 3.9).

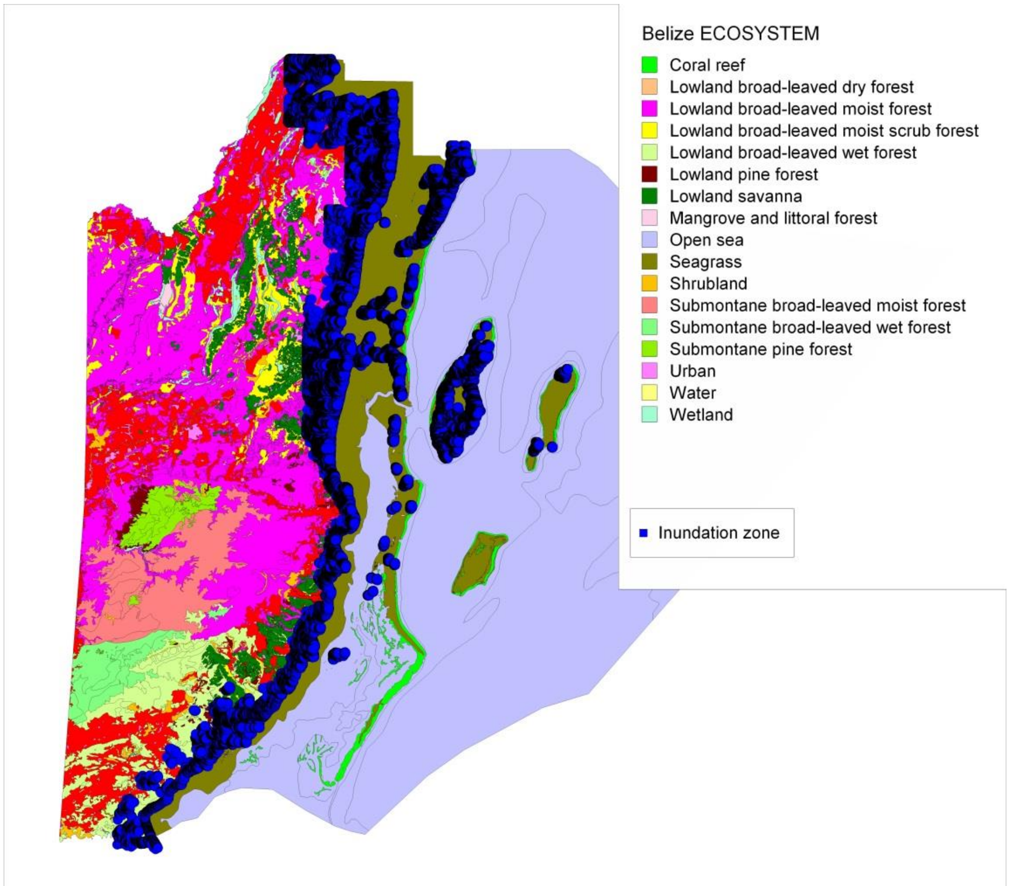


Figure 3.12: Coastal Zone and Land Use categories inundated by a combination of sea level rise and a storm surge for a category 5 hurricane and during highest tide level (Level 6.31 m: 2081-2100)

Table 3.9: Land Use categories inundated by a combination of sea level rise and a storm surge for a category 5 hurricane and during highest tide level (Level 6.31 m: 2081-2100)

Land Use Category	Areas inundated (km ^{2})
Agricultural uses	54.3051
Coral reef	2.052
Lowland broad-leaved dry forest	27.4806
Lowland broad-leaved moist forest	63.5526
Lowland broad-leaved moist scrub forest	30.825
Lowland broad-leaved wet forest	2.0538
Lowland pine forest	0.2925
Lowland savanna	184.7709
Mangrove and littoral forest	631.737
Seagrass	185.9877
Shrubland	1.161
Urban	57.5775
Water	10.5867
Wetland	502.0533
Total Area	1754.436

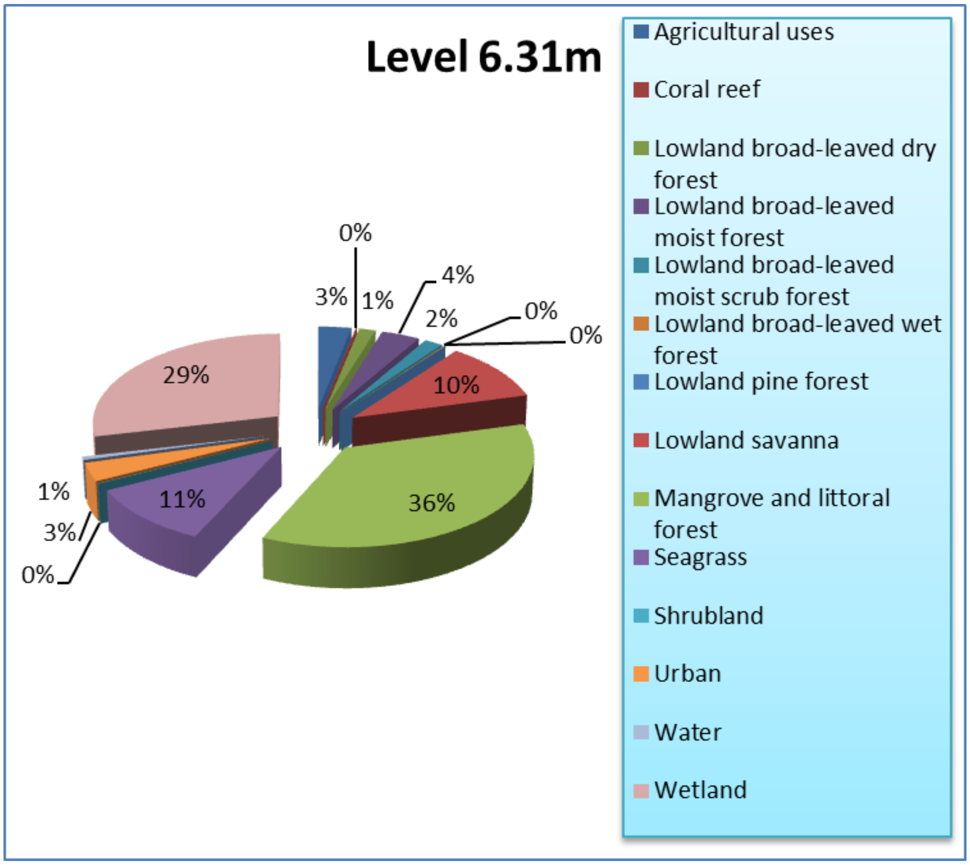


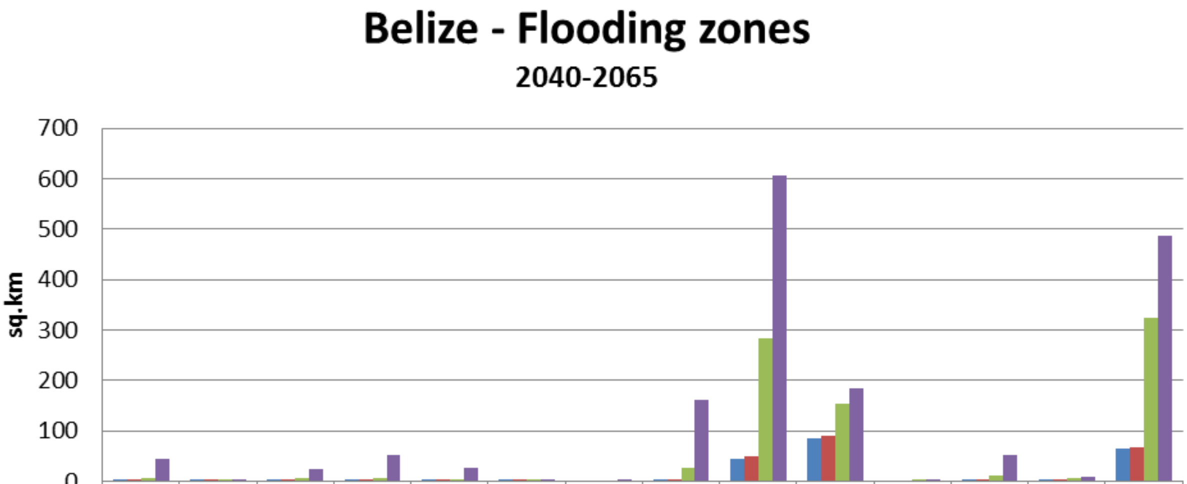
Figure 3.13: Percentage of Land Use categories inundated by a combination of sea level rise and a storm surge for a category 5 hurricane and during highest tide level (Level 6.31 m: 2081-2100)

In summary then, total land area at risk to inundation are (Table 3.10):
For a sea level rise of 0.47 m (2040-2065), ~ 210 km^2;
For a sea level rise of 0.91 m (2081-2100), ~ 291 km^2;
For a sea level rise of 0.47 m coupled with a storm surge for a category 2 hurricane (2040-2065), ~ 827 km^2;
For a sea level rise of 0.47 m coupled with a storm surge for a category 2 hurricane (2081-2100), ~ 941 km^2;
For a sea level rise of 0.47 m coupled with a storm surge for a category 5 hurricane (2081-2100), ~ 1,651 km^2;
For a sea level rise of 0.91 m coupled with a storm surge for a category 5 hurricane (2081-2100), ~ 1,754 km^2.

It should be noted that the landuse categories most susceptible to sea level rise and hurricane storm surges are: Mangrove and littoral forest, Wetland, Seagrass, Lowland savanna, Lowland broad-leaved moist forest, Urban areas and Agricultural land (See Figures 3.14 (2040-2065) and Figure 3.15 (2081-2100) and Table 3.10).

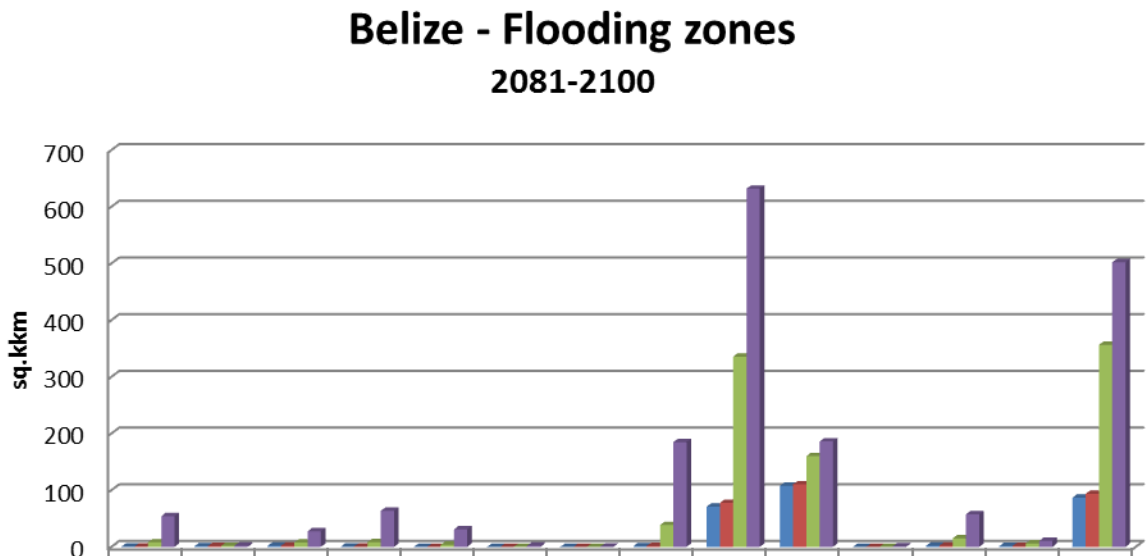
Table 3.10: Summary of Land Use categories inundated (km^2) by a combination of sea level rise (Level 0.47: 2040-2065 and Level 0.91: 2081-2100) and storm surges for category 2 (Level 2.47: 2040-2065 and Level 2.91: 2081-2100) and category 5 (Level 5.47: 2040-2065 and Level 6.31: 2081-2100) hurricane and during highest tide level

	Level 0.47	Level 0.91	Level 2.47	Level 2.91	Level 5.87	Level 6.31
Agricultural uses	0.3096	0.7551	6.0021	8.0262	44.2755	54.3051
Coral reef	1.1007	1.3779	1.8468	1.8927	2.0439	2.052
Lowland broad-leaved dry forest	1.4391	2.0529	6.3027	7.65	24.0327	27.4806
Lowland broad-leaved moist forest	0.2907	0.5922	5.5341	8.2827	51.8913	63.5526
Lowland broad-leaved moist scrub forest	0.1035	0.2088	2.4615	3.6297	25.5159	30.825
Lowland broad-leaved wet forest	0.0018	0.0036	0.0531	0.099	1.4445	2.0538
Lowland pine forest	0	0	0	0.0009	0.1854	0.2925
Lowland savanna	0.5697	1.6956	26.4762	38.5191	162.2934	184.7709
Mangrove and littoral forest	48.3156	77.5287	284.229	335.6352	606.8493	631.737
Seagrass	88.9164	110.3589	153.9297	160.0731	183.8619	185.9877
Shrubland	0	0	0.0045	0.0108	0.6318	1.161
Urban	1.0404	2.2023	11.5146	15.0966	52.2549	57.5775
Water	0.8964	1.5453	5.6475	6.1425	9.8586	10.5867
Wetland	67.3506	93.5775	323.1765	356.3793	486.2574	502.0533
Total Area	210.335	291.899	827.178	941.438	1651.397	1754.436



	Agricultural uses	Coral reef	Lowland broad-leaved dry forest	Lowland broad-leaved moist forest	Lowland broad-leaved moist scrub forest	Lowland broad-leaved wet forest	Lowland pine forest	Lowland savanna	Mangrove and littoral forest	Seagrass	Shrubland	Urban	Water	Wetland
Level 0.38	0.2754	1.0278	1.3509	0.2412	0.0855	0.0018	0	0.4851	44.8353	84.1203	0	0.8847	0.8442	64.2213
Level 0.47	0.3096	1.1007	1.4391	0.2907	0.1035	0.0018	0	0.5697	48.3156	88.9164	0	1.0404	0.8964	67.3506
Level 2.47	6.0021	1.8468	6.3027	5.5341	2.4615	0.0531	0	26.4762	284.229	153.9297	0.0045	11.5146	5.6475	323.1765
Level 5.87	44.2755	2.0439	24.0327	51.8913	25.5159	1.4445	0.1854	162.2934	606.8493	183.8619	0.6318	52.2549	9.8586	486.2574

Figure 3.14: Summary of Land Use categories inundated (km^2) by a combination of sea level rise (Level 0.47: 2040-2065) and storm surges for category 2 (Level 2.47: 2040-2065) and category 5 (Level 5.47: 2040-2065) hurricane and during highest tide level



	Agricultural uses	Coral reef	Lowland broad-leaved dry forest	Lowland broad-leaved moist forest	Lowland broad-leaved moist scrub forest	Lowland broad-leaved wet forest	Lowland pine forest	Lowland savanna	Mangrove and littoral forest	Seagrass	Shrubland	Urban	Water	Wetland
Level 0.82	0.5724	1.3392	1.9251	0.5184	0.189	0.0027	0	1.2726	70.9245	107.7516	0	1.9368	1.3428	86.7627
Level 0.91	0.7551	1.3779	2.0529	0.5922	0.2088	0.0036	0	1.6956	77.5287	110.3589	0	2.2023	1.5453	93.5775
Level 2.91	8.0262	1.8927	7.65	8.2827	3.6297	0.099	0.0009	38.5191	335.6352	160.0731	0.0108	15.0966	6.1425	356.3793
Level 6.31	54.3051	2.052	27.4806	63.5526	30.825	2.0538	0.2925	184.7709	631.737	185.9877	1.161	57.5775	10.5867	502.0533

Figure 3.15: Summary of Land Use categories inundated (km^2) by a combination of sea level rise (Level 0.91: 2081-2100) and storm surges for category 2 (Level 2.91: 2081-2100) and category 5 (Level 6.31: 2081-2100) hurricane and during highest tide level

4.0 Belize City

In order to protect the low-lying coastal area that is near sea level in the vicinity of Belize City, hard structures in the form of sea walls are being built around the city. However, the height and engineering quality of these structures varies according to location and for the most part are not high enough to protect the coastal zone of the city from future sea level rise and storm surges (See Figure 3.16)

Figure 3.16: Fortified sea wall along the coast of Belize City

Focussing on Belize, city, where a large percentage (~ 22 %) of the population reside, Figures 3.17 (0.47 m: 2040-2065) and Figure 3.18 (0.91 m: 2081-2100) graphically displays, the low-lying coastal zones that would be at risk to sea level rise under futures sea level rise scenarios, namely 0.47 m in 2040-2065 (Figure 3.17) and 0.91 m in 2081-2100 (Figure 3.18).

Although a variety of sea walls have been constructed in certain areas, they are at highest ~ 1m and may protect against these future scenarios of sea level rise. But since, the length of these walls is not continuous even at these levels rising sea water would be able to penetrate from the unprotected sides and cause flooding even in the protected areas.

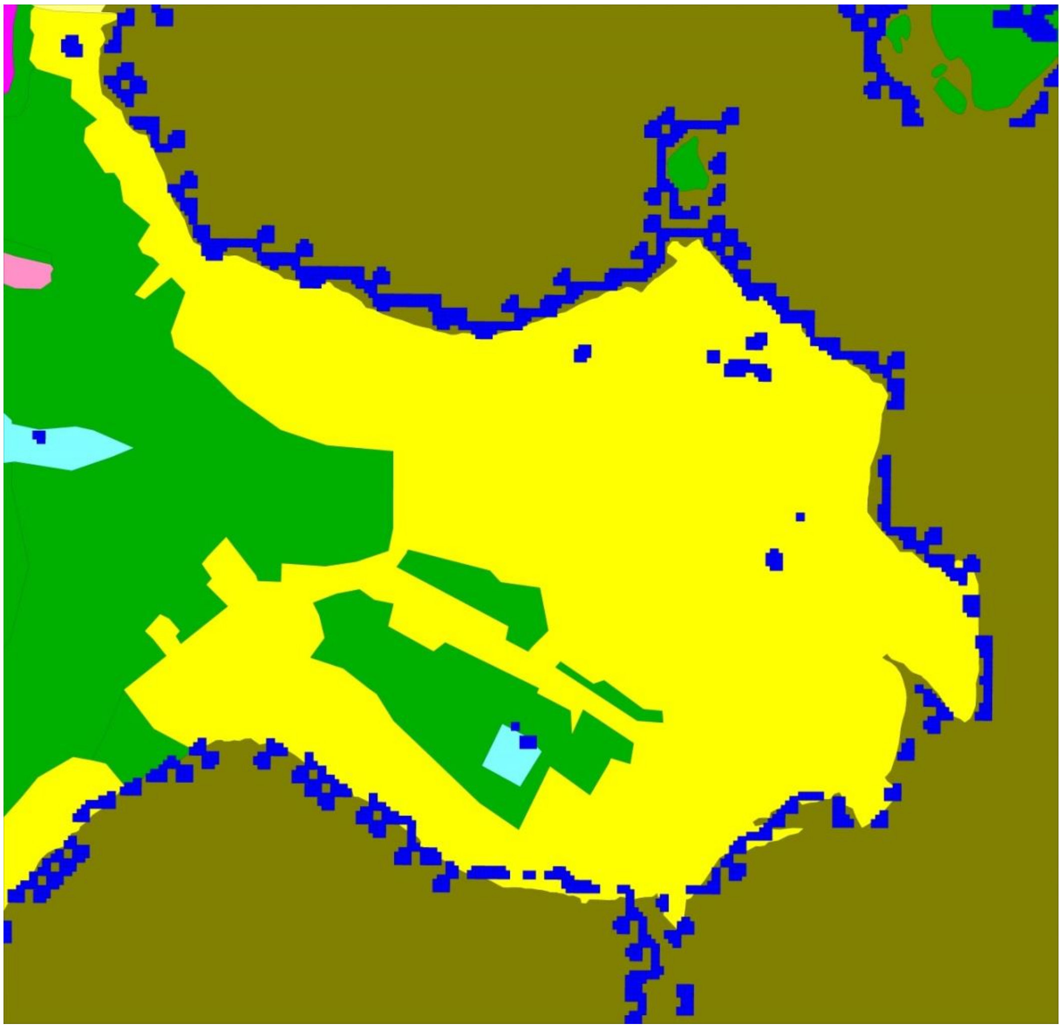


Figure 3.17: Flooding zones for Belize City following a 0.47 m rise in sea level (Level 0.47: 2040-2065) and during highest tide level

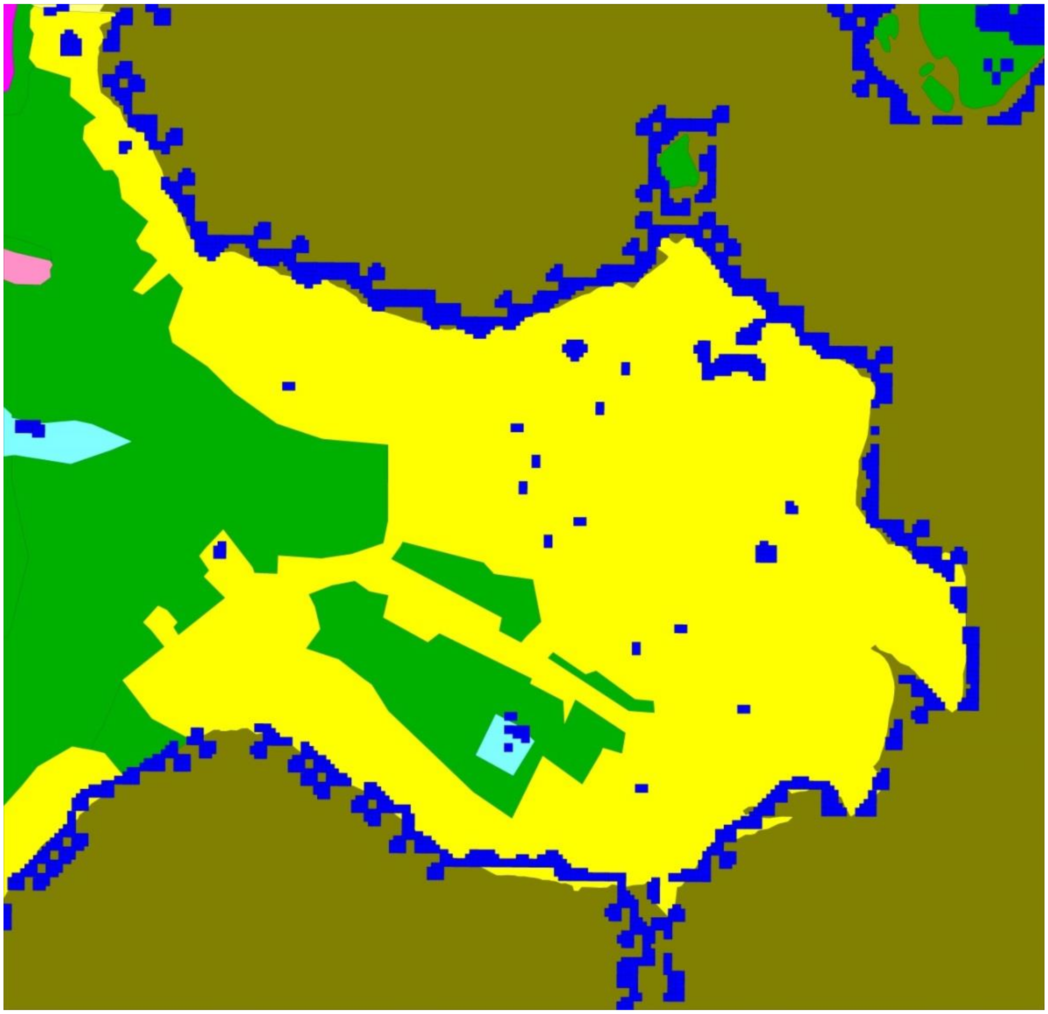


Figure 3.18: Flooding zones for Belize City following a 0.91 m rise in sea level (Level 0.91: 2081-2100) and during highest tide level

But when one considers the higher water level caused by a category 2 hurricane, the flooding of Belize City increases substantially. For a category 2 storm, Figures 3.19 (2.57 m: 2040-2065) and 3.20 (2.91 m: 2081-2100), the flooding increases at the low-lying boundary with the sea and the interior of the city via drainage channels.

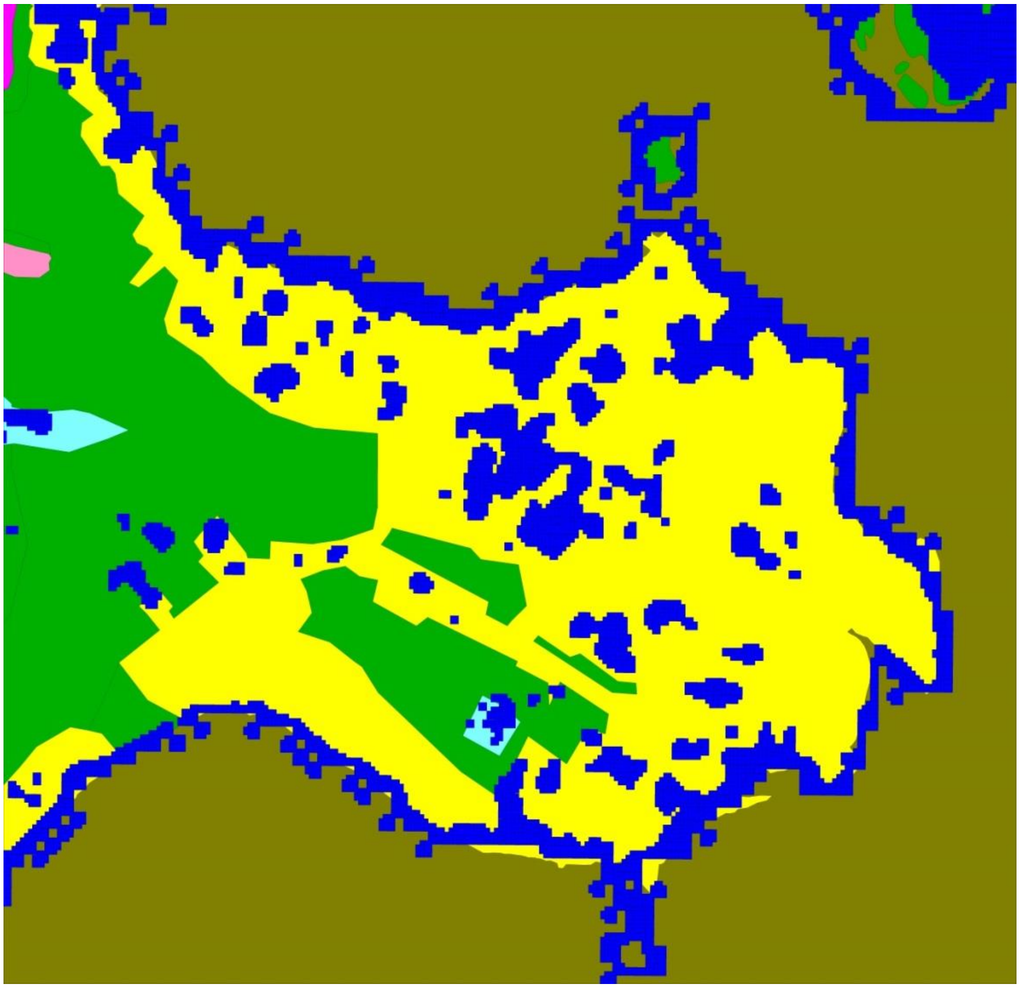


Figure 3.19: Flooding zones for Belize City following a combination of sea level rise and storm surges for category 2 (Level 2.47: 2040-2065) hurricane and during highest tide level

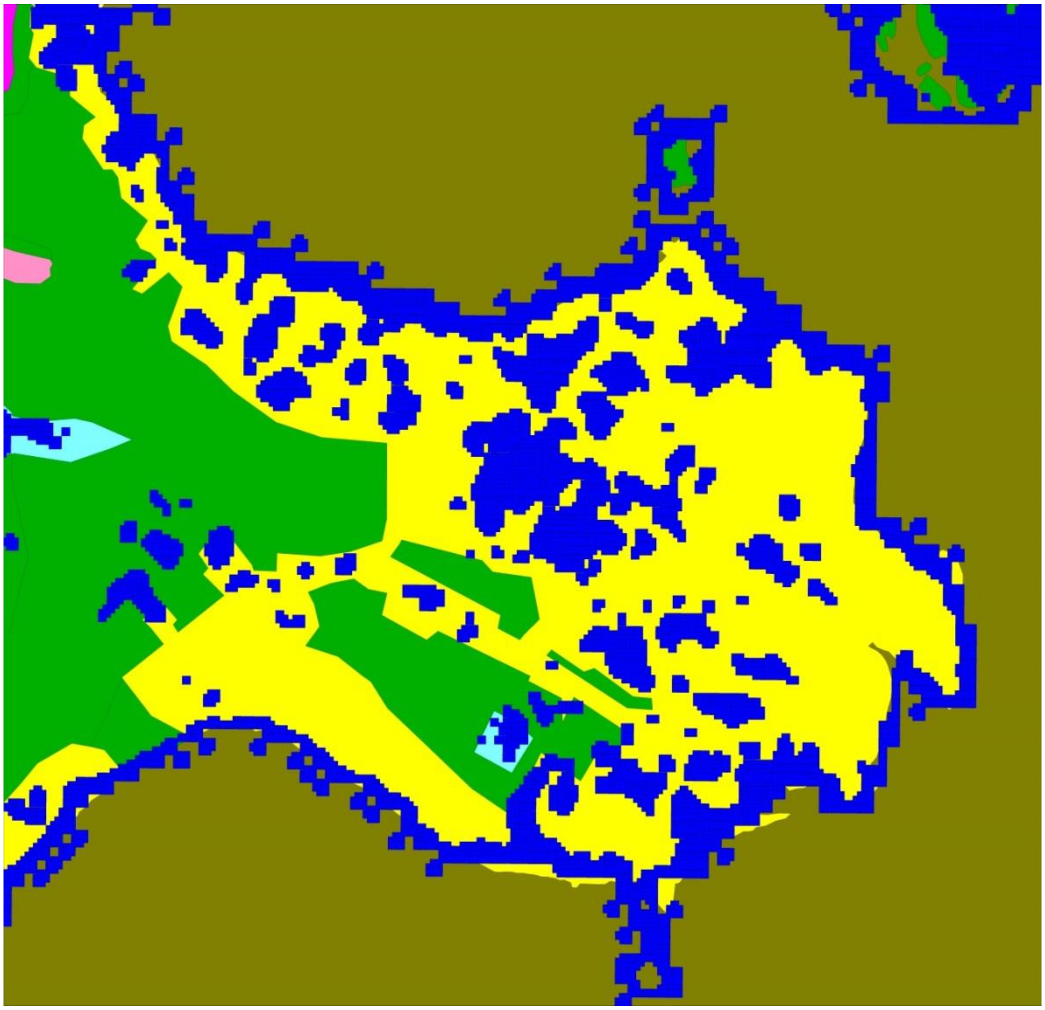


Figure 3.20: Flooding zones for Belize City following a combination of sea level rise and storm surges for category 2 (Level 2.91: 2081-2100) hurricane and during highest tide level

Furthermore, when one considers the higher water level caused by a category 5 hurricane, the flooding of Belize City increases even more substantially, to the extent that almost the entire city is flooded. For a category 5 storm, Figures 3.21 (5.87 m: 2040-2065) and 3.22 (6.31 m: 2081-2100), the flooding encompasses the entire zone along the coastline.

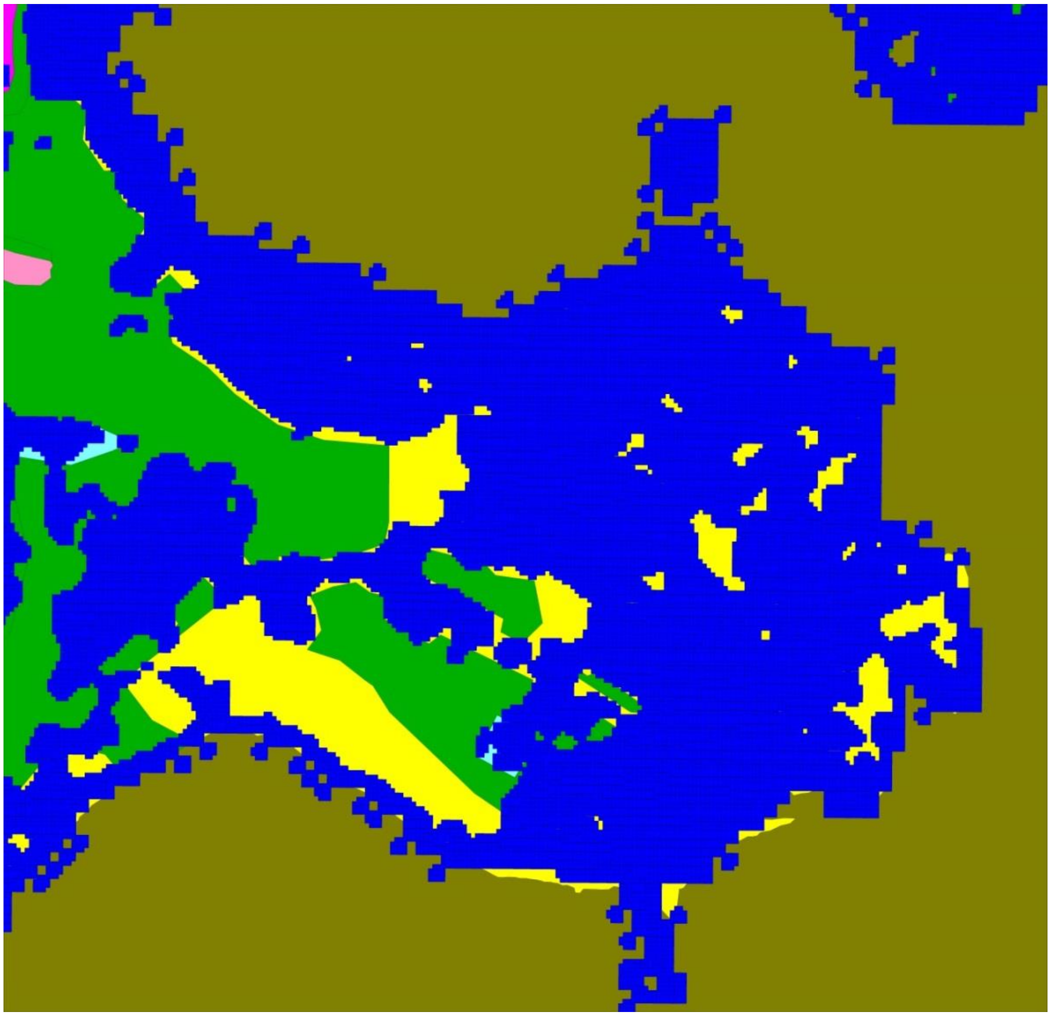


Figure 3.21: Flooding zones for Belize City following a combination of sea level rise and storm surges for category 5 (Level 5.87: 2040-2065) hurricane and during highest tide level

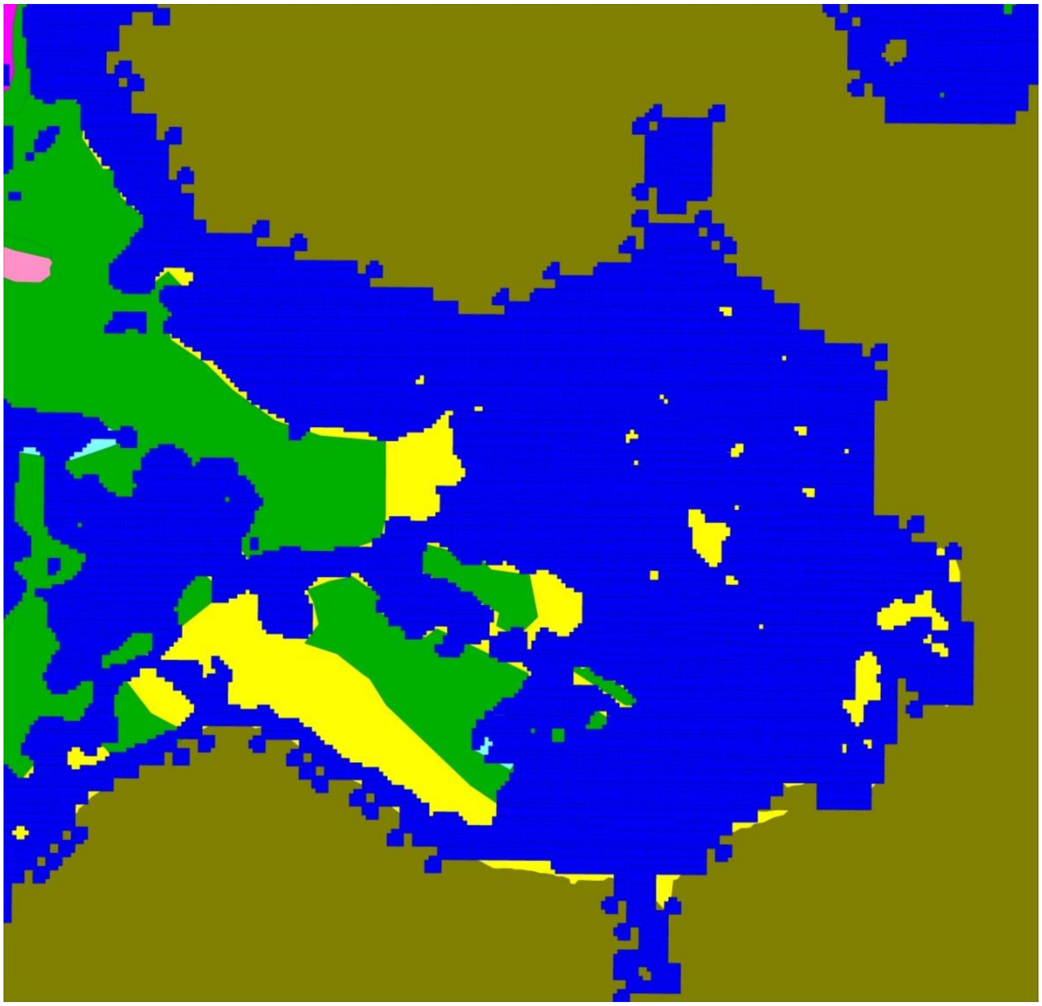


Figure 3.22: Flooding zones for Belize City following a combination of sea level rise and storm surges for category 5 (Level 6.31: 2081-2100) hurricane and during highest tide level

5.0 Climate Change and Sea Level Rise Impacts

The importance of the coastal zone in the productive sector of Belize is increasing rapidly. Most industries in Belize are either directly or indirectly reliant on some component of the coastal environment to function. Industries such as fishing and tourism are dependent on the organisms that inhabit the coastal area to sustain them. Other industries such as agriculture, aquaculture, and petroleum use the coastal waters to transport their products, thereby allowing them to engage in overseas trade. It is estimated that $350 to $400 million BZD is generated directly through resource-based economic activity in the coastal zone. Perhaps a further $450 to $500 million BZD are transported through the area in exports of products such as sugar, citrus, bananas, timber, and other agricultural products. Furthermore, approximately $650 million BZD worth of imports entered the country in 2010, more than half of this through the sea ports (Clarke et al. 2013).

The impacts of climate change and climate-driven sea level rise and storm surges will certainly have an impact on coastal ecosystems and economic activities in the coastal zone of Belize.

5.1 Coastal Zone

The area most susceptible to the effects of climate change is the coastal ecosystem. Anticipated increases in sea surface temperatures, salinity, pH, sea level, and intensity of tropical cyclone events have direct implications on the future state of the coastal zone and the ability of Belizean people to utilize the resources it provides. Belize's coastal ecosystems and rich biodiversity will also be affected by global climate change. Delicate marine ecosystems such as sea grass beds, mangroves and coral reefs are directly dependent on climatic conditions for distribution, function and growth. Change in climatic conditions can lead to degradation of these already threatened ecosystems (Clarke et al. 2013).

5.2 Coral Reefs

Perhaps the most sensitive components of the coastal area of Belize, coral reefs require a very specific range of environmental conditions for it to function optimally. Therefore, slight variations in environmental conditions can affect the viability of coral reef systems. The following are the expected effects of climate change on coral reef ecosystems (Clarke et al. 2013):

It has been shown that an increase in sea temperature of about 1^{o} – 2^{o}C has triggered massive coral bleaching events;

Increased temperature has been shown to magnify the effects of infectious diseases since stress lowers the functionality of the immune system;

Decrease in ocean pH by an average of 0.1units has been shown to decrease coral growth rate. This has competition implications as corals often compete with species such as sponges and seaweeds for resources.

Although it is suggested that healthy corals will be resilient to effects of global climate change, it has been shown that corals that do recover are more brittle and less efficient. Therefore, under the most conservative IPCC scenarios, models indicate that coral growth will decrease by 50% by 2050 (Clarke et al. 2013).

5.3 Mangroves

The major threat to mangrove ecosystems has been shown to be human development since many projects involve mangrove removal. However mangroves are still vulnerable to the effects of global climate change but, unlike other marine ecosystems, they are more tolerant of changing environmental conditions. Negative effects are as a result of the expected direct physical effects of climate change. The projected effects on mangroves are as follows (Clarke et al. 2013):

Increased intensity of tropical cyclones is expected to increase the removal of mangroves along the coastline, especially in areas that are vulnerable to erosion and inundation;

Distribution will change relative to sea level rise. Increased sea level will alter the concentration of salt in the soil thereby altering mangrove growth in the area. It is expected that mangroves will retreat in response.

5.4 Seagrass Beds

Seagrass beds are the most widely dispersed marine ecosystem within the coastal area of Belize. This suggests that they are able to survive under a wide range of environmental conditions. The following are the predicted effects of climate on sea grass (Clarke et al. 2013):

Increased ocean temperature is expected to cause a shift in distribution as a result of stress and resulting changes in reproductive patterns;

Increased intensity of tropical cyclones and possible increase in frequency is expected to increase sedimentation and turbidity which will affect growth rates;

Some communities of sea grass are carbon limited; therefore increased atmospheric carbon dioxide will promote growth in new areas.

Climate change and sea level rise will also impact on important economic Sectors of Belize (Clarke et al. 2013):

5.5 Agriculture

Generally, higher temperature and lower precipitation is expected to be amongst the major changes associated with climate change projections for Belize. Therefore, crops that favor warmer temperatures such as rice will thrive under climate change conditions. However, for more economically important crops such as sugar cane and citrus, decrease in precipitation will decrease yield leading to a decrease in export income.

5.6 Fisheries

The Fisheries sector in Belize is comprised of three main industries; capture fisheries, aquaculture and inland subsistence fishing. This sector is particularly vulnerable to the effects of climate change since they rely on resources from coastal waters, inland coastal lands and major rivers respectively. The following is a summary of predicted impacts of climate change (Clarke et al. 2013):

An increased sea surface temperature has been shown to trigger large scale coral bleaching events and mortality. Many economically important fish species such as the spiny lobster, snappers, Queen Conch, and several other important fin fish species rely on nutrients and protection from coral reefs. Loss of this habitat can lead to lowered fish stock;
Ocean acidification affects the growth and stability of coral reefs; therefore it will contribute to bleaching and mortality and ultimately decreases in fish stock due to loss of habitat. Also decreased ocean pH has been shown to reduce the ability of species with exoskeletons to form shells sine the amount of available calcium carbonate will decrease;
Sea level rise threatens sensitive ecosystems such as mangroves, sea grass beds and coral reefs which act as nursery habitats for many commercial fish species;
Degradation of mangroves and loss of coastal lands as a result of sea level rise will directly reduce the total area of coastal lands available for aquaculture activities. Subsequent loss of mangroves also leaves areas exposed / vulnerable to impacts from tropical cyclone events;
Increased temperatures and decreased precipitation associated with climate change is expected to increase stratification in ponds and decrease water levels of inland aquatic systems.

5.7 Tourism

Belize is ranked among the top eco-tourism destinations in the world offering some the world's most unique natural attractions. Therefore, the future of tourism in Belize is particularly vulnerable to the effects of climate change since it is largely resources dependent. The general consensus is that climate change will dictate the type and quality of tourist attractions (Clarke et al. 2013).

The susceptibility of the nature-based tourism sector of Belize to the effects of climate change is very high. The two most critical resources utilized in the tourism sector are the barrier reef and coastal areas. According to the Belize Tourism Board over 70% of tourists visit the Cayes and an additional 12% visits Placencia. Also 80% participates in reef based activities such as snorkeling and diving. However it has been suggested that the effects of climate change will reduce the appeal of the coastal areas because of heat stress, erosion and declining reef health. In addition, the following are other expected effects of global climate change (Clarke et al. 2013):

Increase in sea level will lead to flooding, inundation, saltwater intrusion and erosion which affect the sustainability of the industry;

Warmer seas threaten the coral reef which attracts thousands of tourists yearly and is also associated with an increase in the frequency and intensity of tropical cyclones;

Very generally, climate change is expected to affect the availability, overall comfort and enjoyment of outdoor activities. Also there is expected loss in function of ecological systems that are the attractants for tourists.

5.8 Coastal Erosion

Several coastal areas of Belize are experiencing severe problems of coastal erosion. One of the more significant regions being affected by coastal erosion of loss of beaches is the coastline at the mouth of Monkey River in Toledo District. The loss of coastal land and the erosion of the village beach are happening even while the Swasey River is generating sand. In other words, the beach loss is not because sand is not being generated from the granitic and metasedimentary rocks in the Maya Mountains and transported to the main channels of the Swasey and Monkey River. However, the generated sand is not accreting on the village coastline. In the past, the beach was maintained by a constant supply of sand from the Monkey River watershed. Yet, due to a number of natural physical and climate-related factors and anthropogenic factors, including low rate of sand sediment transport, the beach is rapidly eroding along the Monkey River coastline, particularly on the south side of the village (Galen University Applied Research and Development Institute (2007).

Based on our literature review, field observations, community consultations and analysis of the current situation, beach erosion and coastal land loss along Monkey River Village are attributed to three major factors namely: (1) stresses to the river system of the Monkey River Watershed, (2) the effects of marine and climatic conditions on the Gulf of Honduras, and (3) the effects of global climate change. Principal among the stresses on the river system is the diversion of millions of gallons of water for agricultural purposes. The stresses to the river system reduce sediment transport to the coast and exacerbate the effects of the marine and climatic conditions on the coastline and the effects of global climate change. As a result, Monkey River Village is faced with the following alternatives: hard stabilization solutions, soft stabilization solutions or relocation and retreat (Galen University Applied Research and Development Institute (2007).

A recent study (CARIBSAVE, 2012) estimated the beach area losses for three beach areas in Belize Caye Caulker, Rocky Point and San Pedro. At 0.5 m SLR scenario, Rocky Point is projected to lose 75% of its beach area, followed by San Pedro (19%) and Caye Caulker (17%). With a 1 m SLR, Caye Caulker would lose almost its entire beach area (96%), followed by Rocky Point (90%) and Sand Pedro (45%). With a 2 m SLR, both Caye Caulker and Rocky Point would lose all (100%) of its beach area, with San Pedro losing its beach area with a 3 m SLR scenario (See Table 3.11). The losses of beach area would have severe repercussions for the tourism industry of Belize (CARIBSAVE, 2012).

Table 3.11: Beach area (m^2 and %) losses due to varying scenarios of Sea Level Rise (SLR) for Caye Caulker, Rocky Point and San Pedro (Ambergris Caye) (Source: CARIBSAVE, 2012)

Caye Caulker		Rocky Point		San Pedro		
SLR Scenario	Beach Area Lost To SLR (m^2)	Beach Area Lost (%)	Beach Area Lost To SLR (m^2)	Beach Area Lost (%)	Beach Area Lost To SLR (m^2)	Beach Area Lost (%)
0.5m	723	17%	6112	75%	7375	19%
1.0m	3424	96%	1251	90%	10147	45%
2.0m	180	100%	788	100%	18662	93%
3.0m	-	-	-	-	2596	100%

5.9 Coastal Communities

Almost 50% of the population has settled along the coastline of Belize. This has severe implications since almost half of the population is vulnerable to the effects of climate change. Many direct and indirect effects of climate change and sea level rise are projected and include (Clarke et al. 2013):

Sea level rise, flooding, erosion, increased storm intensity and salinization of ground water are amongst the main threats to coastal communities and their economies, infrastructure, households and ways of life;
Remote coastal communities are particularly vulnerable since their access points can be affected by sea level rise and tropical cyclone activity;
Climate change can bring about an increase in food, water and vector borne diseases as well as diseases related to heat stress.

6.0 Coastal Zone Adaptation

From the foregoing sections it is very evident that climate-driven sea level rise is expected to have far reaching consequences on coastal zone of Belize. When extreme events such as storm surges are also considered the impacts on the coastal zone of the mainland and the Cayes could be disastrous. This is because of the diverse coastal assets found in this region. These include the major towns, such as Belize City, San Pedro, Dangriga, Placentia and Punta Gorda that represents close to one half of the population. Furthermore these flooding events would certainly cause damage to human settlements, infrastructure, including roads, mangroves ecosystems that stabilize the coast, purifies runoff water and serves as an invaluable habitat for various flora and fauna, and agricultural land and crops. These resources and activities are extremely sensitive to climate change because, in the event of sea level rises and storm surges, inundation and flooding, erosion, saline intrusion into surface and ground water sources would very likely occur.

Adaptation options, guided by policy changes and legislation, that may warrant immediate short-term consideration would include (Leary et al, 2008a; 2008b):

The formulation and implementation of land-use planning policies to address people and settlements and agricultural lands at risk to inundation deriving from sea level rise and storm surges;
Fortification of sea and river defenses in accordance with sea level rise and storm surges in vulnerable areas;
Further implementation of early warning systems in the event of storm surges (NEMO);
The building of more shelters on higher ground either near the coast or inland to house people in the event of inundation due to storm surges;

Longer-term policy changes and adaptation measures to address sea level rise and storm surges would include:

Adopt more proactive mitigation measures such the use of building set-backs legislation to limit buildings and other major developmental work on the coast and encourage gradual retreat to higher grounds by making land available in the interior, in an effort to decentralize economic activities and settlement on the coast;
Undertake detailed surveys to identify most vulnerable areas along the coast, such as Belize City, San Pedro, Dangriga, Placentia and Punta Gorda, and determine appropriate adaptation strategies;
Also undertake evaluation of agricultural lands, coastal aquifers and drainage and irrigation systems.

However, these adaptation response strategies should also be integrated with economic development policies, disaster mitigation and management plans and integrated coastal zone management plans (ICZM).

The costs of coastal protection works however are enormous, ranging from 0.1 % to 10 % of GDP, depending on the sensitivity of the coastal zone and the extent of sea level rise and storm surges (IPCC, 2007). These huge costs, which are very likely to be applicable to Belize, could be prohibitive, unless funding can be leveraged through, for instance, the Adaptation Fund.

When beaches are destroyed by storm surges, the cost of beach nourishment could also be very expensive. For instance, beach nourishment in Caye Caulker (Playa Asuncion) of a beach 1, 000 feet long and 30 feet wide cost $170,000.00 BZ, following Hurricane Keith (2000). Since then half of the nourished beach has already been lost (Interview: Mr. Alberto Villanueva, formerly with the Caye Caulker Council).

7.0 Conclusion

The results of the preceding section highlight the vulnerability of the coastal zone of Belize to climate-driven sea level rise and the potential impacts of extreme events such as storm surges.

But, all things being equal, these results provide credible scenarios of the vulnerability of the coastal zone of Belize to future sea level rise and storm surges. Not only would settlements, infrastructure and people be at risk of coastal inundation, but also valuable tourism facilities and agricultural lands and crops that form part of the most significant economic sectors of Belize. Given these potential losses, investing in the most beneficial adaptation measures would significantly increase estimated national income in Belize, and would likely be essential to attracting investors.

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Section 4: Water Sector

1.0 Introduction and Background

This Section deals with the **Water** sector of the vulnerability and adaptation (V&A) assessment component of the Third National Communication (TNC) of Belize.

Water supply in Belize comes from underground water, mainly, surface water (rivers, lakes and lagoons) and desalinisation of sea water (Ambergris Caye). The underground water resources are considered to be extensive, especially in the Savannah and Campur provinces. The Department of Agriculture Irrigation Unit promotes and encourages irrigation and relies heavily on underground water; however no assessment of the underground water resources is done prior to the installation of the irrigation systems, so the knowledge of groundwater resources is limited. The knowledge of underground water quality is also limited (Belize Enterprise for Sustainable Technology (BEST): 2008, 2009).

Belize shares five major watersheds with Mexico and Guatemala. When considering complete watersheds by including Guatemala and Mexico, 31% of the Rio Hondo basin lies in Guatemala and 50.5% lies in south-eastern Mexico and 30.6% of the Belize River basin lies in Guatemala. The majority (91.2%) of the Sarstoon river watershed lies in Guatemala. The Moho and the Temash rivers have (31.6%) and (24.2%) respectively, of their watersheds in Guatemala. The potable water supply for Benque Viejo Town and Belize City and all the communities along the Belize River originate in Guatemala (Belize Enterprise for Sustainable Technology (BEST): 2008, 2009).

Climate change is very likely to have a significant impact on the water sector of Belize. Rainfall is projected to decrease slightly and become more variable leading to intense rains and flooding on the one hand and droughts on the other. Warmer temperatures would also exacerbate drought conditions (McSweeney *et al*, 2008, 2009; IPCC, 2007; 2013).

Rainfall amounts and variability are critical to the economy of Belize. Not only would there be risks of flooding from excessive rainfall in the low-lying coastlands, but also agricultural production, a key contributor to GDP, would be subject to the alternating conditions of excessive rainfall and flooding on the one hand and drought on the other.

Sea level rise and storm surges, by-products of climate change, will also affect the water sector through saline intrusions into coastal aquifers and soils and flooding of coastal lowlands and towns, where the bulk of the population of Belize is located (Singh and El Fouladi, 2007).

Recent flooding of the coastal zone of Belize by Hurricane Richard (2010: Category 2 hurricane) and previously by hurricane Hattie (1961: a Category 5 storm) demonstrates the immediate vulnerability of Belize to climate driven events and exposes the shortcomings in the current infrastructure to protect the coastland and the people.

Other related sectors, especially human health also risk to be directly affected, through loss of life due to flooding or indirectly though the impacts on food supply and the proliferation of disease-spreading vectors.

2.0 Current Vulnerabilities of the Water Sector

Under current climate conditions, the water resources sector is already subject to a number of pressures, including tropical storms and hurricanes that lead to flooding problems and droughts that restrict the available water supply and that is extremely detrimental to agriculture.

Climate change that may lead to more extreme conditions, namely more intense rainfalls and extended dry periods would very likely exacerbate this situation. Furthermore, sea level rise and storm surges may lead to loss of coastal areas including agricultural lands and salinization of coastal aquifers.

2.1 Tropical Storms and Hurricanes

Based on recent climate data (Gonguez, 2007), one can safely assume that Belize is vulnerable to climate change. Recent and projected trends suggest an increase in surface temperatures, changes in precipitation pattern and more extreme weather (Gonguez, 2007). Vulnerability to climate change is the degree to which geophysical, biological and socio-economic systems are susceptible and unable to cope with adverse impacts of climate change (Williams, 2008).

Belize is at risk from extreme events such as tropical cyclones, which can impact on the water sector through flooding and drought or prolonged dry season (Diaz and Pulwarty, 1997). Recently, Belize has been affected by four strong tropical cyclones and associated storm surge. These included hurricanes Keith, Iris and Dean which were of categories 3, 4 and 5. These intense and slow moving storms can dump significant amounts of rainfall thereby increasing risk of flooding in low lying areas and which can result in millions of dollars agricultural losses and death. Furthermore, the magnitude of these impacts could be exacerbated by other environmental stressors such as land use change. The impacts on water quality are unknown since there is no comprehensive water-quality monitoring program in Belize (Belize Enterprise for Sustainable Technology (BEST): 2008, 2009).

2.2 Droughts

Droughts are recurrent events that frequently occur during the dry season in Belize that often lead to severe water shortages of potable water for several communities and crop losses. For instance, the drought of 2004 to 2005 resulted in losses of over $5 million to the Livestock and Poultry Association (Williams, 2008; Gonguez, 2007). Although information on drought episodes and its causes are sparse in Belize, the country remains highly vulnerable. Reports indicated that the droughts coupled with the heat waves of 1975 and 2003-2005 affected the major economic sectors. In 1975, river levels decreased and, therefore, affected agriculture, cattle ranching and availability of potable water (First National Communications, 2000). Report on the 2004 to 2005 drought episode indicated that event resulted in lower water levels. Rainfall levels for the stations in the Region 7 watershed were between 20 to 30% below normal. For Region 9 watershed area, total rainfall amounts for stations within the watershed were also significantly below normal (Williams, 2008; Gonguez, 2007).

Drought conditions may also have led to the drying-up of Five Blues Lake along the Hummingbird Highway near Santa Martha in Stann Creek District in 2006. An anomalous feature with characteristics of a karst window or cenote but in the setting of a polje or ponor lake, Five Blues has both surface and underground drainage components. With the impression that the lake was a permanent feature, a national park proceeded under was established in 1991. But during July in 2006, the lake drained rapidly underground (Day and Reynolds, 2011). Without the lake, visitor numbers and park revenues declined, and the park was all but abandoned. The lake refilled in 2007, but visitor numbers continue to lag. Management and promotion of hydrologic features within protected areas needs to take such possibilities into account, emphasizing climate variability and change and avoiding a focus on conditions that may not prevail at any given time (Day and Reynolds, 2011).

Furthermore droughts lead to an increase in the operational cost to water utilities as a result of increased pumping cost. The reduction in water levels also leads to a decrease in hydropower generation. Even though Belize is vulnerable to drought, because of insufficient information and the slow onset of this event, drought is not identified as key vulnerability.

3.0 Methodology: climate change impacts on regional water excess/deficits

The focus on the water sector will be on future changes in precipitation (P) and evaporation (ET), in response to higher temperatures, and how these may lead to water deficits (droughts) or excesses (flooding) (P-ET) in the future.

The methodology simply consists of comparing values of precipitation (P), evaporation (E) and water deficits or excess (P-E) for a selected current decadal (2000-2009) period against a future decadal period (2060-2069).

Furthermore, at least one representative station within each of the major hydrological regions of Belize (Figure 4.1) was selected. The

For the water sector calculations, at least one weather station was selected for each hydrological region (7, 9, 11 and 13). Furthermore, the choice of weather station was dictated by data availability for the current decadal period (2000-2009). Even as such, for certain stations missing data were filled in by choosing the mean value for the rest of the decadal period for the corresponding missing data.

In the final analysis then, the following stations were selected for analysis (See Table 4.1):

- Tower Hill in Hydrological Region 7 representing the northern districts (Orange Walk and Corozal);

- Central Farm in Hydrological Region 9 representing the central (Cayo and part of Belize);

- Melinda in Hydrological Region 11 representing the central and southern mountainous districts (Stann Creek and Toledo);

- Punta Gorda, close to Hydrological Region 13, representing the extreme southern district (Toledo);

- The Maya King station had too many missing values for the current period and was left out of the analysis.

Even as such, because of missing data, the decadal period for Punta Gorda is taken to be 1997-2006.

For the future decadal scenario (2060-2069), the values of precipitation (P) and evaporation (E) were extracted from the two climate models, namely, ECHAM5 and HadCM3Q11, all forced by the SRES A1B socio-economic scenario.

Precipitation data in the climate models (kg.m^2.s^-1) were multiplied by 84000 so as to derive mm/day, and then by the number of days per month to derive monthly values. Furthermore, noise in the climate models simulations at times produced negative values of precipitation. This was resolved by setting all negative values of precipitation at zero. Temperature values of the models (^{0}K) were also subtracted by -273.15 to obtain values in ^{0} C.

Table 4.1: Stations and locations for data analysis

Station	District	Hydrological Region	Latitude-deg. N	Longitude deg. W
Tower Hill	Orange Walk	Region 7	18^0 34’	88^0 34’
Melinda Forest	Stann Creek	Region 11	16^0 59’	88^0 19’
Central Farm	Cayo	Region 9	17^0 11’	89^0 0’
Maya King	Stann Creek	Region 11	16^0 43’	88^0 25’
Punta Gorda	Toledo	Region 11 (13)	16^0 8’	88^0 51’

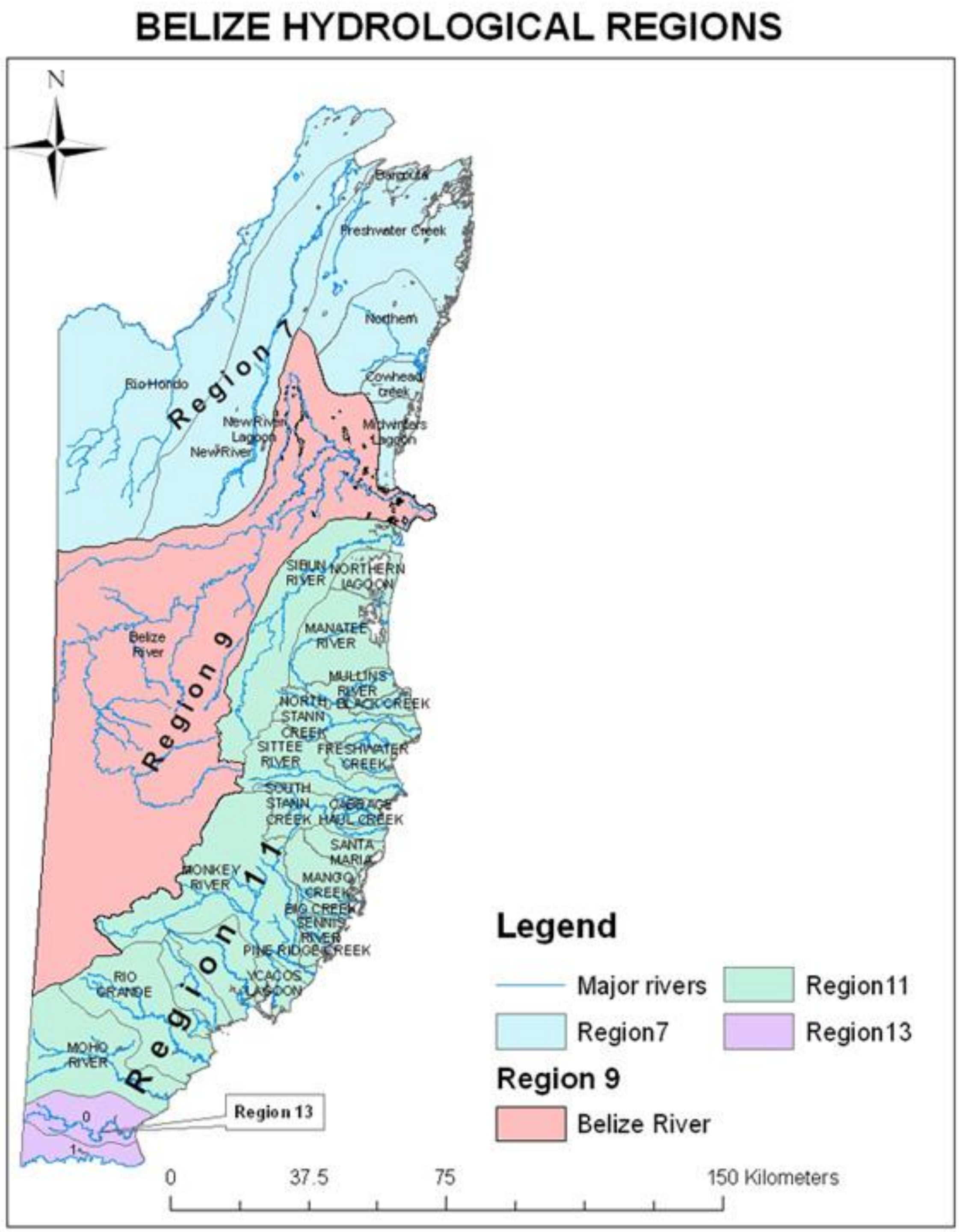

Figure 4.1: Major hydrological regions of Belize

4.0 Current (2000-2009) mean monthly values of P, PE and P-ET (mm/day)

Under the current climate, namely the decade of 2000-2009, the average monthly precipitation (mm/day), evaporation (mm/day) and water excess (+) or deficit (-) for the Tower Hill station in Stann Creek District and representing hydrological region number 7 in the northern districts (Corozal and Orange Walk) of Belize are presented in Table 4.2 and Figure 4.2. Table 4.2 and Figure 4.2 show that for this hydrological region, under the current climate (2000-2009), precipitation is highest from May (5.05 mm/day) to October (6.52 mm/day). On the other hand evaporation is highest between March (5.71 mm/day) and September (4.50 mm/day). The balance of these two variables results in water excess (P > E) in the months of June, August, September and October, whilst water deficits (P < E) occur during the dry season, namely from November to May) (See Table 4.2 and Figures 4.1 and 4.2).

Table 4.2: Mean monthly observed values of P, PE and P-ET (mm/day) for Tower Hill station (2000-2009)

Month	P	E	P-E
Jan	1.85	3.39	-1.54
Feb	1.11	4.32	-3.21
Mar	0.97	5.71	-4.73
Apr	0.68	6.63	-5.95
May	5.05	6.46	-1.41
June	7.03	5.32	1.71
July	4.52	5.42	-0.90
Aug	7.14	5.09	2.05
Sept	5.48	4.50	0.97
Oct	6.52	3.38	3.14
Nov	3.37	3.39	-0.02
Dec	2.01	3.11	-1.10
Average Annual	3.81	4.73	-0.92

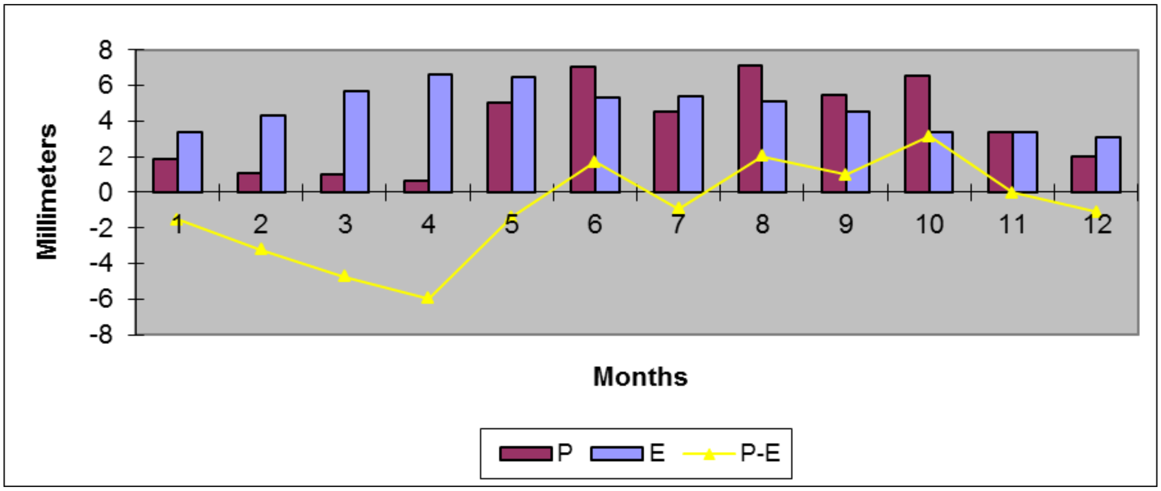

Figure 4.2: Mean monthly values of P, E and P-E (mm/day) for observed data (2000-2009) - Tower Hill station

Again, under the current climate, namely the decade of 2000-2009, the average monthly precipitation (mm/day), evaporation (mm/day) and water excess (+) or deficit (-) for the Melinda Forest station in Orange Walk District and representing hydrological region number 11 that occupies the southern and eastern half of Belize and includes the districts of Belize, Stann Creek and northern Corozal, are presented in Table 4.3 and Figure 4.3. Table 4.3 and Figure 4.3 show that for this hydrological region, under the current climate (2000-2009), precipitation is highest from May (5.88 mm/day) to November (7.19 mm/day). On the other hand evaporation is highest between March (4.40 mm/day) and September (4.16 mm/day). The balance of these two variables results in water excess (P > E) in all months, except the dry season months of February, March and April, when there occurs a water deficit (P < E) (See Table 4.3 and Figures 4.1 and 4.3).

Table 4.3: Mean monthly observed values of P, PE and P-ET (mm/day) for Melinda Forest station (2000-2009)

Month	P	E	P-E
Jan	5.26	3.20	2.06
Feb	2.12	3.80	-1.69
Mar	2.08	4.40	-2.32
Apr	1.11	4.95	-3.84
May	5.88	5.15	0.73
June	7.76	4.85	2.91
July	6.25	4.88	1.37
Aug	8.35	4.70	3.65
Sept	8.02	4.16	3.86
Oct	9.42	3.94	5.49
Nov	7.19	3.35	3.84
Dec	4.54	3.12	1.42
Average Annual	5.66	4.21	1.46

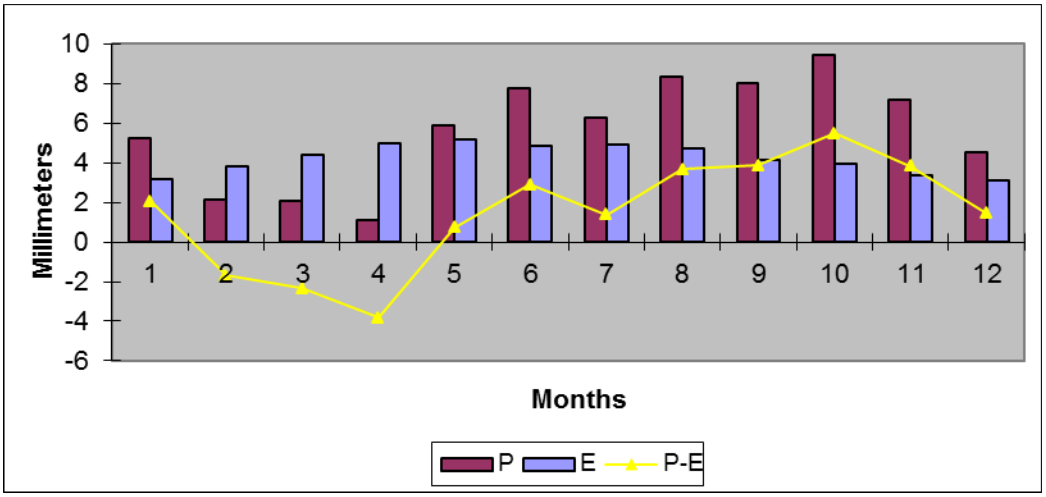

Figure 4.3: Mean monthly values of P, E and P-E (mm/day) for observed data (2000-2009) - Melinda Forest station

For the Central Farm station, that represents region 9 and covers the mountainous parts of the districts of Cayo, mainly, and Stann Creek and Toledo, under the current climate (2000-2009), the average monthly precipitation (mm/day), evaporation (mm/day) and water excess (+) or deficit (-) are presented in Table 4.4 and Figure 4.4. Again, Table 4.4 and Figure 4.4 show that for this hydrological region (9), under the current climate (2000-2009), precipitation is highest from May (4.22 mm/day) to November (4.87 mm/day). On the other hand evaporation is highest between March (5.34 mm/day) and September (4.33 mm/day). The combination of these two variables results in water excess (P > E) in the rainy months of June to October, and even, in this case November, December and January. So the only months that suffer a water deficit (P < E) are the dry season months February to May (See Table 4.4 and Figures 4.1 and 4.4).

Table 4.4: Mean monthly observed values of P, PE and P-ET (mm/day) for Central Farm station (2000-2009)

Month	P	E	P-E
Jan	3.80	2.75	1.05
Feb	2.15	3.90	-1.75
Mar	1.27	5.34	-4.07
Apr	0.82	6.29	-5.46
May	4.22	6.24	-2.02
June	5.41	5.08	0.33
July	6.16	4.77	1.39
Aug	5.13	4.78	0.35
Sept	6.37	4.33	2.04
Oct	7.45	3.50	3.95
Nov	4.87	2.93	1.95
Dec	3.65	2.50	1.15
Annual	4.27	4.37	-0.09

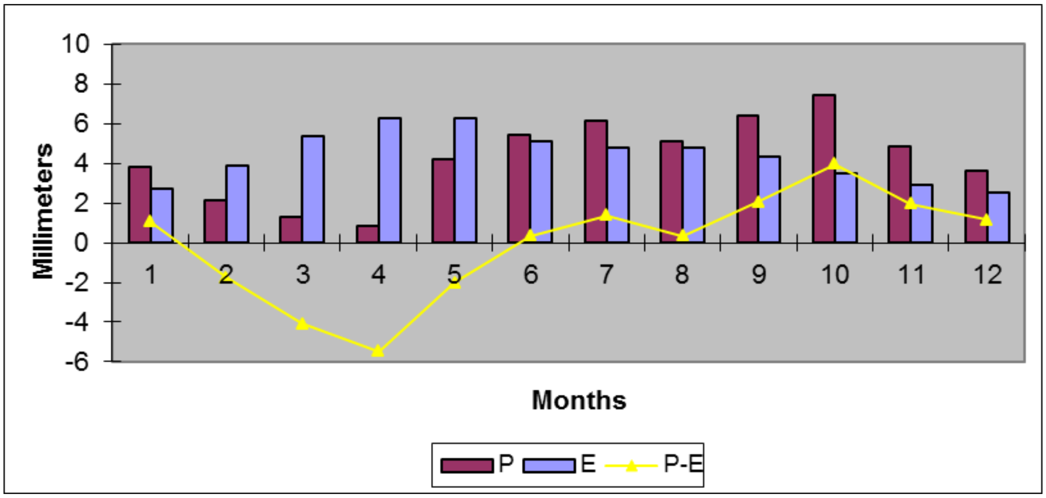

Figure 4.4: Mean monthly values of P, E and P-E (mm/day) for observed data (2000-2009) - Central Farm station

Finally, for the Punta Gorda station, that represents regions 11 and 13 and covers southern districts of Stann Creek and Toledo, under the current climate (2000-2009), the average monthly precipitation (mm/day), evaporation (mm/day) and water excess (+) or deficit (-) are presented in Table 4.5 and Figure 4.5. Table 4.5 and Figure 4.5 show that for these hydrological regions (11 and 13), under the current climate (2000-2009), precipitation is highest when compared with the other districts of Belize. Furthermore, precipitation is from June (16.76 mm/day) to November (10.16 mm/day) and even reaches the highest amount in July (24.29 mm/day). On the other hand evaporation is highest between March (4.85 mm/day) and September (4.67 mm/day). On account of the very high rainfalls in these hydrological regions (11 and 13), when comparing these two variables water excess (P > E) occurs in the rainy season months of June to November, and even, in this case, December and January. In fact the water excess in July reaches 24.29 mm/day. So the only months that suffer a water deficit (P < E) are the dry season months February to April (See Table 4.5 and Figures 4.1 and 4.5).

Table 4.5: Mean monthly observed values of P, PE and P-ET (mm/day) for Punta Gorda station (1997-2006)

Month	P	E	P-E
Jan	5.15	2.95	2.20
Feb	2.83	3.96	-1.13
Mar	2.01	4.85	-2.83
Apr	2.62	5.69	-3.07
May	6.41	5.29	1.13
June	16.76	5.69	11.07
July	24.29	4.88	19.41
Aug	21.35	4.78	16.57
Sept	16.58	4.67	11.91
Oct	12.46	3.96	8.50
Nov	10.16	3.25	6.91
Dec	5.34	2.83	2.51
Annual	10.50	4.40	6.10

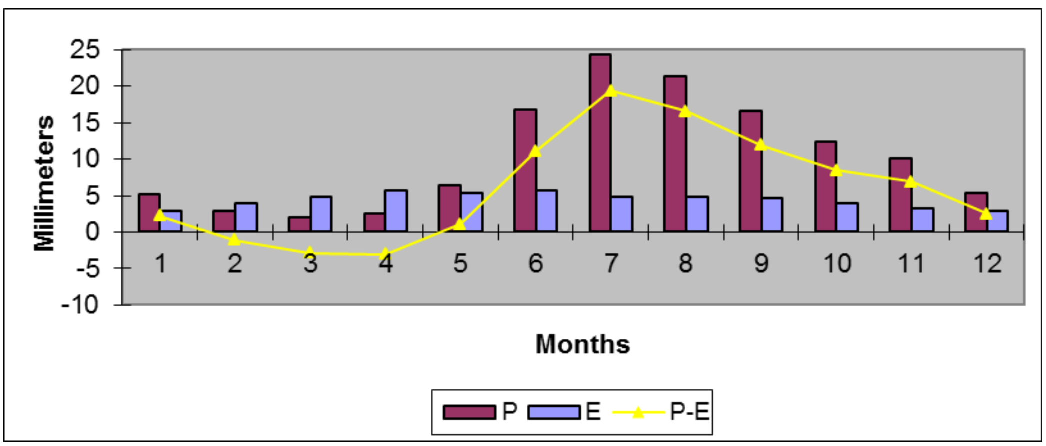

Figure 4.5: Mean monthly values of P, E and P-E (mm/day) for observed data (2000-2009) - Punta Gorda station

5.0 Current (2000-2009) and future (2060-2069) mean monthly values of P, PE and P-ET (mm/day): ECHAM 5 Climate Model

When examining both the current (2000-2009) and future (2060-2069) climate, according to the ECHAM5 model, for the Tower Hill station in Stann Creek District that represents hydrological region number 7 in the northern districts (Corozal and Orange Walk) of Belize, the results are presented in Table 4.6 and Figures 4.6 and 4.7. These show that water deficits (P < E) will occur in the future (2060-2069) during the dry season months of January (- 0.24 mm/day) to April (-0.27 mm/day), but water excess (P > E) will occur during the other wetter months of the year spanning from May to December. However, the changes in water deficits or excess in the future (2060-2069) compared to the current (2000-2009) will be such that decreasing water excess (P > E) will occur in the wetter months of April to September and decreasing water deficits (P <E) will occur in the drier months of the year, namely January to April (Table 4.6 and Figures 4.6 and 4.7).

Table 4.6: Mean monthly values of P, E and P-E (mm/day), according the ECHAM5 model for Tower Hill station (current 2000-2009 and future 2060-2069)

	Current Period			Future Period			Changes P-E	
Month	P	E	P-E	P	E	P-E	mm/day	%
Jan	1.41	2.10	-0.69	1.62	1.86	-0.24	0.45	-64.7
Feb	0.94	2.27	-1.33	1.64	2.12	-0.48	0.85	-64.1
Mar	1.40	1.91	-0.51	1.43	2.01	-0.58	-0.07	14.4
Apr	1.86	1.63	0.23	1.52	1.79	-0.27	-0.50	-217.2
May	3.94	1.45	2.49	2.81	1.41	1.40	-1.09	-43.7
June	5.03	1.92	3.10	4.47	1.79	2.68	-0.42	-13.6
July	4.54	2.10	2.44	3.67	1.99	1.68	-0.75	-30.9
Aug	3.76	2.20	1.56	3.18	1.76	1.42	-0.14	-8.7
Sept	4.92	1.97	2.95	4.38	1.72	2.66	-0.28	-9.6
Oct	5.30	2.38	2.92	6.28	1.96	4.32	1.40	48.0
Nov	1.76	2.78	-1.02	3.50	2.41	1.09	2.12	-207.3
Dec	2.35	1.92	0.42	2.56	2.01	0.55	0.13	30.0
Annual	3.10	2.05	1.05	3.09	1.90	1.19	0.14	13.4

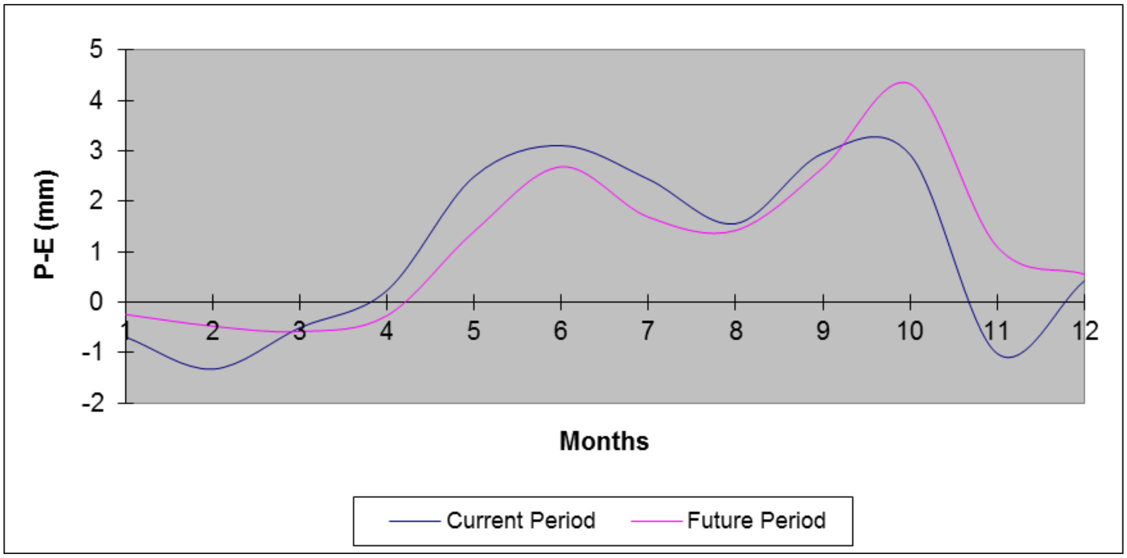

Figure 4.6: Mean monthly trend of P-E (mm/day), according the ECHAM5 model for Tower Hill station (current 2000-2009 and future 2060-2069)

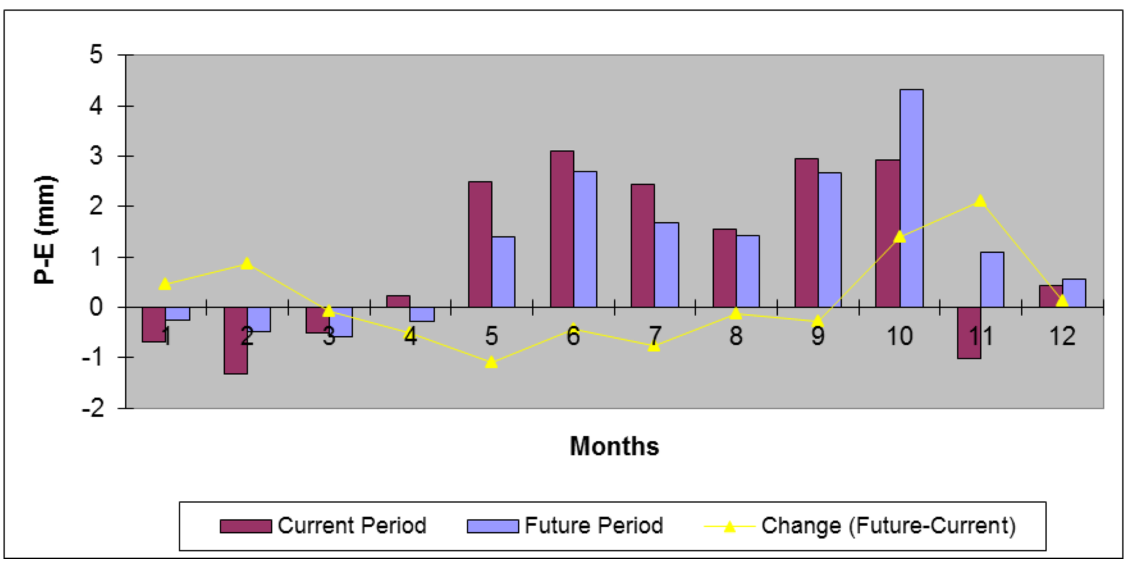

Figure 4.7: Mean monthly values of P-E (mm/day) for current (2000-2009) and future (2060-2069) periods and changes between periods according to the ECHAM5 model for Tower Hill station

But when examining both the current (2000-2009) and future (2060-2069) climate according to the ECHAM5 model, for the Melinda Forest station in Orange Walk District and representing hydrological region number 11 that occupies the southern and eastern half of Belize and includes the districts of Belize, Stann Creek and northern Corozal, the results are presented in Table 4.7 and Figures 4.8 and 4.9. These show that water deficits (P < E) will occur in the future (2060-2069) only during the dry season months of March (- 0.62 mm/day) and April (- 0.13 mm/day), but water excess (P > E) will occur during the other wetter months of the year spanning from May to December and even into January and February. However, the changes in water deficits in the future (2060-2069) compared to the current (2000-2009) will be such that decreasing water excess (P-E: +) will again occur in the wetter months of May to September and even December and January. On the other hand water deficits (P < E) will persist through the months of February to April, though to a lesser extent (Table 4.6 and Figures 4.6 and 4.7).

Table 4.7: Mean monthly values of P, E and P-E (mm/day), according the ECHAM5 model for Melinda Forest station (current 2000-2009 and future 2060-2069)

	Current Period			Future Period			Changes P-E	
Month	P	E	P-E	P	E	P-E	mm/day	%
Jan	2.30	1.89	0.41	3.18	1.67	1.50	1.09	265.1
Feb	1.46	2.51	-1.05	2.28	2.12	0.16	1.21	-115.6
Mar	1.67	2.73	-1.07	1.64	2.26	-0.62	0.45	-42.4
Apr	2.15	2.48	-0.33	2.10	2.23	-0.13	0.20	-60.6
May	5.94	1.85	4.08	4.40	2.07	2.33	-1.76	-43.0
June	8.71	1.75	6.96	7.59	1.64	5.95	-1.01	-14.5
July	8.06	1.46	6.59	7.33	1.54	5.79	-0.80	-12.2
Aug	5.33	1.73	3.60	5.18	1.60	3.58	-0.02	-0.6
Sept	5.44	1.73	3.71	4.75	1.51	3.24	-0.46	-12.5
Oct	6.42	1.98	4.43	6.48	1.65	4.83	0.40	9.0
Nov	3.02	2.26	0.76	4.39	2.06	2.34	1.58	209.3
Dec	5.13	1.56	3.57	4.79	1.68	3.11	-0.46	-13.0
Annual	4.63	2.00	2.64	4.51	1.84	2.67	0.03	1.3

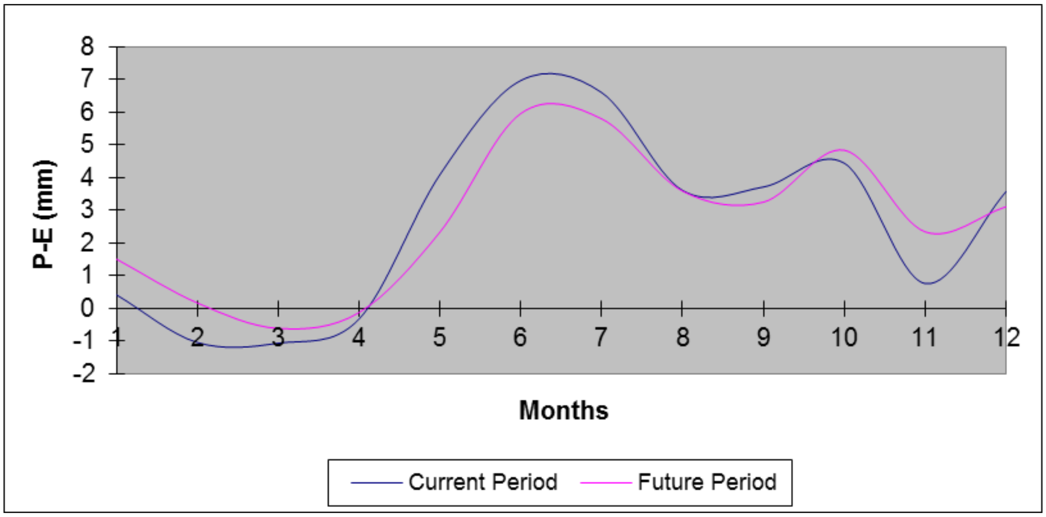

Figure 4.8: Mean monthly trend of P-E (mm/day), according the ECHAM5 model for Melinda Forest station (current 2000-2009 and future 2060-2069)

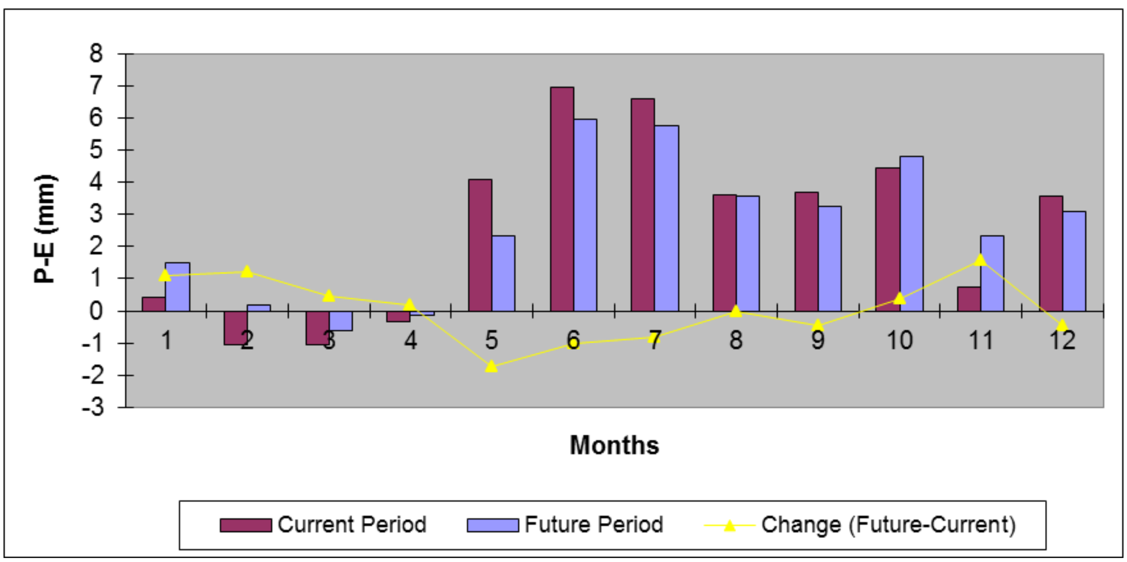

Figure 4.9: Mean monthly values of P-E (mm/day) for current (2000-2009) and future (2060-2069) periods and changes between periods according to the ECHAM5 model for Melinda Forest station

Next, when examining both the current (2000-2009) and future (2060-2069) climate, according to the ECHAM5 model, for the Central Farm station that represents region 9 and covers the mountainous parts of the districts of Cayo, mainly, and Stann Creek and Toledo, and located in Cayo District, the results are presented in Table 4.8 and Figures 4.10 and 4.11. These results show that water deficits (P < E) will occur in the future (2060-2069) only during the dry season months from January (- 0.27 mm/day) to April (- 0.83 mm/day), and water excess (P > E) will occur during the other wetter months of the year spanning from May to December. However, the changes in water deficits in the future (2060-2069) compared to the current (2000-2009) will be such that decreasing water excess (P-E: +) will again occur in the wetter months of May to September. But water excess in the future will increase between October and November. On the other hand water deficits (P < E) will persist through the months of January to April, though to a lesser extent in January and February and to a greater extent in March and April (Table 4.8 and Figures 4.10 and 4.11).

Table 4.8: Mean monthly values of P, E and P-E (mm/day), according the ECHAM5 model for Central Farm station (current 2000-2009 and future 2060-2069)

	Current Period			Future Period			Changes P-E	
Month	P	E	P-E	P	E	P-E	mm	%
Jan	1.16	1.71	-0.55	1.44	1.71	-0.27	0.28	-51.1
Feb	0.81	2.01	-1.20	1.49	1.99	-0.51	0.70	-57.9
Mar	1.34	1.78	-0.44	1.32	2.01	-0.69	-0.25	57.6
Apr	1.38	1.60	-0.22	1.02	1.85	-0.83	-0.61	283.6
May	2.56	1.34	1.22	2.07	1.43	0.63	-0.58	-47.9
June	3.04	1.58	1.46	2.28	1.64	0.64	-0.82	-56.4
July	2.64	1.60	1.04	1.72	1.54	0.18	-0.87	-83.1
Aug	2.13	1.49	0.64	1.32	1.22	0.11	-0.54	-83.5
Sept	3.76	1.37	2.39	2.93	1.20	1.73	-0.66	-27.6
Oct	5.07	1.69	3.38	6.38	1.46	4.92	1.54	45.5
Nov	2.70	2.07	0.63	3.52	1.90	1.62	0.99	158.5
Dec	2.44	1.53	0.91	2.55	1.58	0.97	0.06	6.7
Annual	2.42	1.65	0.77	2.34	1.63	0.71	-0.06	-8.2

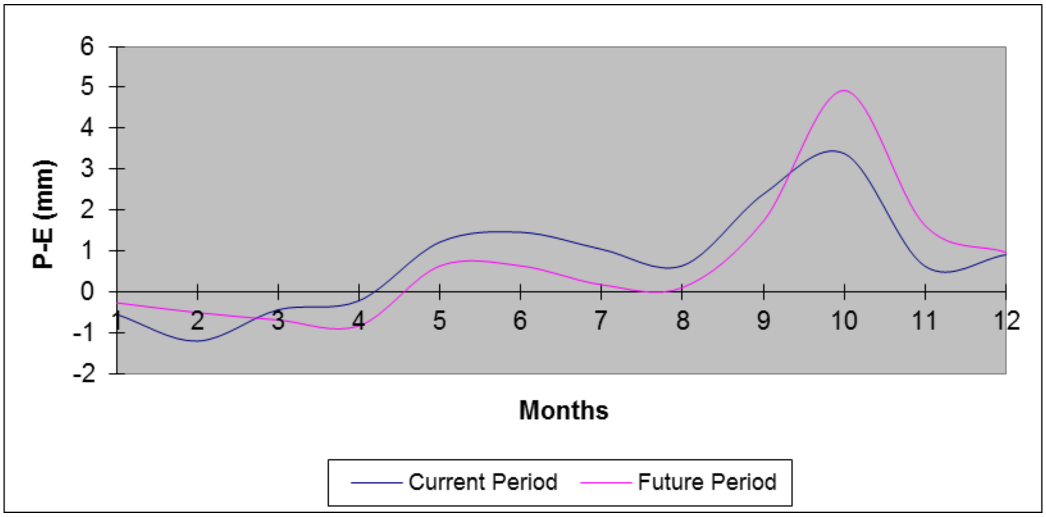

Figure 4.10: Mean monthly trend of P-E (mm/day), according the ECHAM5 model for Central Farm station (current 2000-2009 and future 2060-2069)

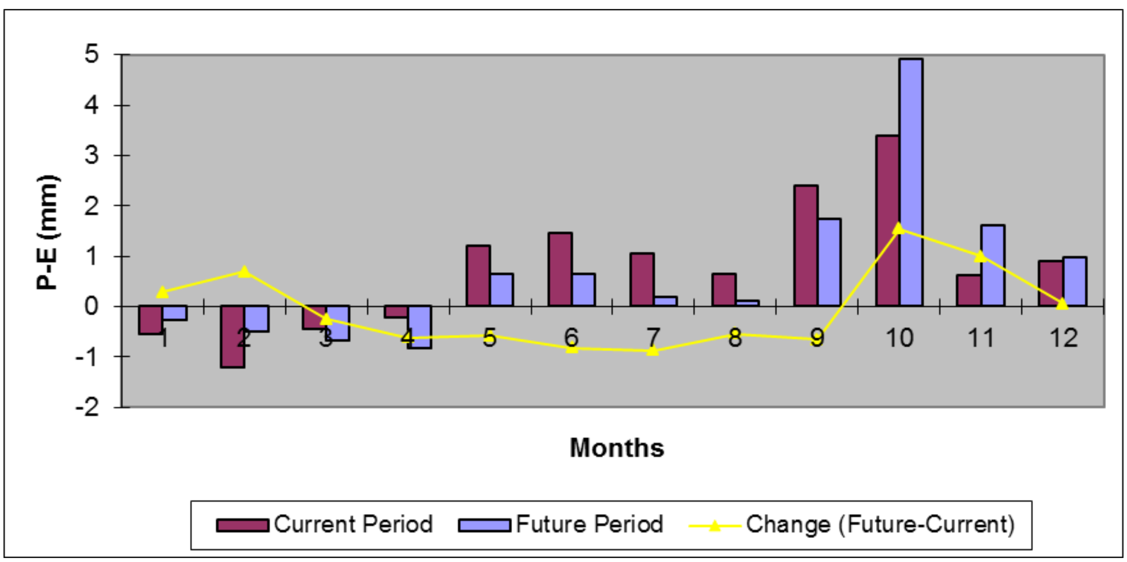

Figure 4.11: Mean monthly values of P-E (mm/day) for current (2000-2009) and future (2060-2069) periods and changes between periods according to the ECHAM5 model for Central Farm station

Finally, when examining both the current (2000-2009) and future (2060-2069) climate, according to the ECHAM5 model, for the Punta Gorda station, that represents regions 11 and 13 and covers southern districts of Stann Creek and Toledo and located in Toledo District, the results are presented in Table 4.9 and Figures 4.12 and 4.13. These results again show that water deficits (P < E) will occur in the future (2060-2069) only during the dry season months from January (- 0.22 mm/day) to April (- 0.39 mm/day), and water excess (P > E) will decrease during the rainy season months of May, June, August and December, but increase during the rainy season months of July September and October. On the other hand, water deficits (P < E) in the future (2060-2069) will decrease in November and then gain from January to April (Table 4.9 and Figures 4.12 and 4.13).

Table 4.9: Mean monthly values of P, E and P-E (mm), according the ECHAM5 model for Punta Gorda station (current 2000-2009 and future 2060-2069)

	Current Period			Future Period			Changes P-E	
Month	P	E	P-E	P	E	P-E	mm/day	%
Jan	1.33	1.92	-0.60	1.57	1.79	-0.22	0.38	-63.8
Feb	0.87	2.08	-1.21	1.25	1.99	-0.74	0.48	-39.3
Mar	1.26	1.88	-0.61	1.48	1.88	-0.39	0.22	-35.5
Apr	2.08	1.72	0.36	1.70	1.73	-0.03	-0.39	-107.4
May	4.08	1.52	2.57	2.76	1.50	1.26	-1.30	-50.7
June	5.83	1.94	3.89	5.55	1.75	3.80	-0.10	-2.5
July	5.43	2.11	3.32	5.44	1.95	3.49	0.17	5.1
Aug	4.34	2.30	2.03	3.70	2.00	1.69	-0.34	-16.7
Sept	4.41	2.29	2.12	4.17	1.99	2.18	0.05	2.5
Oct	4.42	2.43	1.99	4.89	2.10	2.78	0.80	40.0
Nov	1.88	2.52	-0.64	2.61	2.31	0.30	0.93	-146.7
Dec	2.77	1.74	1.02	2.46	1.95	0.51	-0.51	-50.1
Annual	3.23	2.04	1.19	3.13	1.91	1.22	0.03	2.7

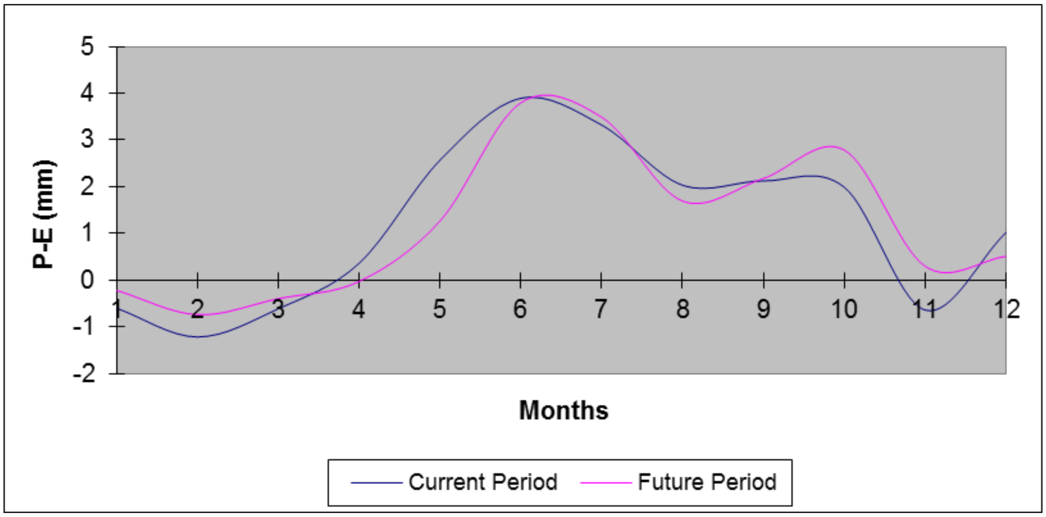

Figure 4.12: Mean monthly trend of P-E (mm/day), according the ECHAM5 model for Punta Gorda station (current 2000-2009 and future 2060-2069)

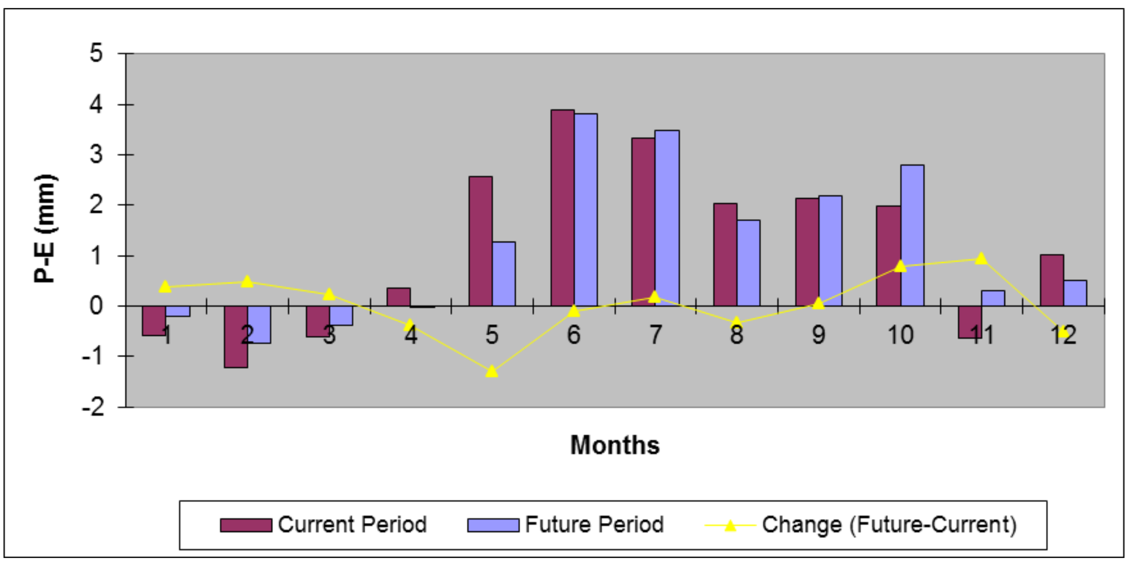

Figure 4.13: Mean monthly values of P-E (mm/day) for current (2000-2009) and future (2060-2069) periods and changes between periods according to the ECHAM5 model for Punta Gorda station

6.0 Current (2000-2009) and future (2060-2069) mean monthly values of P, PE and P-ET (mm/day): HadCM3Q11 Climate Model

By examining both the current (2000-2009) and future (2060-2069) climate, according to the HadCM3Q11 model, for the Tower Hill station in Stann Creek District that represents hydrological region number 7 in the northern districts (Corozal and Orange Walk) of Belize, the results are as presented in Table 4.10 and Figures 4.14 and 4.15. These results show that for the HADCM3Q11 model water excess (P > E) occurs in all months of the year for both current (2000-2009) and future (2060-2069) climates for the Tower Hill station. However, the changes in water excess in the future (2060-2069) compared to the current (2000-2009) will be such that decreasing water excess (P > E) will occur in all months of the year, except August and September, thereby leading to drier soil moisture conditions (Table 4.10 and Figures 4.14 and 4.15).

Table 4.10: Mean monthly values of P, E and P-E (mm/day), according to the HadCM3Q11 model for Tower Hill station (current 2000-2009 and future 2060-2069)

	Current Period			Future Period			Changes P-E	
Month	P	E	P-E	P	E	P-E	mm/day	%
Jan	3.17	1.87	1.30	1.83	1.40	0.43	-0.87	-66.8
Feb	2.98	1.90	1.08	2.23	1.37	0.86	-0.22	-20.0
Mar	2.83	2.03	0.80	2.18	1.32	0.86	0.05	6.7
Apr	3.02	2.05	0.97	1.69	1.32	0.37	-0.60	-62.1
May	3.02	1.94	1.08	1.86	1.36	0.51	-0.58	-53.2
June	2.75	1.92	0.83	2.08	1.37	0.72	-0.11	-13.8
July	3.68	1.89	1.80	2.28	1.35	0.93	-0.86	-48.1
Aug	2.72	1.91	0.81	2.49	1.32	1.17	0.36	45.1
Sept	2.61	1.95	0.67	2.29	1.34	0.95	0.28	42.5
Oct	5.13	1.93	3.20	2.17	1.37	0.80	-2.40	-75.1
Nov	4.50	1.94	2.55	2.54	1.38	1.16	-1.40	-54.7
Dec	3.13	1.88	1.25	2.34	1.38	0.96	-0.29	-23.4
Annual	3.30	1.93	1.36	2.17	1.36	0.81	-0.55	-40.6

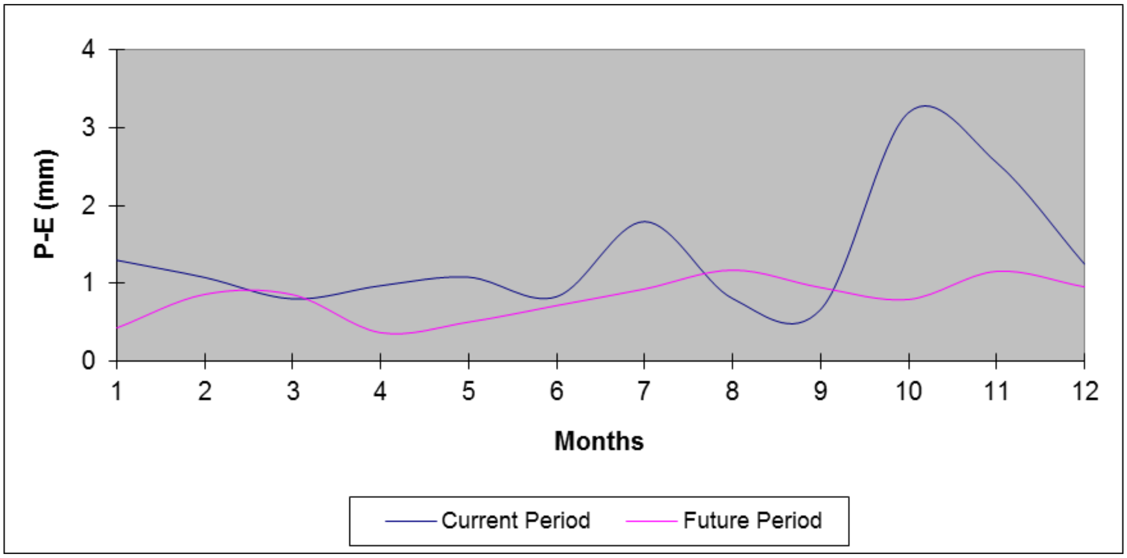

Figure 4.14: Mean monthly trend of P-E (mm/day), according to the HadCM3Q11 model for Tower Hill station (current 2000-2009 and future 2060-2069)

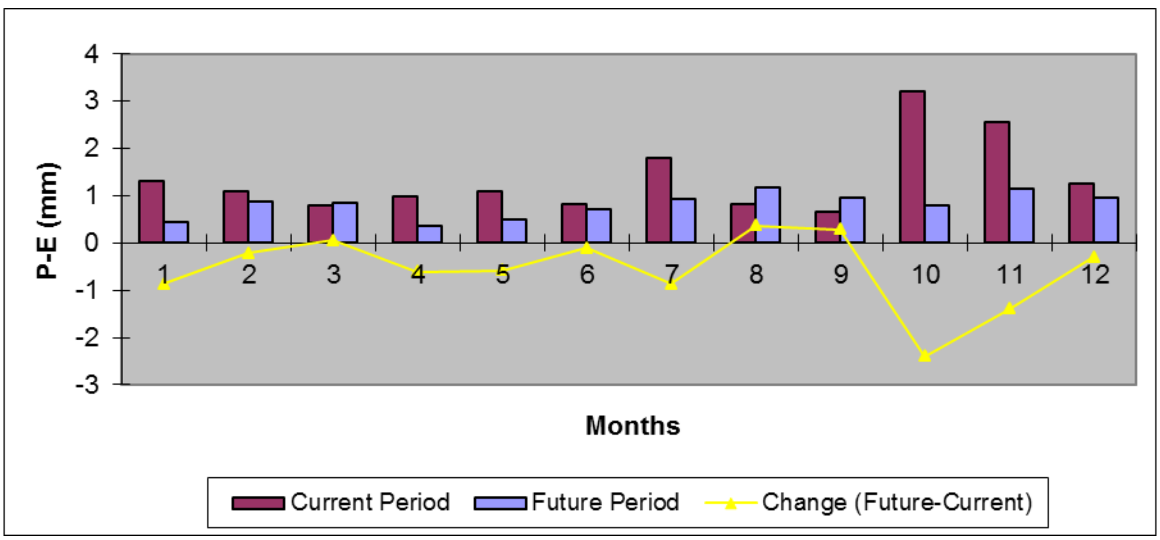

Figure 4.15: Mean monthly values of P-E (mm/day) for current (2000-2009) and future (2060-2069) periods and changes between periods according to the HadCM3Q11 model for Tower Hill station

But when examining both the current (2000-2009) and future (2060-2069) climate according to the HadCM3Q11 model, for the Melinda Forest station in Orange Walk District and representing hydrological region number 11 that occupies the southern and eastern half of Belize and includes the districts of Belize, Stann Creek and northern Corozal, the results are as presented in Table 4.11 and Figures 4.16 and 4.17. The HadCM3Q11 model again shows that water excess (P > E) occurs in all months of the year for both current (2000-2009) and future (2060-2069) climates for the Melinda Forest station. Furthermore, the changes in water excess in the future (2060-2069) compared to the current (2000-2009) will be such that decreasing water excess (P > E) will occur in all months of the year, thereby leading to generally drier soil moisture conditions (Table 4.11 and Figures 4.16 and 4.17).

Table 4.11: Mean monthly values of P, E and P-E (mm/day), according to the HadCM3Q11 model for Melinda Forest station (current 2000-2009 and future 2060-2069)

	Current Period			Future Period			Changes P-E	
Month	P	E	P-E	P	E	P-E	mm/day	%
Jan	4.21	1.89	2.32	3.41	1.83	1.58	-0.74	-31.8
Feb	4.56	1.93	2.62	3.89	1.78	2.11	-0.51	-19.5
Mar	4.35	2.07	2.28	3.43	1.88	1.55	-0.73	-32.1
Apr	4.10	2.19	1.91	2.90	1.83	1.07	-0.83	-43.7
May	4.34	1.97	2.37	3.36	1.74	1.62	-0.75	-31.5
June	4.69	2.04	2.64	3.83	1.79	2.04	-0.61	-22.9
July	4.65	2.01	2.64	3.85	1.74	2.11	-0.53	-20.0
Aug	4.97	1.86	3.11	3.62	1.82	1.80	-1.32	-42.3
Sept	4.94	1.81	3.12	3.24	1.86	1.39	-1.74	-55.6
Oct	5.58	1.85	3.73	3.46	1.77	1.70	-2.04	-54.6
Nov	4.75	1.99	2.76	3.92	1.81	2.12	-0.64	-23.3
Dec	4.25	2.02	2.23	3.85	1.86	2.00	-0.23	-10.4
Annual	4.61	1.97	2.64	3.56	1.81	1.76	-0.89	-33.6

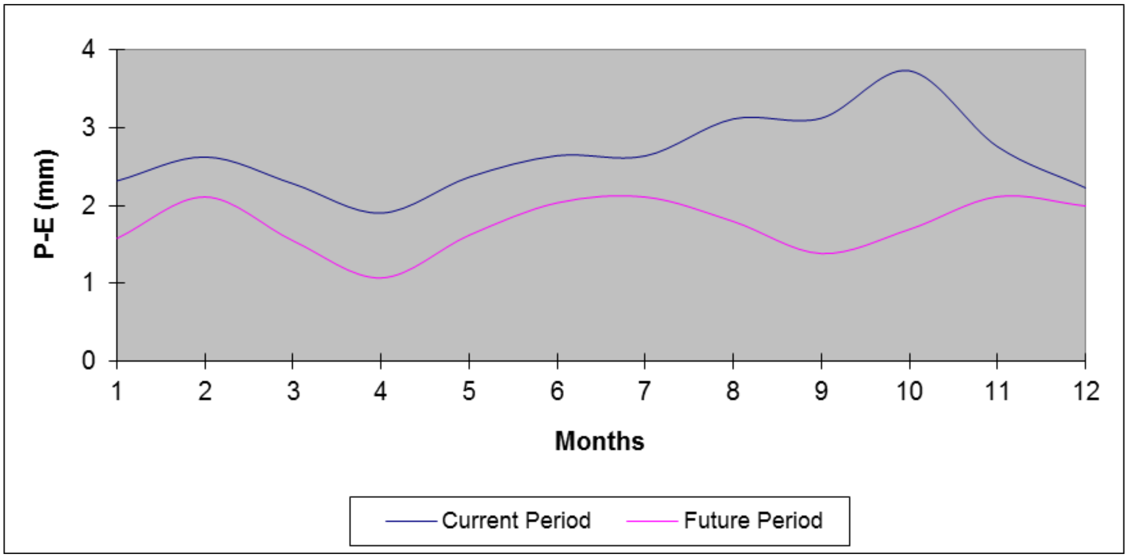

Figure 4.16: Mean monthly trend of P-E (mm/day), according to the HadCM3Q11 model for Melinda Forest station (current 2000-2009 and future 2060-2069)

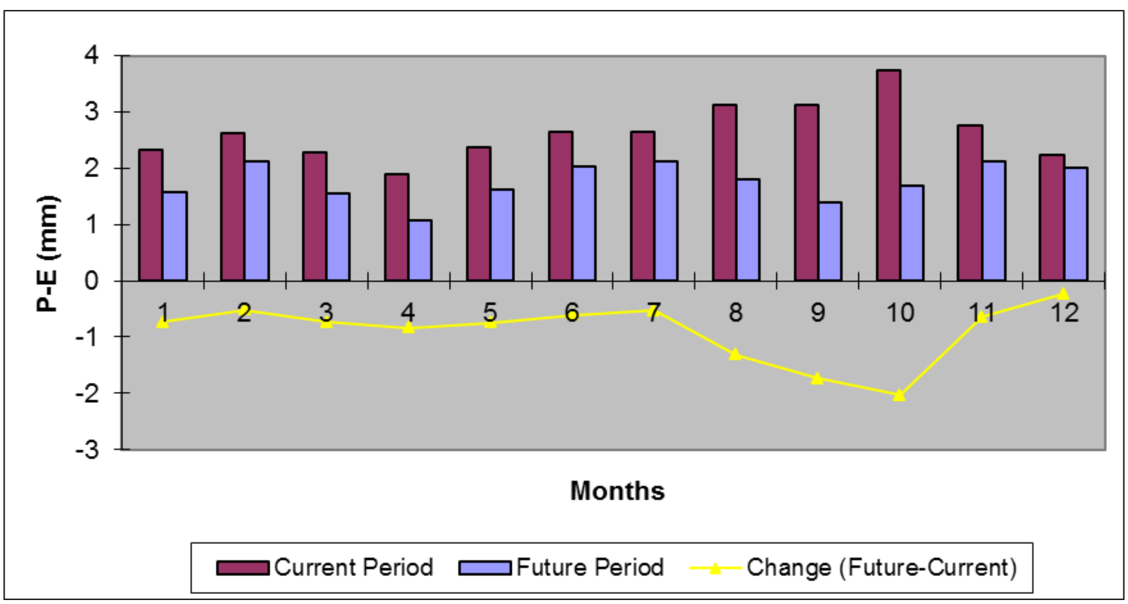

Figure 4.17: Mean monthly values of P-E (mm/day) for current (2000-2009) and future (2060-2069) periods and changes between periods according to the HadCM3Q11 model for Melinda Forest station

Next, when examining both the current (2000-2009) and future (2060-2069) climate, according to the HadCM3Q11 model, for the Central Farm station that represents region 9 and covers the mountainous parts of the districts of Cayo, mainly, and Stann Creek and Toledo, and located in Cayo District, the results are as presented in Table 4.12 and Figures 4.18 and 4.19. These results show that water excess (P > E) occurs in all months of the year for both current (2000-2009) and future (2060-2069) climates for the Central Farm station as was the case for the Melinda Forest station. Furthermore, the changes in water excess in the future (2060-2069) compared to the current (2000-2009) will be such that decreasing water excess (P > E) will occur in the months of January and then from July to November, when the decrease in P-E is greatest. However, the magnitude of water excess (P > E) will decrease in the future (2060-2069) climate, when compared to the current (2000-20009) climate, at the same time leading to generally drier soil moisture conditions (Table 4.12 and Figures 4.18 and 4.19).

Table 4.12: Mean monthly values of P, E and P-E (mm/day), according to the HadCM3Q11 model for Central Farm station (current 2000-2009 and future 2060-2069)

	Current Period			Future Period			Changes P-E	
Month	P	E	P-E	P	E	P-E	mm	%
Jan	1.86	1.28	0.58	0.99	0.79	0.20	-0.37	-65.0
Feb	1.69	1.31	0.38	1.18	0.80	0.38	0.00	-0.6
Mar	1.86	1.40	0.46	1.46	0.79	0.68	0.21	46.4
Apr	1.60	1.44	0.16	1.30	0.76	0.54	0.38	235.3
May	1.53	1.39	0.13	1.17	0.78	0.39	0.26	192.3
June	1.60	1.32	0.29	1.21	0.81	0.40	0.12	40.7
July	1.94	1.29	0.65	1.04	0.78	0.26	-0.38	-59.1
Aug	1.78	1.27	0.51	1.36	0.78	0.58	0.07	14.4
Sept	2.24	1.35	0.90	1.22	0.79	0.43	-0.47	-52.0
Oct	4.03	1.27	2.76	1.59	0.79	0.80	-1.96	-71.0
Nov	2.85	1.29	1.56	1.42	0.82	0.60	-0.96	-61.6
Dec	1.89	1.31	0.58	1.62	0.81	0.80	0.23	39.1
Annual	2.07	1.33	0.75	1.30	0.79	0.51	-0.24	-32.2

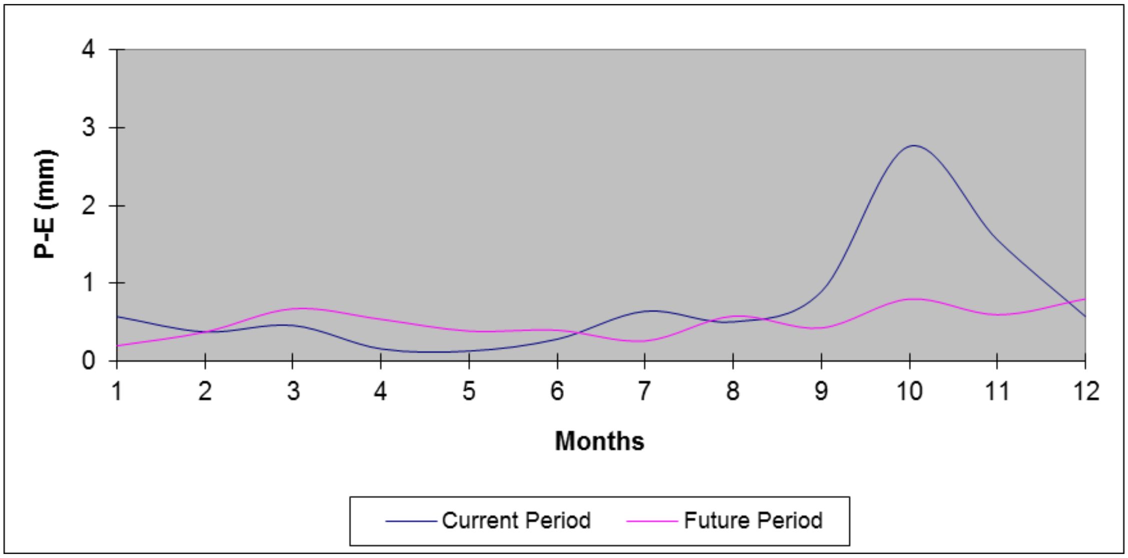

Figure 4.18: Mean monthly trend of P-E (mm/day), according to the HadCM3Q11 model for Central Farm station (current 2000-2009 and future 2060-2069)

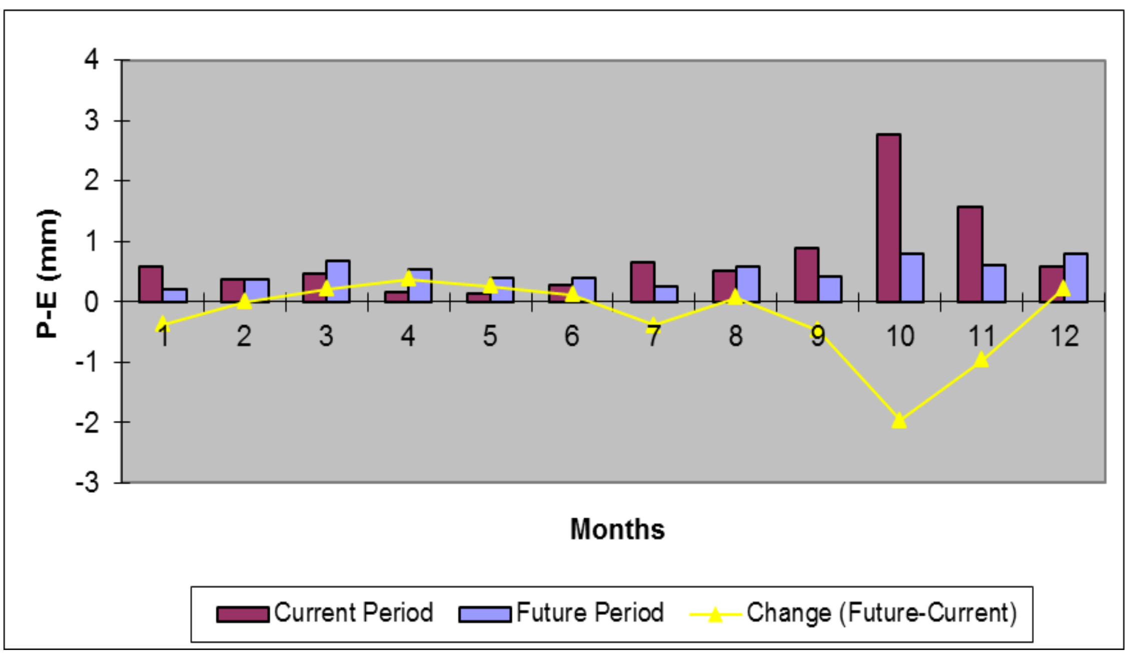

Figure 4.19: Mean monthly values of P-E (mm/day) for current (2000-2009) and future (2060-2069) periods and changes between periods according to the HadCM3Q11 model for Central Farm station

Finally, when examining both the current (2000-2009) and future (2060-2069) climate, according to the HadCM3Q11 model, for the Punta Gorda station, that represents regions 11 and 13 and covers southern districts of Stann Creek and Toledo and located in Toledo District, the results are as presented in Table 4.13 and Figures 4.20 and 4.21. These results show that for the HADCM3Q11 model water excess (P > E) occurs in all months of the year for both current (2000-2009) and future (2060-2069) climates for the Punta Gorda station, as was the case for the Tower Hill station. Similarly, the changes in water excess in the future (2060-2069) compared to the current (2000-2009) will be such that decreasing water excess (P > E) will occur in January, and then again from July to September, but still leading to drier soil moisture conditions (Table 4.13 and Figures 4.20 and 4.21).

Table 4.13: Mean monthly values of P, E and P-E (mm), according to the HadCM3Q11 model for Punta Gorda station (current 2000-2009 and future 2060-2069)

	Current Period			Future Period			Changes P-E	
Month	P	E	P-E	P	E	P-E	mm/day	%
Jan	2.59	1.90	0.68	2.00	1.63	0.37	-0.31	-45.8
Feb	2.80	1.90	0.90	2.60	1.52	1.08	0.18	20.0
Mar	2.64	2.01	0.63	2.70	1.58	1.12	0.49	78.5
Apr	2.41	1.99	0.42	2.12	1.54	0.58	0.16	37.1
May	2.56	2.00	0.56	2.48	1.48	1.00	0.44	77.7
June	2.65	1.98	0.68	2.68	1.53	1.15	0.48	70.2
July	3.10	1.92	1.18	2.68	1.49	1.19	0.01	0.7
Aug	3.06	1.85	1.21	2.41	1.57	0.84	-0.37	-30.7
Sept	2.77	1.89	0.88	2.28	1.57	0.71	-0.17	-19.4
Oct	2.71	1.87	0.84	2.52	1.56	0.96	0.12	14.4
Nov	2.89	1.89	1.00	3.26	1.49	1.76	0.76	75.9
Dec	2.87	2.03	0.84	2.63	1.51	1.11	0.27	32.7
Annual	2.75	1.94	0.82	2.53	1.54	0.99	0.17	20.9

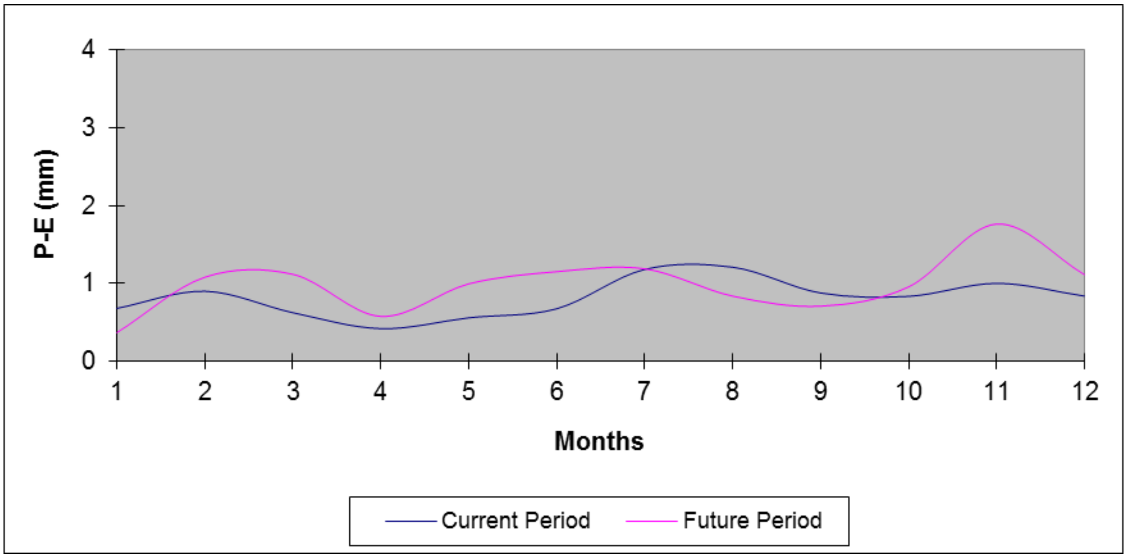

Figure 4.20: Mean monthly trend of P-E (mm/day), according to the HadCM3Q11 model for Punta Gorda station (current 2000-2009 and future 2060-2069)

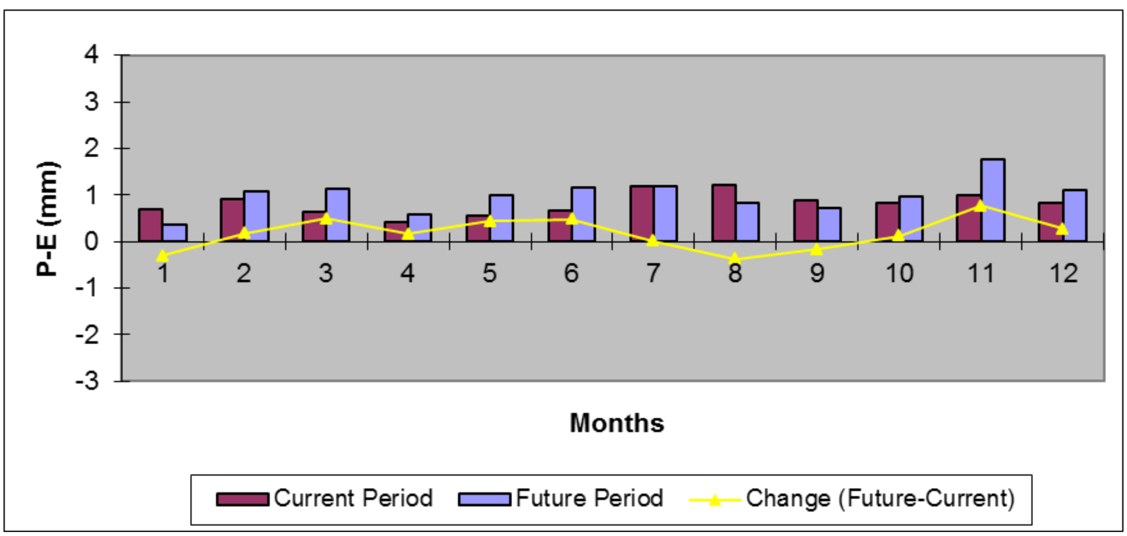

Figure 4.21: Mean monthly values of P-E (mm/day) for current (2000-2009) and future (2060-2069) periods and changes between periods according to the HadCM3Q11 model for Punta Gorda station

7.0 Socio-economic Impacts of Water Deficits or Excesses

Based on the results presented above, it is apparent that all of the regions/stations examined will generally suffer increasing water deficits in the future (2060-2069) due to a combination of slight decreases in rainfall and moderate increases in temperature and evaporation.

Belize is a country rich in surface water sources including streams and rivers as well as many groundwater aquifers found in calcareous rock. The main source of freshwater in rural areas is predominantly groundwater, where approximately 95% of freshwater is extracted from groundwater supplies. There is also one desalinisation plant is operating in the country on Ambergris Caye. Freshwater supplies are sufficient for the current population, though there is an increased stress on these supplies due to population growth, increases in economic and agricultural activities, as well as an increase in droughts (BEST, 2009; CARIBSAVE, 2012).

The Belize Water Services (BWS) is the controlling agency for water distribution in the country. Recently, the rates for water use have increased many folds for tariffs and connection rates (CARIBSAVE, 2012).

Despite its water abundance, recent issues with water scarcity in some areas and water quality have become more commonplace as various stresses on water resources increase. Key issues with water vulnerability in Belize are the uneven distribution of water resources. The southern region (Toledo) has the lowest population, with the highest amount of freshwater availability, whereas the central and northern regions (Orange Walk and Corozal) both have much larger populations and much less water resources (CARIBSAVE, 2012).

Several Cayes have become popular tourist destinations but have low availabilities of freshwater. In particular, Caye Caulker is vulnerable to contamination of its underground water through poor sewer construction and intrusion of salt water into aquifers. It has also been noted that there has been changes in precipitation and that this has led to severe droughts that have affected many parts of the country (CARIBSAVE, 2012).

In Belize, the distribution of all wells that have been drilled or dug out by hand is unknown. There is a lack of coordination between the BWS and the local village water boards, of which there approximately 90 and thus no concrete number exists. Under the village board, the households are usually charged a flat rate per month as these are not often metered. Where there is no access to piped water service, or no local provider, then the water is accessed using hand pumps (CARIBSAVE, 2012).

There is no fully operational central administration for water resources management and because of this main issue, financial resources for water management have been minimal and have been focused on the delivery end primarily for residential/domestic use (CARIBSAVE, 2012).

The lack of information regarding groundwater, especially in northern Belize, where karstic conditions may promote the leaching of solutes and salinization, leads to a difficulty in the management of future water resources under climate change and increases the vulnerability of communities. The government could also develop pilot projects to assess artificial recharge of aquifers and conduct feasibility studies explore the possibility of additional projects. The development of mechanisms to facilitate Integrated Water Resources Management (IWRM) should be considered. Such an approach allows an equitable management of water resources, which will be particularly important with declining water resources under climate change (CARIBSAVE, 2012).

Belize consumed around 579 Million m^3 (15.3 billion gallons) of water in 2007 Belize Enterprise for Sustainable Technology (BEST) (2009). The demand for fresh water resources in Belize emanates from three (3) broad economic sub-sectors: agricultural, industrial and domestic/residential. In 2005 agriculture, industrial and domestic /residential users required 43.7%, 36.5% and 19.7% respectively of the total demand (Belize Enterprise for Sustainable Technology (BEST) (2009) (Table 4.14 and Figure 4.22).

With a growing population and economy, this will lead to a greater competition for amongst key sectors, namely agriculture, industry and domestic/residential (including tourism) for increasingly lesser and lesser water supplies.

Table 4.14: Water demand by economic sectors (2005)

Economic Sub-Sector	Demand (%)
Agriculture	43.7
Industrial	36.5
Domestic/Residential Including Tourism	19.7

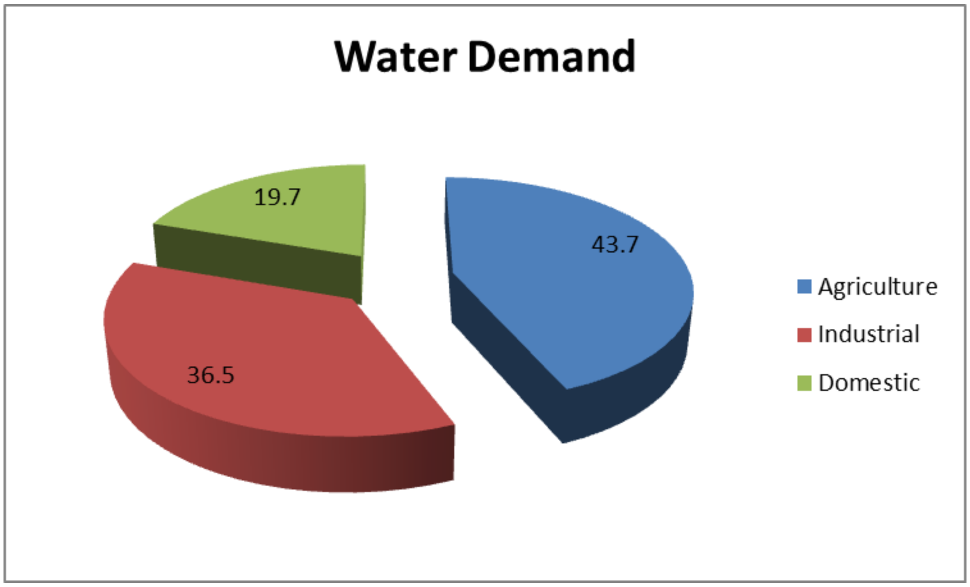

Figure 4.22: Water demand by economic sectors (2007)

7.1 Agriculture

The economic effects of climate variability and extremes on agriculture are already noticeable as seen in recent incidents of flooding and drought (Belize Enterprise for Sustainable Technology (BEST: 2008, 2009). Decreasing rainfall amounts and increased variability of rainfall will make it more difficult to plan for agricultural production. Furthermore, increasing temperatures and lesser and more variable rainfall will lead to yield losses for major crops such as sugarcane, rice bananas, citrus and beans (See Agriculture Section).

7.2 Hydroelectric Power Generation

Belize has three hydropower sites: Mollejon (dam), Chalillo and Hydro Maya (run of the river) which supply the nation with 25 MW, 7 MW and 0.50 MW of hydroelectricity, respectively. There is also a small scale power plant at Blue Creek on the Rio Hondo which provides 15KW of power to the Mennonite community. Belize Electricity Limited generates the remainder of electricity for the country from diesel-burning thermal plants (Belize Enterprise for Sustainable Technology (BEST): 2008, 2009).

Hydropower generation utilizes high volumes of water. Therefore, any significant change in the hydrological cycle will affect hydropower facilities. A decrease in the river levels during the dry season would have significant adverse effects to the power generating plants and will, therefore, threaten the reliability and security of Belize's electric supply. Falling rivers levels will affect water intake and availability of water in the reservoirs. River flow would be further reduced if agriculture and potable water demands were given higher priority. Consequently, water replenishment rates may not keep up with rates of desired usage. This will cause hydroelectric dams to be less efficient leading to higher costs of electricity as the country becomes increasingly reliant on fossil fuels (Belize Enterprise for Sustainable Technology (BEST): 2008, 2009).

8.0 Adaptation Strategy and Action Plan

The impacts of Climate Change on the water resources of the Belize are outlined in the National Adaptation Strategy and Action Plan (Belize Enterprise for Sustainable Technology (BEST): 2008, 2009) so as to ensure that Belize has the capacity to conserve and efficiently use this most critical resource. The strategy and Action Plan are guided by the principles inherent in Integrated Water Resources Management (IWRM). Belize has a particular water security concern because the potable water supply for more than fifty percent of the population originates in neighboring countries (Belize Enterprise for Sustainable Technology (BEST): 2008, 2009).

Water can become a scarce especially in localized areas. Scarcity of this resource will lead to conflict. The nature of conflict will have to be understood and appropriate conflict resolution mechanisms put into place. Communication with stakeholders is required from the outset for those sub-sectors of the economy that are directly affected such as: food producers and processors, manufacturers, the Belizean people and their visitors.

Although there are various water management institutions in existence, the country however lacks the complete range and integrated responses required for adaptation to climate change.

But the following recommendations can be made in regards to adapting to climate change, by enabling and enacting measures aimed at a more rational and efficient use of water resources (Belize Enterprise for Sustainable Technology (BEST): 2008, 2009).

8.1 Water Conservancy Management Systems and Protection of Watersheds

Water Conservancy Management Systems and Protection of Watersheds should take into consideration:

- Enhance the protection and restoration of ecosystems;
- Adopt forest management plans to prevent and control soil erosion;
- Encourage water harvesting;
- Protection of the water environment, preventing and controlling water pollution;
- Raising awareness to promote the effective and efficient use of water.

8.2 Efficient Use of Water in Agriculture

The Banana Industry relies heavily on surface water for the irrigation of its plantation and processing. Likewise the aquaculture industry uses surface water for their ponds and processing.

To minimize costs and to conserve water, farmers should (Belize Enterprise for Sustainable Technology (BEST): 2008, 2009):

- Develop drip and sprinkle irrigation practices to increase water efficiency;
- Improve management practices;
- Select and cultivate stress-resistant varieties.

Furthermore, in order reduce excess soil water under increased precipitation, the following options can be implemented:

- Improve drainage infrastructure as well as improved harvesting practices to maintain quality of crop;
- New cultivars with higher resistance to soil anaerbiosis would be suitable;
- Enhance national capacity to test new cultivars and to conduct genetic improvement;
- Change management practices such as planting dates to compensate for crop cycle modifications;
- Use of technology to enhance management practices to improve crop yield;
- Research pest/disease resistant crop varieties.

8.3 Hydroelectricity

As for hydroelectricity, the following adaptation measures are proposed:

- Improve hydrology and meteorology observation network and data collection;
- Improve flood and drought forecasting;
- Promote energy efficiency;
- Promote alternative sources of energy.

9.0 Conclusion

The impacts of Climate Change show that there are going to be challenges to Belize's capacity to respond. Climate Change is already upon us and Belize must be prepared to adapt to this challenge. A priority then would be the further development of the Water Sector Adaptation Strategy to Climate Change in the Water Sector of Belize (Belize Enterprise for Sustainable Technology (BEST): 2008, 2009).

The Strategy and Action Plan (SAP) points to critical areas in need of further development and strengthening. These areas have to be pursued if the country is to sustain its abundant supply and preserve a sufficiently high quality of water for all users (Belize Enterprise for Sustainable Technology (BEST: 2008, 2009).

The implementation of the Strategy and Action Plan (SAP) will require a concerted effort by all the stakeholders from both the private and public sectors. It will also require effective trans-boundary cooperation between Belize and Guatemala, to the west and Mexico to the north. Similarly, the financing of the Strategy and Action Plan (SAP) will require the mobilization of national, bilateral and international resources (Belize Enterprise for Sustainable Technology (BEST): 2008, 2009).

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Section 5: Agriculture Sector

1.0 Introduction

Agriculture is very important for the economy of Belize. In earlier years agriculture was the primary sector, and contributed substantially to the growth of Gross Domestic Product (GDP). For instance, in 2007, Agriculture and Forestry contributed 9.1 % to the GDO of Belize (GEO Belize, 2010). In recent years this has changed, but the sector is still important because of its export earnings and the employment it creates for a large percentage of the population in rural Belize (Environmental Statistics for Belize (2012).

Economic performance in the agriculture sector is primarily dependent on traditional export crops such as sugar, citrus and banana which currently account for about 60% of the earnings with citrus exports being the principal source of income followed by sugar and banana. Rice, corn and beans are the main domestic food crops.

It is expected that climate change would have severe impacts on the agriculture sector of Belize.

Current climate changes are already affecting the agriculture sector: variability of yields/harvests for rainfed agriculture is already suffering from changes in the timing and amounts of rainfall and there is widespread perturbation of the agricultural calendar. Intense rainfalls are causing problems of soil drainage and erosion and warmer temperatures are leading to the increased incidence of yield-reducing weeds, pests and diseases.

Future climate changes would very likely exacerbate these conditions. Climate change is expected to be accompanied by increasing water deficits and moisture stress, increased practice of irrigation and increased use of chemicals and fertilizers, changes in the choice and mix of crops/cultivars, all of which would definitely increase the costs of agricultural production and threaten overall food security in Belize (IPCC, 2007).

Previous studies have shown that climate change may lead to yield reductions of sugarcane, citrus (Belize Second National Communication: 2012)

But apart from climate, non- climate factors also need to be considered. For instance, the sugar sector in Belize suffers from a lack of investment and the need for modernization at the farm, processing and transport levels. Also, the costs of producing sugar cane are steadily increasing because of poor or non-existent farm drainage systems, lack of modern plant types and harvesting machinery, and badly-maintained roads that at times of heavy rains and floods prevent collection trucks reaching farms. After harvest, sugar cane is transported to the Belize Sugar Industry (BSI) mill by trucks owned or hired by the farmers. A lack of coordination meant that large numbers of trucks converged on the mill creating lengthy queues which had a detrimental effect on the quality of the cane and thereby the ability of the mill to produce high quality sugar.

The global sugar market has also been heavily distorted by a complex combination of international trade agreements. Since 1968, as part of its Common Agricultural Policy (CAP), the European Union (EU) operated a system of high internal prices and export subsidies for its domestic sugar beet producers and import tariffs to limit competition, with the aim of protecting domestic producers and supplying the EU market from its own production. This policy, called Common Market Organization (CMO), led to overproduction, dumping of excess sugar onto world markets and depression of global sugar prices.

2.0 Methodology

For the agriculture sector, we at first examine the vulnerabilities of the agriculture sector to current climate conditions through a review of existing documents (IPCC, 2007; GEO Belize (2010); Environmental Statistics for Belize (2012) and Belize Second National Communication to the Conference of the Parties of the United Nations Framework Convention on Climate Change and through focus group meetings with technical experts in the Ministry of Agriculture and Famers Associations. We also examine and attempt to correlate changing yields of the major crops, namely, sugarcane, rice and beans using the DSSAT (Decision Support System for Agrotechnology Transfer) (Hoogenboom et al., 2010; Jones et al., 2010) crop model, and possible impacts of water shortages on citrus and bananas using the CROPWAT model (FAO, 2013) and trends from the literature on climate and non-climate factors.

During discussions with the relevant stakeholders (Ministry of Natural Resources and Agriculture: September - October, 2013), it was agreed that for the crop simulations with DSSAT the following stations were recommended for the crops in question:

Sugarcane: Richmond Hill or Tower Hill in Orange Walk District;
Rice: Blue Creek or Richmond Hill in Orange Walk District;
Citrus: Melinda Forest Station in Stann Creek District;
Banana: Maya King or Cow Pen in Stann Creek District;
RK Beans: Central Farm in Cayo District.

We then address how future climate change may affect future crop yields, through the influence of erratic weather and lack of water for unirrigated fields, irrigation requirements and the choice and mix of crops and cultivars most suited to the changed future climate data presented in section 2. This again was done through simulating future yield changes of the major crops based on downscaled A-OGCM (ECHAM5 and HadCM3Q11) daily climate data coupled with a crop model (DSSAT).

In order to evaluate crop yield changes caused by climate change we compared crop yield simulations for a current (2003-2012) decadal period to crop yield simulations for a future (2061-2070) decadal period.

3.0 Simulation of Sugarcane Yield Changes

This section examines the changes in sugarcane yields between the current decadal period (2000-2009) and the future (2060-2069). The current decadal period was selected based on data availability. The site selected for the case study is the SIRDI (Sugar Industry Research and Development Institute), Orange Walk Town and the station data used for the current observed climate was Tower Hill.

The current planting date of sugarcane (Barbados - B79474 variety: 65 % of all varieties) is June June-July and current harvest date is 11 months after (May-June of following year). But yields are low and sucrose content is low (15-16 months needed for maximum yields); the B52298 variety is susceptible to disease. Also, under the old planting-harvest cycle, harvest takes place in the rainy season, namely June to August, and flooding of the roadways can seriously affect the transport of cane from fields to factory: the Riohond River on the Mexican border causes severe floods every 3 to 5 years. Early maturing varieties planted in October-November (BBZ80240) take 14-15 months to reach maximum yields, while the CD7121312 takes 15-16 months to reach maximum yields in Belize. SRDI recommendation to farmers is to plant early maturing varieties (BBZ80240 and CD7121312) in October-November and harvest 15-16 months later, namely January-March of following year) (Personal Communication: Mr. Saul Osorio - Field Supervisor: SIRDI (Sugar Industry Research and Development Institute), Orange Walk Town).

According to SRDI, 30 % of farmers are already following this new schedule and this will be the major planting-harvest cycle in the future. Under this new planting regime, yields are 15 to 20 tons per acre, if harvest is after 12 months and yields are 25 tons per acre, if harvest is after 15-16 months later. Row spacing under the old planting regime is 6 feet. But under the new planting regime new regime it is reduced to 5feet so as to gain economy of land and greater yield per acre. Ratoon cane is maintained for 10 to 12 years before a new crop is planted and harvest is 12 months after the first harvest. Since sugarcane is rainfed, climate has a significant influence on crop production: weather is becoming more and more unpredictable and this affects the planting-harvest cycle. Pests, mainly the froghopper, cause yield reductions of ~ 30 % industry-wide. Diseases such as smut cause minimal losses and are now remedied and under control (Personal Communication: Mr. Saul Osorio - Field Supervisor: SIRDI (Sugar Industry Research and Development Institute), Orange Walk Town).

In the DSSAT simulations of annual sugarcane yields we used the following planting-harvest cycle. For the first year of crop production the sugarcane stalks were planted in October-November and harvested 15 to 16 months later, namely in January-March of the following year. For the second and following 10 to 12 years, the ratoon system, where the plant is considered as perennial, is used and the sugarcane is harvested 12 months later, namely in January-March. The sub-model used is CANEGROW within DSSAT. The sugarcane crop is treated as rainfed, namely no irrigation. The row spacing used is 5 feet. The CO_2 fertilisation effect is held constant at 380 ppm. The addition of nutrients and the effects of pests and diseases are not included in the crop simulations. The choice of cultivar is selected from within the DSSAT library and corresponds to the one closest to the varieties used under the new planting-harvest cycle

(BBZ80240 and CD7121312) (Personal Communication: Mr. Saul Osorio - Field Supervisor: SIRDI (Sugar Industry Research and Development Institute), Orange Walk Town).

3.1 DSSAT-CANEGROW Simulations vs Observed Data

At first, simulated data using ECHAM5 and HadCM3Q11 climate model data coupled with the DSSAT-CANEGROW crop model is compared with observed sugarcane production data, both as aerial biomass sucrose mass, for the Orange Walk District in the vicinity of the Tower Hill station for the current period, namely 2000-2009 (Table 5.1 and Figure 5.1).

Table 5.1 shows that both yearly (1-10: 2000-2010) and mean values of simulated (ECHAM5 and HadCM3Q11) values of aerial dry biomass of sugarcane harvested (t/ha) matches very closely with aerial dry biomass of sugarcane harvested calculated in DSSAT with observed data for Tower Hill station (t/ha).

In fact, Mean and Standard Deviation (σ) statistics bear out these relationships. Mean observed (50 t/ha) aerial biomass harvested is very close to the DSSAT-CANEGROW/ECHAM5 (52.6 t/ha) and to the DSSAT-CANEGROW/HadCM3Q11 (49.0 t/ha) aerial dry biomass harvested (Table 5.1 and Figure 5.1).

Table 5.1: DSSAT-CANEGROW simulation of aerial dry biomass at harvest (t/ha) for sugarcane production in Orange Walk District with observed (Tower Hill station) and modeled (ECHAM5 and HadCM3Q11) climatic data: 2000-2009.

Year	Observed	ECHAM5	HadCM3Q11
1	52.2	48.6	40.1
2	55.3	51.7	53.9
3	52.4	53.7	53.2
4	51.3	58.8	45.2
5	46.7	47.7	50.7
6	45.8	51.2	47.1
7	45.8	54.8	53.2
8	49.6	57.8	48.2
9	51.0	50.3	46.2
10	50.1	51.4	51.7
Mean	**50.0**	**52.6**	**49.0**
σ	**3.0**	**3.5**	**4.2**

Similarly, Table 5.2 that presents data on sucrose dry mass (sugar) production, also shows that both yearly (1-10: 2000-2010) and mean values of simulated (ECHAM5 and HadCM3Q11) values of sucrose dry mass of sugarcane harvested (t/ha) matches very closely with sucrose dry mass of sugarcane harvested calculated in DSSAT with observed data for Tower Hill station (t/ha) (Table 5.2 and Figure 5.1).

Moreover, Mean and Standard Deviation (σ) statistics again bear out these relationships. Mean observed (11.8 t/ha) sucrose dry mass harvested is very close to the DSSAT-CANEGROW/ECHAM5 (12.8 t/ha) and to the DSSAT-CANEGROW/HadCM3Q11 (11.9 t/ha) sucrose dry mass harvested (Table 5.2 and Figure 5.1).

Both these sets of results on aerial biomass harvested (Table 1 and Figure 1) and sucrose dry mass harvested (Table 5.2 and Figure 5.1) demonstrate that both the DSSAT-CANEGROW/ECHAM and the DSSAT-CANEGROW/HadCM3Q11 simulations are then suitable for evaluating changes in aerial biomass and sucrose dry mass of sugarcane harvested in response to changes in climate, namely air temperature, rainfall and solar radiation.

Table 5.2: DSSAT-CANEGROW simulation of sucrose dry mass at harvest (t/ha) for sugarcane production in Orange Walk District with observed (Tower Hill station) and modeled (ECHAM5 and HadCM3Q11) climatic data: 2000-2009.

Year	Observed	ECHAM5	HadCM3Q11
1	11.7	12.3	9.4
2	13.8	11.7	13.6
3	12.7	11.6	11.7
4	11.9	14.5	11.8
5	11.6	12.6	12.9
6	10.7	12.5	12.5
7	9.5	14.4	12.0
8	12.3	14.4	12.3
9	12.4	12.8	11.9
10	11.7	11.1	10.7
Mean	**11.8**	**12.8**	**11.9**
σ	**1.1**	**1.2**	**1.1**

3.2 DSSAT-CANEGROW Simulations of Sugarcane Yield Changes

At first, when examining the changes in aerial dry biomass of sugarcane harvested by comparing dry biomass yields (t/ha) for the current decadal period (2000-2009) with dry biomass yields (t/ha) for the future decadal period (2060-2069) for sugarcane production in the Orange Walk District in the vicinity of the Tower Hill, it is evident that according to the ECHAM5 model the sugarcane yields expressed as aerial dry biomass harvested, will be lower or the future (2060-2069) decadal period. According to the ECHAM 5 model, the mean sugarcane yields expressed as aerial dry biomass harvested, are projected to drop from 52.6 t/ha (2000-2009) to 45.9 t/ha (2060-2069), a mean decrease in sugarcane yield, expressed as aerial dry biomass harvested, of -12.7 % (Table 5.3 and Figure 5.1).

Moreover, according to the ECHAM5 model, future (2060-2069) interannual yields of sugarcane expressed as aerial dry biomass harvested, will decrease by between -1.5 % (year 7: 2066) and –37 % (year 3: 2062), except for year 9 (2068) when yields will increase slightly (0.3 %) (Table 5.3 and Figure 5.1).

Table 5.3: DSSAT-CANEGROW simulation of aerial dry biomass at harvest (t/ha) for sugarcane production, Tower Hill station with climatic data of ECHAM5 model.

Year	2000-2009	2060-2069	Δ (%)
1	48.6	45.8	-5.8
2	51.7	50.8	-1.8
3	53.7	33.8	-37.0
4	58.8	49.7	-15.5
5	47.7	42.4	-11.2
6	51.2	46.1	-9.9
7	54.8	54.0	-1.5
8	57.8	44.5	-22.9
9	50.3	50.4	0.3
10	51.4	41.7	-18.9
Mean	**52.6**	**45.9**	**-12.7**
σ	**3.5**	**5.5**	**11.0**

Similarly, when examining the changes in aerial dry biomass of sugarcane harvested by comparing dry biomass yields (t/ha) for the current decadal period (2000-2009) with dry biomass yields (t/ha) for the future decadal period (2060-2069) for sugarcane production in the Orange Walk District in the vicinity of the Tower Hill, it is evident that according to the HadCM3Q11model the sugarcane yields expressed as aerial dry biomass harvested, will again be lower or the future (2060-2069) decadal period. According to the HadCM3Q11 model, the mean sugarcane yields expressed as aerial dry biomass harvested are projected to drop from 49.0 t/ha (2000-2009) to 38.7 t/ha (2060-2069), a mean decrease in sugarcane yield, expressed as aerial dry biomass harvested, of -14.7 % (Table 5.4 and Figure 5.1).

Also, according to the HadCM3 Q11model, future (2060-2069) interannual yields of sugarcane expressed as aerial dry biomass harvested will decrease by between -2.2 % (year 5: 2064) and – 35.4 % (year 4: 2063), except for year 1 (2060) when yields will increase (12.3 %) (Table 5.4 and Figure 5.1)

Table 5.4: DSSAT-CANEGROW simulation of aerial dry biomass at harvest (t/ha) for sugarcane production, Tower Hill station with climatic data of HadCM3Q11 model

Year	**2000-2009**	**2060-2069**	**Δ (%)**
1	40.1	45.0	12.3
2	53.9	46.7	-13.5
3	53.2	37.7	-29.2
4	45.2	29.2	-35.4
5	50.7	49.6	-2.2
6	47.1	36.1	-23.4
7	53.2	40.7	-23.5
8	48.2	31.8	-34.0
9	46.2	36.5	-20.9
10	51.7	33.8	-34.5
Mean	**49.0**	**38.7**	**-20.9**
σ	**4.2**	**6.3**	**14.7**

In essence then, both the ECHAM5 and HadCM3Q11 climate models data coupled with the DSSAT-CANEGROW crop model show that sugarcane yields, expressed as aerial biomass harvested (t/ha), will decrease in the future (2060-2069) when compared to the current period (2000-2009 in the Orange Walk District in the vicinity of the Tower Hill station. Furthermore, the overall decrease of sugarcane yields, expressed as aerial biomass harvested is greater for the HadCM3Q11 model compared to the ECHAM5 model (Figure 5.1).

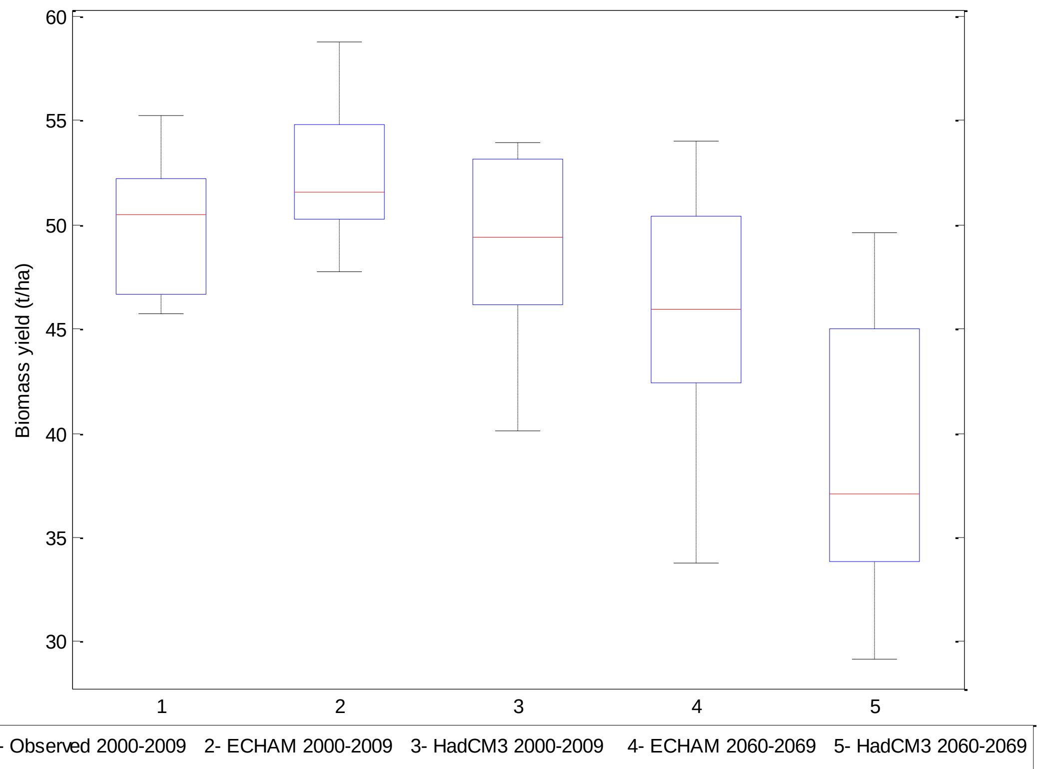

Figure 5.1: DSSAT-CANEGROW simulation of aerial dry biomass at harvest (t/ha) for sugarcane production, Tower Hill station with observed and modeled climatic data.

When examining the changes in sucrose dry mass (sugar) of sugarcane harvested by comparing sucrose dry mass yields (t/ha) for the current decadal period (2000-2009) with sucrose dry mass yields (t/ha) for the future decadal period (2060-2069) for sugarcane production in the Orange Walk District in the vicinity of the Tower Hill, it is evident that according to the ECHAM5 model the sugarcane yields expressed as sucrose dry mass harvested, will be lower or the future (2060-2069) decadal period. According to the ECHAM5 model, the mean sugarcane yields expressed as sucrose dry mass harvested, are projected to drop from 12.8 t/ha (2000-2009) to 10.0 t/ha (2060-2069), a mean decrease in sugarcane yield, expressed as sucrose dry mass harvested, of -16.9 % (Table 5.5 and Figure 5.2).

Furthermore, according to the ECHAM 5 model, future (2060-2069) interannual yields of sugarcane expressed as sucrose dry mass harvested, will decrease by between -5.9 % (year 1: 2060) and – 60.1% (year 3: 2062), except for year 2 (2061) when yields will increase slightly (5.2 %) (Table 5.5 and Figure 5.2).

Table 5.5: DSSAT-CANEGROW simulation of sucrose dry mass at harvest (t/ha) for sugarcane production, Tower Hill station with climatic data of ECHAM model

Year	2000-2009	2060-2069	Δ (%)
1	12.3	11.6	-5.9
2	11.7	12.4	5.2
3	11.6	4.6	-60.1
4	14.5	12.3	-15.4
5	12.6	9.2	-26.7
6	12.5	10.1	-19.5
7	14.4	9.3	-35.3
8	14.4	11.4	-21.3
9	12.8	9.5	-26.2
10	11.1	9.9	-10.7
Mean	**12.8**	**10.0**	**-21.7**
σ	**1.2**	**2.1**	**16.9**

Next, when examining the changes in sucrose dry mass (sugar) of sugarcane harvested by comparing sucrose dry mass yields (t/ha) for the current decadal period (2000-2009) with sucrose dry mass yields (t/ha) for the future decadal period (2060-2069) for sugarcane production in the Orange Walk District in the vicinity of the Tower Hill, it is evident that according to the HadCM3Q11 model the sugarcane yields expressed as sucrose dry mass harvested, will be lower or the future (2060-2069) decadal period. According to the HadCM3Q11 model, the mean sugarcane yields expressed as sucrose dry mass harvested, are projected to drop from 11.9 t/ha (2000-2009) to 8.5 t/ha (2060-2069), a mean decrease in sugarcane yield, expressed as sucrose dry mass harvested, of -28.2 % (Table 5.6 and Figure 5.2).

Also, according to the HadCM3Q11 model, future (2060-2069) interannual yields of sugarcane expressed as sucrose dry mass harvested, will decrease by between -4.7 % (year 1: 2060) and –51.1% (year 4: 2063) (Table 5.5 and Figure 5.2).

Table 5.6: DSSAT - CANEGROW simulation of sucrose dry mass at harvest (t/ha) for sugarcane production, Tower Hill station with climatic data of HadCM3Q11 model

Year	2000-2009	2060-2069	Δ (%)
1	9.4	8.9	-4.7
2	13.6	11.1	-19.0
3	11.7	9.2	-21.8
4	11.8	5.8	-51.1
5	12.9	11.9	-7.6
6	12.5	7.7	-38.5
7	12.0	9.2	-23.1
8	12.3	7.0	-43.0
9	11.9	8.8	-26.0
10	10.7	5.7	-46.5
Mean	**11.9**	**8.5**	**-28.2**
σ	**1.1**	**1.9**	**15.2**

It is again apparent that both the ECHAM5 and HadCM3Q11 climate models data coupled with the DSSAT-CANEGROW crop model show that sugarcane yields, expressed as sucrose dry mass harvested (t/ha), will decrease in the future (2060-2069) when compared to the current period (2000-2009 in the Orange Walk District in the vicinity of the Tower Hill station. Furthermore, the overall decrease of sugarcane yields, expressed as sucrose dry mass harvested, is greater for the HadCM3Q11 model compared to the ECHAM5 model (Figure 5.2).

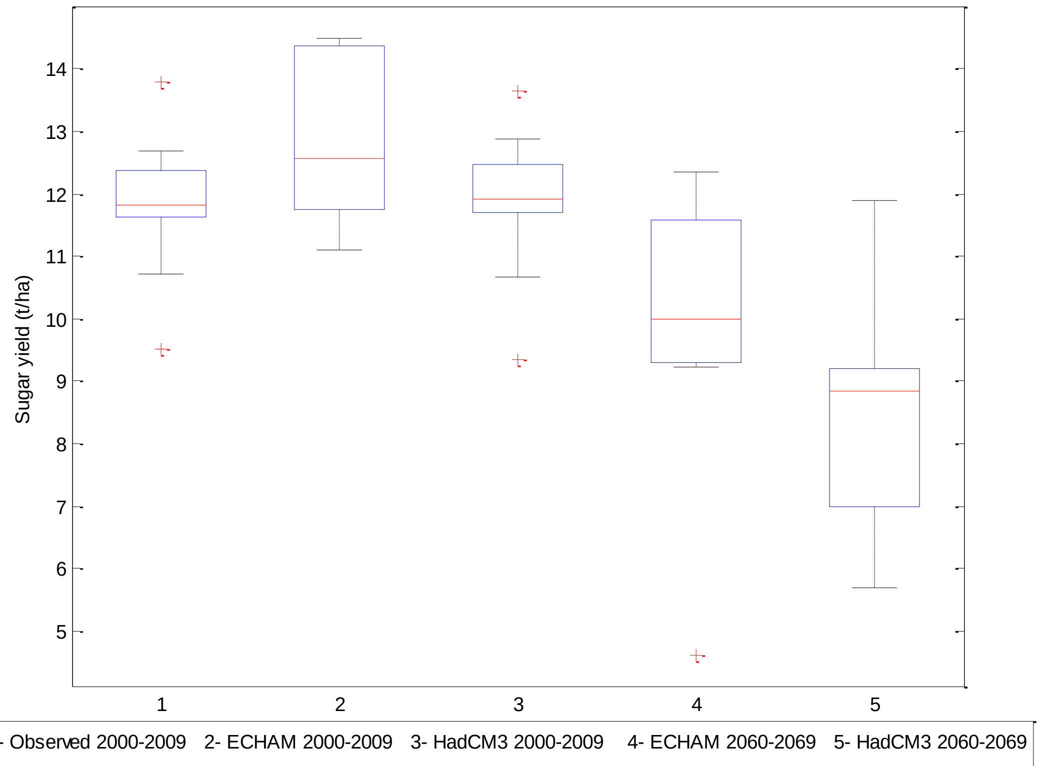

Figure 5.2: DSSAT- CANEGROW simulation of sucrose dry mass at harvest (t/ha) for sugarcane production, Tower Hill station with observed and modeled climatic data.

These future (2040-2069) yield changes in sugarcane aerial biomass and sucrose are most likely due to changes in the amount and timing of rainfall, increasing moisture stress due to the warmer temperatures due to higher evaporation rates and the change in the optimal temperature required for these varieties of sugarcane. The optimal temperature for sugarcane production in northern Belize is ~ 32.5 ^{0}C. But in the future (2060-2069) temperatures are expected to rise to ~ 34.3 ^{0}C (Ramirez et al. 2013). At higher temperatures reversion of sucrose into fructose and glucose may occur besides enhancement of photorespiration thus leading to less accumulation of sugars (Singh and El Maayar, 1998; Meyer et al., 2011).

On the other hand flooding of sugarcane fields in Orange Walk District caused by the Riohond River on the Mexican border is a common problem (see Figure 5.3). It is believed that sugarcane yields in this region can be increased by up to 40 % with proper drainage (Personal

Communication: Dr Anil K. Sinha: Caribbean Agricultural Research and Development Institute, Central Farm, Cayo District, February, 2014).

Figure 5.3: Flooding of sugarcane fields in northern Orange Walk District caused by the Riohond River on the Mexican border

4.0 Simulation of Rice Yield Changes

This section examines the changes in upland and irrigated rice yields between the current decadal period (2000-2009) and the future (2060-2069). The current decadal period was selected based on data availability. The site selected for the case study is the Blue Creek valley in Orange Walk District, the main rice-producing region in Belize. The station data used for the current observed climate was Tower Hill in Orange Walk District. Other rice farms can be found at Little Belize in Corozal District, Shipyard and Hillbank in Orange Walk District, Spanish Lookout in Cayo District, and in several locations in Toledo District.

Rice production in Blue Creek comes in two varieties: 1) upland farming (rainfed), where the regular fields are planted at the beginning of the rainy season around June-July and are harvested in September-October; and 2) irrigated rice farming, practiced mostly in lower-lying areas and are planted in December-January and harvested in April-May.

The upland farmers comprise about 66% of the total rice acreage in Blue Creek (Amandala Newspaper, Sunday October 13, 2013). Extended periods of no rainfall in the wet season are a major problem. On the other hand, extensive flooding from major hurricanes crossing the area can also be problematic, but rice seems to handle this better than other crops. But Circle R, a private company run by Mennonites and one of the largest rice farms in Blue River plants ~ 2,000 acres of irrigated rice, drawing water from the Rio Bravo River and ~ 1,500 acres of non-irrigated rice and supplies ~ 60 % of rice consumption for all of Belize. Yields of Irrigated rice are normally 4,500 to 5,000 pounds per acre, whereas yields of Rainfed rice are normally 3,000 to 3,500 pounds per acre (Jacob Neufeld of Circle R Mills: Personal Conversation).

Rice cultivation for both upland and irrigated rice is mechanical. Rice seeds are planted using drill planters at a seeding depth of 2-5cm and that have row spacings of 7.5 inches or 8 inches (Varieties: 150 to 250 plants/square meter, Hybrids: 60 to 100 plants /square meter). In case of lots of rain, seeds are flown on by plane with a fertilizer spreader, but it has a lower in efficiency. Since the 1980s about 25 farmers are involved in rice production in Blue Creek. Farmers in Blue Creek have historically planted the variety, Cypress, due to its superior grain characteristics. But in recent years, due to increasing disease pressure, they have imported the variety Cheniere from Louisiana which has better resistance to blast a disease which requires less fungicide to control diseases. Farmers in Blue Creek are growing more and more hybrids the past 2 years with RiceTec products, XL753, XL723 and Clearfield XL745 making up the majority of the acres. The cultivar used was the IR43 variety in DSSAT-CERES-RICE which most closely matched the varieties used in Blue Creek (Robert Miller, RiceTec, Texas, USA: Personal Communication).

Diseases are a problem in rice production. The main diseases are Spinki mite (an insect) and blast (a fungal disease) that can cause yield losses of up to 20%. The hybrids are more resistant these diseases and require little fungicide is use (Robert Miller, RiceTec, Texas, USA: Personal Communication).

In recent years, government policy aimed at controlling prices, namely crippling taxes on input for rice production, particularly fuel and electricity, have sent the average price of a pound of rice soaring from $0.85/lb. to $1.31 in 2012-2013. This conflict with the Government of Belize has caused one of the major rice growers in Blue River (Peter Dyck Rice Company) to temporarily shut down its operations (Amandala Newspaper, Sunday October 13, 2013).

4.1 DSSAT-CERES-RICE Simulations vs Observed Data

At first, simulated data using ECHAM5 and HadCM3Q11 climate model data coupled with the DSSAT-CERES-RICE crop model is compared with observed rice production data for upland rice for the Blue Creek valley in Orange Walk District in the vicinity of the Tower Hill station for the current period, namely 2000-2009 (Table 5.7 and Figure 5.4).

Table 1 shows that both yearly (1-10: 2000-2010) and mean values of simulated (ECHAM and HadCM3) values of upland rice harvested (t/ha) matches very closely with rice yields calculated in DSSAT with observed data for Tower hill station (t/ha).

Also, very low mean and standard deviation (σ) statistics bear out these relationships. Mean observed yields (11.8 t/ha) of rice harvested is very close to the DSSAT-RICE-CERES/ECHAM5 (11.1 t/ha) and to the DSSAT-CERES-RICE/HadCM3Q11 (11.3 t/ha) simulated rice yields (Table 5.7 and Figure 5.4).

Table 5.7: DSSAT- CERES-RICE simulation of upland rice yield (t/ha) for Blue Creek with observed (Tower Hill station) and modeled (ECHAM5 and HadCMQ11) climatic data: 2000-2009

Year	Observed	ECHAM5	HadCM3Q11
1	10.2	11.9	12.4
2	11.8	7.9	11.6
3	11.2	11.3	11.2
4	12.1	6.6	11.5
5	13.8	13.8	11.5
6	11.2	12.0	12.8
7	10.8	12.1	10.6
8	12.0	11.9	13.4
9	11.9	12.5	6.8
10	12.5	11.4	11.4
Mean	**11.8**	**11.1**	**11.3**
σ	**0.9**	**2.1**	**1.7**

Similarly, Table 5.8 that presents data on irrigated rice yields, also shows that both yearly (1-10: 2000-2010) and mean values of simulated (ECHAM5 and HadCM3Q11) rice yields (t/ha) matches very closely with observed (ECHAM5 and HadCM3Q11) values of rice yields (t/ha) (t/ha) (Table 5.8 and Figure 5.5).

Moreover, very low mean and standard deviation (σ) statistics again bear out these relationships. Mean observed (13.7 t/ha) irrigated rice yields calculated in DSSAT with observed data for Tower Hill station are very close to the DSSAT-CERES-RICE/ECHAM5 (12.8 t/ha) and to the DSSAT-CERES-RICE/HadCM3Q11 (11.5 t/ha) simulated (Table 5.8 and Figure 5.5).

Both these sets of results on upland rice yields (Table 5.7 and Figure 5.4) and irrigated rice yields (Table 5.8 and Figure 5.5) demonstrate that both the DSSAT-CERES-RICE/ECHAM5 and the DSSAT-CERES-RICE/HadCM3Q11 simulations are then suitable for evaluating yield changes in both upland and irrigated rice in response to changes in climate, namely air temperature, rainfall and solar radiation.

Table 5.8: DSSAT- CERES-RICE simulation of irrigated rice yield (t/ha) for Blue Creek with observed (Tower Hill station) and modeled (ECHAM5 and HadCMQ11) climatic data: 2000-2009

Year	Observed	ECHAM	HadCM3Q11
1	13.9	13.0	11.2
2	14.3	12.4	11.3
3	14.7	12.0	12.5
4	13.5	13.6	10.8
5	13.2	12.1	11.2
6	13.2	12.5	12.2
7	13.9	12.7	12.0
8	12.8	14.1	11.8
9	13.2	13.0	11.1
10	13.8	12.2	10.9
Mean	**13.7**	**12.8**	**11.5**
σ	**0.6**	**0.6**	**0.6**

4.2 DSSAT-RICE-CERES Simulations of Rice Yield Changes

This section deals with the simulation of rice yields for both upland and irrigated rice.

4.3 Upland Rice

At first, when examining the changes in rice yields by comparing upland rice yields (t/ha) for the current decadal period (2000-2009) with upland rice yields (t/ha) for the future decadal period (2060-2069) for Blue Creek in Orange Walk District, it is evident that according to the ECHAM5 model, the upland rice yields will be generally lower for the future (2060-2069) decadal period. According to the ECHAM5 model, the mean upland rice yields are projected to drop from 11.1 t/ha (2000-2009) to 7.8 t/ha (2060-2069), a mean decrease in upland rice yield of -30.4 % (Table 5.9 and Figure 5.4).

Moreover, according to the ECHAM5 model, future (2060-2069) interannual yields of upland rice will decrease by between -24.8 % (year 7: 2066) and – 83.3 % (year 1: 2060), except for year 2 (2061: 13.1 %) and year 4 (2063: 39.2 %) when yields are projected to increase (Table 5.9 and Figure 5.4).

Table 5.9: DSSAT - CERES-RICE simulation of upland rice yield (t/ha) for Blue Creek for the current (2000-2009) and future (2060-2069) periods and the differences (%) with climatic data input from the ECHAM5 model

Year	2000-2009	2060-2069	Δ (%)
1	11.9	2.0	-83.3
2	7.9	9.0	13.1
3	11.3	6.5	-42.8
4	6.6	9.1	39.2
5	13.8	10.4	-25.2
6	12.0	8.4	-29.8
7	12.1	9.1	-24.8
8	11.9	5.9	-50.5
9	12.5	9.0	-28.0
10	11.4	8.2	-27.7
Mean	**11.1**	**7.8**	**-30.4**
σ	**2.1**	**2.3**	**31.6**

Similarly, when examining the changes in rice yields by comparing upland rice yields (t/ha) for the current decadal period (2000-2009) with upland rice yields (t/ha) for the future decadal period (2060-2069) for Blue Creek in Orange Walk District, it is evident that according to the

HadCM3Q11 model, the upland rice yields will again be lower for the future (2060-2069) decadal period. According to the HadCM3Q11 model, the mean upland rice yields are projected to drop from 11.3 t/ha (2000-2009) to 5.8 t/ha (2060-2069), a mean decrease in upland rice yield of -49.1 %, a much higher decrease than the ECHAM 5 model (Table 5.10 and Figure 5.4).

Furthermore, according to the HadCM3Q11 model, future (2060-2069) interannual yields of upland rice will decrease by between -12.9 % (year 5: 2064) and – 84.2 % (year 4: 2063) (Table 5.10 and Figure 5.4).

Table 5.10: DSSAT - CERES-RICE simulation of upland rice yield (t/ha) for Blue Creek for the current (2000-2009) and future (2060-2069) periods and the differences (%) with climatic data input from the HadCM3Q11 model

Year	2000-2009	2060-2069	Δ (%)
1	12.4	8.4	-32.1
2	11.6	6.5	-43.9
3	11.2	6.5	-41.9
4	11.5	1.8	-84.2
5	11.5	10.0	-12.9
6	12.8	4.7	-63.2
7	10.6	4.1	-61.1
8	13.4	3.4	-74.7
9	6.8	5.3	-21.2
10	11.4	6.8	-40.2
Mean	**11.3**	**5.8**	**-49.1**
σ	**1.7**	**2.3**	**21.8**

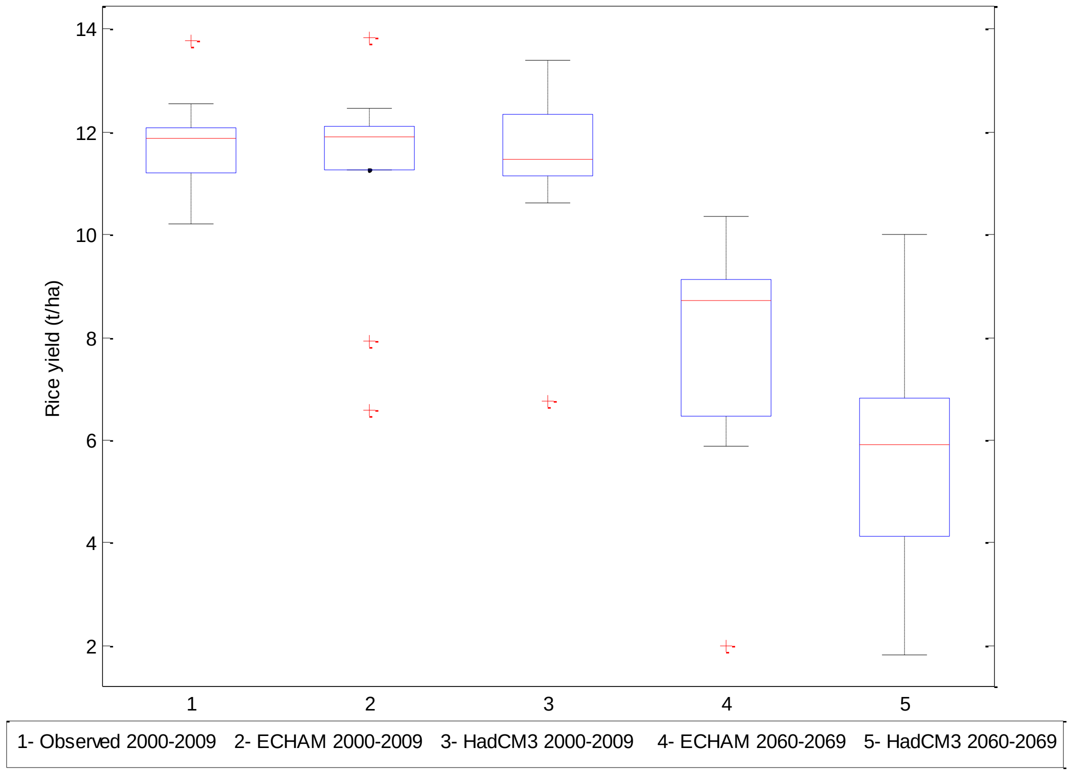

Figure 5.4: DSSAT - CERES-RICE simulation of upland rice yield (t/ha) for Blue Creek for the current observed and modelled (2000-2009) and future modelled (2060-2069) periods with climatic data input from the ECHAM5 and HadCM3Q11 model

4.4 Irrigated Rice

At first, when examining the changes in rice yields by comparing irrigated rice yields (t/ha) for the current decadal period (2000-2009) with irrigated rice yields (t/ha) for the future decadal period (2060-2069) for Blue Creek in Orange Walk District, it is evident that according to the ECHAM5 model, the irrigated rice yields will also be generally lower for the future (2060-2069) decadal period. According to the ECHAM5 model, the mean irrigated rice yields are projected to drop from 12.8 t/ha (2000-2009) to 10.2 t/ha (2060-2069), a mean decrease in irrigated rice yield of -20.4 %, which is less than for upland rice, because irrigation water reduces some of the water stress (Table 5.11 and Figure 5.5).

Moreover, according to the ECHAM5 model, future (2060-2069) interannual yields of upland rice will decrease by between – 10.7 % (year 3: 2062) and – 28.9 % (year 4: 2063) (Table 5.11 and Figure 5.5).

Table 5.11: DSSAT - CERES-RICE simulation of irrigated rice yield (t/ha) for Blue Creek for the current (2000-2009) and future (2060-2069) periods and the differences (%) with climatic data input from the ECHAM5 model

Year	2000-2009	2060-2069	Δ (%)
1	13.0	10.4	-20.2
2	12.4	10.0	-19.7
3	12.0	10.7	-10.7
4	13.6	9.6	-28.9
5	12.1	10.3	-15.3
6	12.5	9.9	-20.9
7	12.7	10.0	-21.0
8	14.1	10.5	-25.6
9	13.0	10.3	-20.6
10	12.2	9.9	-19.3
Mean	**12.8**	**10.2**	**-20.4**
σ	**0.6**	**0.3**	**4.7**

Similarly, when examining the changes in rice yields by comparing irrigated rice yields (t/ha) for the current decadal period (2000-2009) with irrigated rice yields (t/ha) for the future decadal period (2060-2069) for Blue Creek in Orange Walk District, it is also evident that according to the HadCM3Q11 model, the irrigated rice yields will also be generally lower for the future (2060-2069) decadal period. According to the HadCM3Q11 model, the mean irrigated rice yields are projected to drop from 11.5 t/ha (2000-2009) to 9.2 t/ha (2060-2069), a mean decrease in irrigated rice yield of -20.1 %, which again is less than for upland rice, because irrigation water reduces some of the water stress (Table 5.12 and Figure 5.5).

Furthermore, according to the HadCM3Q11 model, future (2060-2069) interannual yields of irrigated rice will decrease by between – 14.4 % (year 1: 2060) and – 25.5 % (year 7: 2066) (Table 5.12 and Figure 5.5).

Table 5.12: DSSAT - CERES-RICE simulation of irrigated rice yield (t/ha) for Blue Creek for the current (2000-2009) and future (2060-2069) periods and the differences (%) with climatic data input from the HadCM3Q11 model

Year	2000-2009	2060-2069	Δ (%)
1	11.2	9.5	-15.4
2	11.3	9.1	-19.1
3	12.5	9.6	-23.1
4	10.8	8.9	-16.8
5	11.2	9.3	-16.9
6	12.2	9.4	-22.8
7	12.0	8.9	-25.5
8	11.8	9.7	-18.4
9	11.1	8.5	-23.2
10	10.9	8.9	-18.7
Mean	**11.5**	**9.2**	**-20.1**
σ	**0.6**	**0.4**	**3.2**

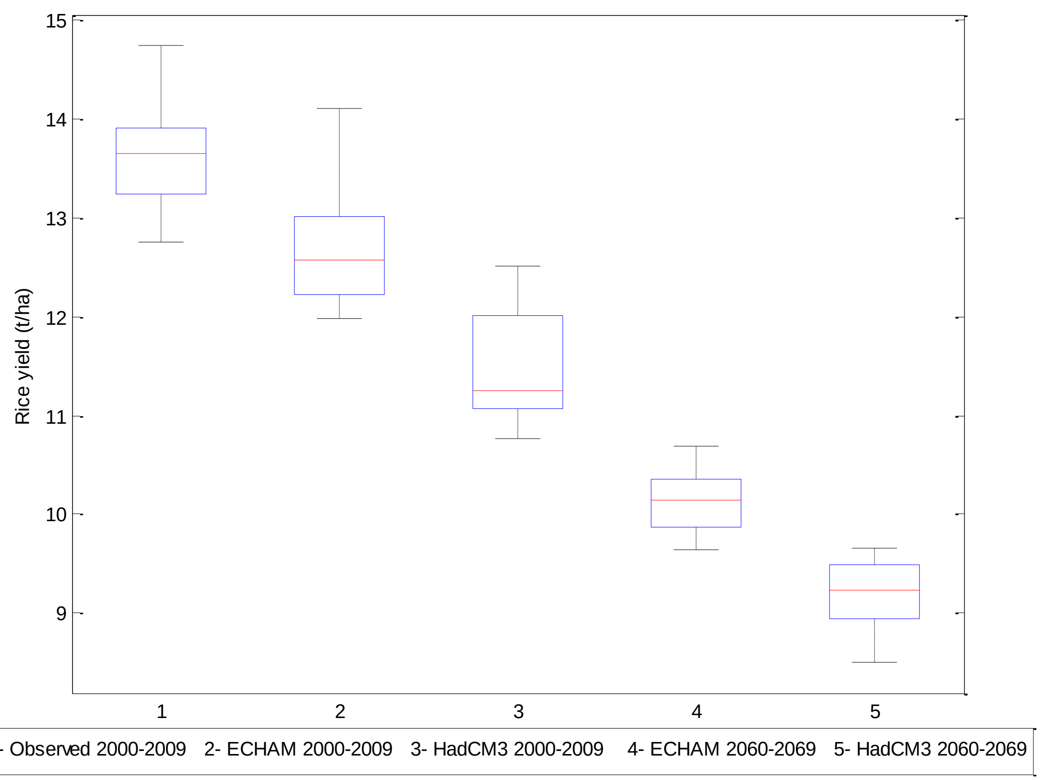

Figure 5.5: DSSAT - CERES-RICE simulation of irrigated rice yield (t/ha) for Blue Creek for the current observed and modelled (2000-2009) and future modelled (2060-2069) periods with climatic data input from the ECHAM5 and HadCM3Q11 model

These future (2060-2069) yield changes in both upland and irrigated rice yields are most likely due to changes in the amount and timing of rainfall, increasing moisture stress due to the warmer temperatures and the change in the optimal temperature required for these varieties of rice. However, as to be expected the yield losses are lower for irrigated rice, but yields also decrease due to less water availability for adequate irrigation. Furthermore, at higher temperatures, the phenological phases are speeded up leading to acceleration in maturation and less grain accumulation during the maturation and grain-filling phases (Singh et al, 1998; Bárcena et al. 2013, Ramirez et al. 2013).

5.0 Simulation of Red Kidney Beans Yield Changes

This section examines the changes Red Kidney (RK) bean yields between the current decadal period (2001-2009) and the future (2060-2069). The current decadal period was selected based on data availability. The site selected for the case study is the Central Farm station Cayo District, one of the main RK bean-producing regions in Belize.

Red Kidney (RK) beans are a staple crop cultivated throughout Belize using both milpa and mechanized farming methods. Approximately 90 % of all RK beans production comes from the Corozal, Orange Walk and Cayo Districts. Belize is self-sufficient in RK beans. In fact, Belize produced 5.53 million pounds of Red Kidney beans in 2008 of which 3.6 million pounds were exported and valued at $3.4 million. Since 1980, production has increased significantly. In recent years production has fluctuated around 800 kg/ha on account of adverse and unpredictable weather conditions and the incidence of diseases such as rust and web blight. There is normally only one production cycle of RK beans in Belize, namely planting in November-December and harvest in February-March (Personal Communication: Dr Anil K. Sinha: Caribbean Agricultural Research and Development Institute, Central Farm, Cayo District, February, 2014). This means that the growing season length, from planting to harvest, is 90 to 100 days (Bárcena et al, 2013).

5.1 DSSAT-CROPGRO Simulations vs Observed Data for RK Beans

At first, simulated data using ECHAM5 and HadCM3Q11 climate model data coupled with the DSSAT-CROPGRO crop model is compared with observed RK bean production data for the an area in the vicinity of Central Farm station in Cayo District for the current period, namely 2000-2009 (Table 5.13 and Figure 5.6).

Table 5.13 shows that both yearly (1-10: 2001-2009) and mean values of simulated (ECHAM5 and HadCM3Q11) yield values of RK bean harvested (t/ha) underestimates RK bean yields calculated in DSSAT with observed climate data for Central Farm station (t/ha). This can be attributed to the fact the ECHAM5 and HadCM3Q11 simulations of the current climate (2000-2009), especially rainfall is lower than the observed values. It can also be due to the fact that the planting-harvest cycle is from November-December to February-March, when yields can be generally lower; this being the dry season and irrigation is not included in the crop simulations.

Also, relatively high mean and standard deviation (σ) statistics bear out these relationships. Mean observed yields (2.0 t/ha) of RK bean harvested is more than double the DSSAT-CROPGRO/ECHAM5 (1.0 t/ha) and the DSSAT-CROPGRO/HadCM3Q11 (0.8 t/ha) simulated RK bean yields (Table5. 13 and Figure 5.6). However, since we are looking at yield changes based on the DSSAT-CROPGRO/ECHAM5 and the DSSAT-CROPGRO/HadCM3Q11simulations this would not affect our assessments of climate change impacts on RK bean yields (Table 5.13 and Figure 5.6).

Table 5.13: DSSAT- CROPGRO simulation of Red Kidney Beans Yields (t/ha) for Cayo District with observed (Central Farm station) and modeled (ECHAM5 and HadCMQ11) climatic data: 2001-2009

Year	Observed	ECHAM5	HadCM3Q11
1	2.0	0.6	0.7
2	2.0	0.8	0.2
3	1.9	1.4	1.5
4	2.1	0.3	0.2
5	2.1	1.8	1.2
6	1.9	0.5	1.7
7	1.9	1.8	0.8
8	2.0	1.4	0.5
9	2.0	0.6	0.0
Mean	**2.0**	**1.0**	**0.8**
σ	**0.1**	**0.5**	**0.6**

5.2 DSSAT-CROPGRO Simulations of RK Bean Yield Changes

At first, when examining the changes in RK bean yields by comparing RK bean yields (t/ha) for the current decadal period (2000-2009) with RK bean yields (t/ha) for the future decadal period (2060-2069) for the Cane Farm area in Cayo District, it is evident that according to the ECHAM5 model, the RK bean yields will fluctuate from year to year for the future (2060-2069) decadal period. According to the ECHAM5 model, the mean RK bean yields are projected to decrease from 2.0 t/ha (2001-2009) to 0.8 t/ha (2060-2069), a mean decrease in RK bean yield of -59.5 % (Table 5.14 and Figure 5.5).

However, according to the ECHAM5 model, future (2060-2069) interannual yields of RK bean will fluctuate between a decrease of -29.0 % (year 3: 2063) and a decrease of -97.5 % (year 9: 2069) (Table 5.14 and Figure 5.5). This fluctuation is very likely due to the interannual fluctuation in rainfall during this planting-harvest cycle (Ramirez et al. 2013).

Table 5.14: DSSAT - CROPGRO simulation of Red Kidney Beans yield (t/ha) for Cayo District (Central Farm station) for the current (2001-2009) and future (2060-2069) periods and the differences (%) with climatic data input from the ECHAM5 model

Year	2001-2009	2061-2069	Δ (%)
1	2.0	1.0	-52.1
2	2.0	1.2	-40.9
3	1.9	1.3	-29.0
4	2.1	1.1	-50.0
5	2.1	1.1	-47.8
6	1.9	1.2	-34.1
7	1.9	0.3	-86.8
8	2.0	0.1	-96.1
9	2.0	0.1	-97.5
Mean	**2.0**	**0.8**	**-59.5**
σ	**0.1**	**0.5**	**25.2**

On the other hand, when examining the changes in RK bean yields by comparing RK bean yields (t/ha) for the current decadal period (2000-2009) with RK bean yields (t/ha) for the future decadal period (2060-2069) for the Central Farm area in Cayo District, it is evident that according to the HadCM3Q11 model, the RK bean yields will also generally decrease for the future (2060-2069) decadal period, except for year 9: 2069- clearly an aberration. Otherwise, according to the HadCM3Q11 model, the mean RK bean yields are projected to decrease from 0.8 t/ha (2000-2009) to 0.1 t/ha (2060-2069), a mean decrease in RK bean yield of - 81.5 % (Table 5.15 and Figure 5.6).

However, according to the HadCM3Q11 model, future (2060-2069) interannual yields of RK bean will decrease in all years of except year 9 (year 9: 2069) when yields are expected to increase by 3970%. But for all other yields RK bean yields are projected to decrease by -75.0 % (year 4: 2063) to – 100.0 % (year 3: 2063) (Table 5.15 and Figure 5.6).

Table 5.15: DSSAT - CROPGRO simulation of Red Kidney Beans yield (t/ha) for Cayo District (Central Farm station) for the current (2000-2009) and future (2060-2069) periods and the differences (%) with climatic data input from the HadCM3Q11 model

Year	2001-2009	2061-2069	Δ (%)
1	0.7	0.0	-94.5
2	0.2	0.0	-87.1
3	1.5	0.0	-100.0
4	0.2	0.1	-75.0
5	1.2	0.3	-78.3
6	1.7	0.3	-84.4
7	0.8	0.1	-87.8
8	0.5	0.1	-78.6
9	0.0	0.4	3970.0
Mean	**0.8**	**0.1**	**-81.5**
σ	**0.6**	**0.1**	**1282.4**

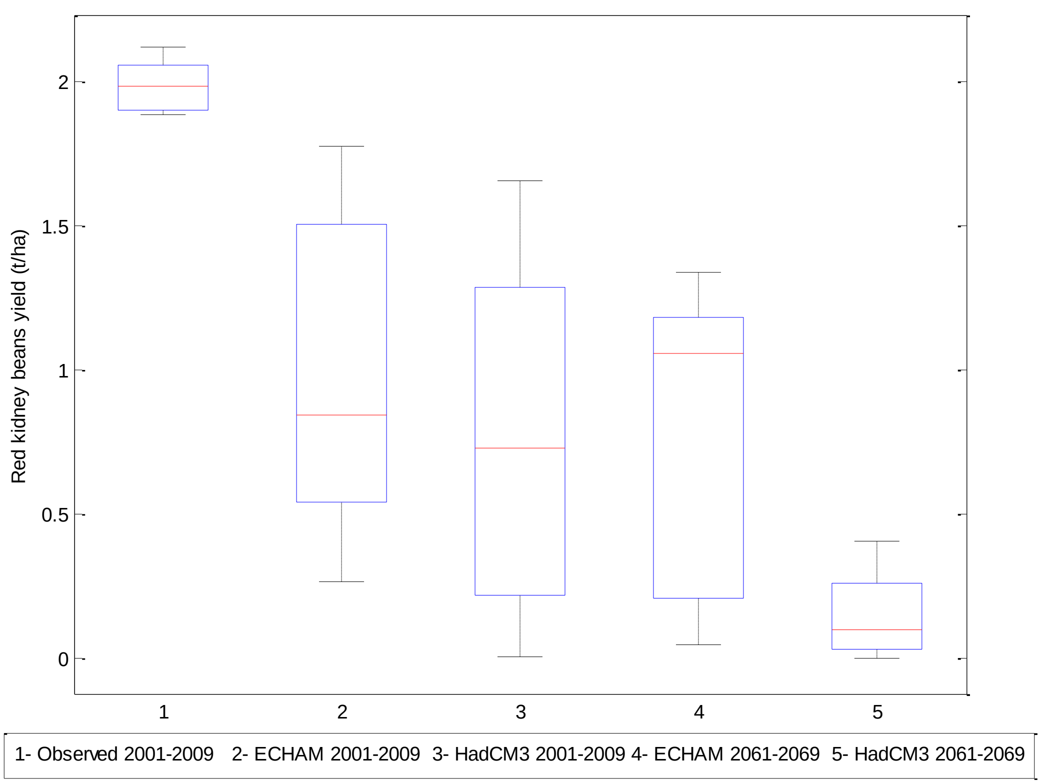

Figure 5.6: DSSAT - CROPGRO simulation of Red Kidney Beans yield (t/ha) for Cayo District (Central Farm station) for the current observed and modelled (2000-2009) and future modelled (2060-2069) periods with climatic data input from the ECHAM5 and HadCM3Q11 model

It would seem then that both the HadCM3Q11 and ECHAM5 model, in general project decreases of RK bean yields for the future (2061-2069) period. The overall decrease in RK bean yields in the future (2061-2069) will very likely be to a combination of warmer temperatures and slightly lower and variable rainfall leading to greeter moisture stress and acceleration in maturation during the grain-filling phase (Singh et al. 1998). Furthermore, optimal air temperature to attain maximum RK beans yields in Central Belize is ~ 31.5 ^{0} C, whereas temperatures near Central Farm in Cayo District is expected to increase to ~ 35.2 ^{0} C in the future (2061-2069). Also accumulated rainfall optimally should be ~ 110 mm. But for the region near Central Farm, rainfalls in the future (2061-2069) for the January-March period would only be ~ 50 mm. Changes in the optimal values of both air temperature and rainfall would therefore together provoke lower RK bean yields in the future (2061-2069) (Ramirez et al. 2013).

6.0 Simulation of Citrus Yield Changes and Irrigation Requirements

This section examines the changes citrus (oranges and grapefruit) yields between the current decadal period (2000-2009) and the future (2060-2069). The current decadal period was selected based on data availability. The site selected for the case study is the Melinda Forest station in Stann Creek District, one of the main citrus-producing regions in Belize.

The conditions for producing citrus in Belize are among the best in the Caribbean region. Citrus blooms in Belize are controlled by both rainfall and temperature. In Belize, oranges normally bloom twice each year. The first bloom usually occurs during December to January and the second during last week of May to June or after the start of the rainy season. Grapefruits usually bloom during February to March and then again during May to July. For oranges, the first bloom is triggered by temperature. Trees that are dormant in the cool December weather begin their bloom as the temperature rises. Citrus blooms occurring from April through July are induced by the rain since the trees undergo water stress due to the dryness of the March and April months.
The amount of sunshine obtained by the plant is also important in citrus cultivation. Sunlight per day recorded at Central Farm (near Melinda) for the Belize River Valley (central Belize) varies from 4 hours per day in September to November to 9 hours per day in April to May (Personal Communication: Mr. Luis Gabriel Tzul, Belize Citrus Growers Association, October 2013).

The recommended varieties for commercial citrus production and processing in Belize are Valencia oranges and Marsh grapefruit (white pulp). There are many cultivars of Valencia orange. Presently, the Belize Citrus Certification Program (BCCP) has six cultivars in its germplasm collection. These are Rohde Red, Delta, Olinda, Campbell, Cutler and Midknight. They are very difficult to distinguish from each other but each has some uniqueness in fruit size, juice quality and maturity period. However, enough data on these cultivars in Belize is not yet available. The most popular variety is Rohde Red because it has a deeper juice color than the other cultivars and the juice quality is very good (Personal Communication: Mr. Luis Gabriel Tzul, Belize Citrus Growers Association, October, 2013).

There are several grove designs suited for citrus. Most of them can be implemented on lands with less than 1 percent slope; others can only be adapted to specific sites such as slopes greater than 6 percent. Each design tries to maximize the number of trees per acre or hectare of land, other designs such as those for hilly sites are for easing the harvesting of fruits on these marginal lands.

The square pattern planting design is one of the most commonly used in Belize. In this layout all trees are equidistant from each other so that machinery can pass in either direction especially in young groves. The 20 x 20 ft. design which is common in Belize can accommodate 109 trees per acre of land and after year 15 the canopy would have filled in all available space.

In total, there are 43,000 to 45,000 acres of citrus in Belize, mainly in Stann Creek, Toledo and Cayo Districts. Of this total area ~ 38,000 acres are Valencia oranges (Rhode Red variety); and ~ 7,000 acres are Grapefruit (White Navel variety). There is a total of 591 citrus growers in all of Belize: 80 large growers account for 90 % of total citrus production and 511 small growers account for 10 % of total citrus production (Personal Communication: Mr. Luis Gabriel Tzul, Belize Citrus Growers Association, October 2013).

The citrus crop season normally begins in November and ends in June of the following year. There are 2 main crops or harvests of citrus per year in Belize. The first crop lasts from November to January for Grapefruit and November to February for Oranges. In the case of this first crop, flowering is triggered by cold fronts, starting in November, that bring cool temperatures from the north. The Second crop lasts from July to August and in this instance flowering is triggered by rains at the beginning of the rainy season, namely May-June. The Second crop is harvested from March to April for Grapefruit and from March to June for Oranges. There are further small harvests of the Second crops in July-August (Personal Communication: Mr. Luis Gabriel Tzul, Belize Citrus Growers Association, October, 2013).

Planting dates for new citrus trees are June to September, the rainy season. New Citrus plants are obtained by the grafting method, using the root stock. The First Harvest occurs 3 years after planting for both Oranges and Grapefruit; Citrus trees, both oranges and grapefruit normally mature 8 years after planting. Row Spacing is ~ 70 trees per acre for grapefruit and 116 trees per acre for oranges. Recently, efforts are being made to increase or even double the plant density to ~ 140 trees per acre for grapefruit and ~ 232 trees per acre for oranges, in order to increase profits per acre of land. Orange and grapefruit orchards are replaced after 20-25 years: the replacement rate is about 6 % of orchards per annum (Personal Communication: Mr. Luis Gabriel Tzul, Belize Citrus Growers Association, October, 2013).

Soils in Stann Creek, Toledo and Eastern Cayo, the major citrus production regions, are mainly acidic, while the soils in Western Cayo are alkaline: pH of the acidic soils normally ranges from 4.0 to 6.0. However, liming is used to maintain soils pH at 5.5 to 6.0; Soil depth is about ~18 inches; soil texture is loamy; soil colour is reddish – brown (Cayo clays); carbon organic matter is between 1 to 4 %. The soils therefore can be described as intermittently lime enriched chacalte soils formed under conditions of constant lime enrichment and fragmented limestone clays

Drainage problems occur from time to time, especially in small farms. There is no irrigation water use for Citrus production (Personal Communication: Mr. Luis Gabriel Tzul, Belize Citrus Growers Association, October, 2013).

Yields for oranges are ~150 boxes per acre (1 box = 90 lbs.), while yields for grapefruit are ~ 200 boxes per acre (1 box = 80 lbs.) (Personal Communication: Mr. Luis Gabriel Tzul, Belize Citrus Growers Association, October, 2013).

Diseases can lead to cop losses for both oranges and grapefruit. Phythoptera (root rats) can lead to losses of up to 5 % of crops. Grapefruits are susceptible to the Mexican Fruit Fly and this can lead to losses of up to 25 % of crops. Recently, in 2009 Hunglongbing (HLB), also known as citrus greening or yellow dragon disease appeared and it was supposedly transmitted by the Asian Citrus Psyllid (a bacterium). Hunglongbing (HLB) commonly known as citrus greening disease can destroy an entire crop (See Figure 5.7). It is controlled by spraying with anti-bacterial agent/chemical twice a year, namely October-November and March-April. In 2012 there was a 20 % drop in Citrus yields due to all diseases.

Hunglongbing (HLB), also known as citrus greening or yellow dragon disease, has been reported to be one of the most serious diseases of citrus. Once a tree is infected, there is no cure for the disease and all citrus varieties are susceptible; regardless of rootstock. It is a bacterial disease that greatly reduces production, destroys the economic value of the fruit and kills trees (Belize Citrus Growers Association, 2012).

There is only one factory (Citrus Production of Belize Ltd) that processes citrus fruits into juice: 95% of citrus processed into juice for local consumption and exports to Europe and Japan (See Figure 5.8). Also fresh fruits are exported to the US, the UK Japan and other Caribbean countries (Belize Citrus Growers Association (2012; Personal Communication: Mr. Luis Gabriel Tzul, Belize Citrus Growers Association, October, 2013).

The return on investments for orange and Grapefruit orchards is usually about 6 years based on a gross margin of $BZ 1,500 to 2000 per acre (Personal Communication: Mr. Luis Gabriel Tzul, Belize Citrus Growers Association, October, 2013).

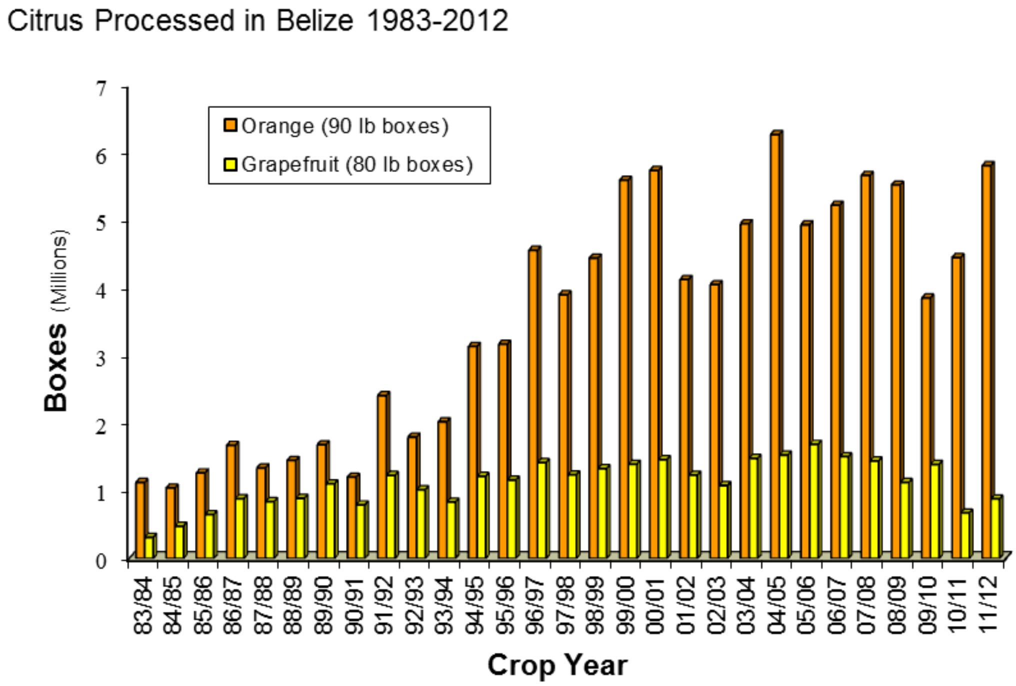

Figure 5.7: Citrus processed in Belize (1983-84 to 2011-12 (Source: Belize Citrus Growers Association).

Figure 5.8: Orange citrus tree destroyed by Hunglongbing (HLB), also known as citrus greening or yellow dragon disease, Stann Creek District

6.1 CROPWAT Simulations vs Observed Data for Yield Reductions of Citrus

CROPWAT simulations of citrus yield changes (%) are limited to yield changes due to a lack of water at the rooting depth, whether from rainfall or irrigation (Steduto et al. 2012).

At first, simulated data using ECHAM5 and HadCM3Q11 climate model data coupled with the CROPWAT crop model is compared with observed citrus yield reduction (%) data for the an area in the vicinity of Melinda Forest station in Stann Creek District for the current period, namely 2000-2009 (Table 5.16).

Table 5.16 shows that for the current period (2000-2009), when using observed data, yield reductions due to lack of water are minimal, with a mean value of 1.1 %. However, when using simulated data from both the ECHAM5 and HadCM3Q11 yield reductions due to lack of water are non-existent (Table 5.16)

This is very likely due to the fact that both the ECHAM5 and HadCM3Q11simulations of rainfall for the current period (2000-2009) in the vicinity if Melinda Forest station is slightly higher than the observed data as seen in Section 2 and leads to lower yield reductions due to the lack of water (Table 5.16).

Table 5.16: CROPWAT simulation of yield reduction (%) caused by lack of water for citrus production with observed and modeled climatic data 2000-2009, Melinda Forest station

Year	Observed	ECHAM5	HadCM3
1	0.4	0	0
2	0.5	0	0
3	0.1	0	0
4	1.5	0	0
5	0	0	0
6	4.5	0	0
7	0.7	0	0
8	1.5	0	0
9	1.1	0	0
10	0.8	0	0
Mean	**1.1**	**0.0**	**0.0**
σ	**1.3**	**0.0**	**0.0**

6.2 CROPWAT Simulations of Yield Reductions due to Lack of Water for Citrus

Furthermore, when assessing yield reductions of citrus due to lack of water when using simulated data from both the ECHAM5 and HadCM3Q11 yield reductions due to lack of water for both the current (2000-2009) and future (2060-2069) are zero (Tables 5.17 and 5.18).

This is again very likely due to the fact that both the ECHAM5 and HadCM3Q11simulations of rainfall for the current (2000-2009) and future (2000-20069) periods in the vicinity if Melinda Forest station are slightly higher than the observed data as seen in Section 2, and thus does not cause any water stress to reduce citrus production (Tables 5.17 and 5.18).

Table 5.17: CROPWAT simulation of yield reduction (%) caused by lack of water for citrus production climatic data of ECHAM model, Melinda Forest station

Year	2000-2009	2060-2069	Δ
1	0	0	0
2	0	0	0
3	0	0	0
4	0	0	0
5	0	0	0
6	0	0	0
7	0	0	0
8	0	0	0
9	0	0	0
10	0	0	0
Mean	**0.0**	**0.0**	**0.0**
σ	**0.0**	**0.0**	**0.0**

Table 5.18: CROPWAT simulation of yield reduction (%) caused by lack of water for citrus production climatic data of HadCM3 model, Melinda Forest station

Year	2000-2009	2060-2069	Δ
1	0	0	0
2	0	0	0
3	0	0	0
4	0	0	0
5	0	0	0
6	0	0	0
7	0	0	0
8	0	0	0
9	0	0	0
10	0	0	0
Mean	**0.0**	**0.0**	**0.0**
σ	**0.0**	**0.0**	**0.0**

6.3 CROPWAT Simulations of Irrigation Requirements for Citrus: Observed vs Models

CROPWAT simulations of citrus yield changes also provide estimates of irrigation requirements to maximize citrus yields (Steduto et al. 2012).

At first, simulated data using ECHAM5 and HadCM3Q11 climate model data coupled with the CROPWAT crop model is compared with observed irrigation requirements (mm) for the an area in the vicinity of Melinda Forest station in Stann Creek District for the current period, namely 2000-2009 (Table 5.19).

Table 5.19 shows that for the current period (2000-2009), when using observed data, irrigation requirements are negative, meaning excess water, with a mean value of - 98.7 mm/year. However, when using simulated data from both the ECHAM5 and HadCM3Q1, irrigation requirements are now slightly positive: a mean value of 7 mm/year for ECHAM5 and 13.8 mm/year for HadCM3Q11 (Table 5.19).

This is very likely due to the fact that both the ECHAM5 and HadCM3Q11simulations of rainfall for the current period (2000-2009) in the vicinity if Melinda Forest station is slightly lower than the observed data as seen in Section 2 and therefore leads to lower irrigation water requirements (Table 5.19).

Table 5.19: CROPWAT simulation of irrigation requirement (mm) for citrus production, with observed and modeled climatic data 2000-2009, Melinda Forest station

Year	Observed	ECHAM5	HadCM3
1	-149.5	5	45.3
2	17.2	0	16.6
3	-163.9	0	0
4	-110.2	2.6	21.4
5	-36.5	8.7	15.6
6	-97.2	14.6	12.8
7	-258.5	24.4	1.2
8	-104	0	9.6
9	-80.5	23	13.9
10	-3.5	-8.6	1.2
Mean	**-98.7**	**7.0**	**13.8**
σ	**81.1**	**10.7**	**13.3**

6.4 CROPWAT Simulations of Irrigation Requirements for Citrus: Current vs Future

When assessing irrigation requirements for citrus due to lack or excess of water when using simulated data from the ECHAM5 model, the mean value of irrigation requirements the current period (2000-2009) is 7.0 mm/year while for the future period (2060-2069) the mean value is -0.2 mm/year, a change (Δ) of -7.2 mm/year (Table 5.20)

This is again very likely due to the fact that the ECHAM5 simulations of rainfall for the future (2060-2069) will be slightly wetter than the current period (2000-2009) in the vicinity of Melinda Forest station as seen in Section 2, and in spite of warmer temperatures and higher evaporation, the irrigation requirements will be lower in the future.

Table 5.20: CROPWAT simulation of irrigation requirement (mm) for citrus production according to climatic data of ECHAM5 model, Melinda Forest station

Year	2000-2009	2060-2069	Δ
1	5	-19.5	-24.5
2	0	0.5	0.5
3	0	1.9	1.9
4	2.6	9.5	6.9
5	8.7	-38.3	-47
6	14.6	0	-14.6
7	24.4	14.4	-10
8	0	19.3	19.3
9	23	0	-23
10	-8.6	10.4	19
Mean	**7.0**	**-0.2**	**-7.2**
σ	**10.7**	**17.1**	**20.9**

But when assessing irrigation requirements for citrus due to lack or excess of water when using simulated data from the HadCM3Q11 model, the mean value of irrigation requirements for both the current period (2000-2009) future (2060-2069) periods are mostly positive: the mean value is 13.8 mm/year for the current period while for the future period the mean value is 12.8 mm/year, a minimal change (Δ) of -0.9 mm/year (Table 5.21)

This is again very likely due to the fact that the HadCM3Q11 simulations of rainfall for the future (2060-2069) will be very slightly wetter than the current period (2000-2009) in the vicinity of Melinda Forest station as seen in Section 2, and in spite of warmer temperatures and higher evaporation, the irrigation requirements will be negligibly lower in the future.

Table 5.21: CROPWAT simulation of irrigation requirement (mm) for citrus production, according to climatic data of HadCM3 model, Melinda Forest station

Year	2000-2009	2060-2069	Δ
1	45.3	41.9	-3.4
2	16.6	44.3	27.7
3	0	21.8	21.8
4	21.4	9.3	-12.1
5	15.6	9.2	-6.4
6	12.8	-7.7	-20.5
7	1.2	16.7	15.5
8	9.6	3.8	-5.8
9	13.9	5.1	-8.8
10	1.2	-16.2	-17.4
Mean	**13.8**	**12.8**	**-0.9**
σ	**13.3**	**19.3**	**16.7**

It transpires from the above that CROPWAT coupled with climate data of the ECHAM5 and HadCM3Q11 models produce simulations of yield reductions (%) due to lack of water and of irrigation requirements (mm/year) do not change appreciably when the current climate (2000-2009) is compared to the future (2060-2069) for citrus production on the vicinity of Melinda Forest station in Stann Creek District. This is very likely due to the fact that both the ECHAM5 and HadCM3Q11 simulations of rainfall for the future (2060-2069) will be very slightly wetter than the current period (2000-2009) in the vicinity of Melinda Forest station as seen in Section 2, and in spite of warmer temperatures and higher evaporation, lack of water will have a minimal impact on citrus yields. Furthermore irrigation requirements, if required, will be negligible in the future climate.

These results are similar to those of Ramirez et al. (2013) using similar climate models, including ECHAM5 and HadCM3Q11, but forced by the SRES-B2 scenario (Ramirez et al. 2013).

7.0 Simulation of Banana Yield Changes due to Lack of Water and Irrigation Requirements

This section examines the changes citrus banana yields between the current decadal period (2000-2009) and the future (2060-2069). The current decadal period was selected based on data availability. The site selected for the case study is the Melinda Forest station in Stann Creek District, one of the main banana-producing regions in Belize.

Two cycles of banana production are simulated in CROPWAT: the first year for new plantations requiring a maturing period of 330 days and the second year requiring a maturing period of 240 days. In both cases the CROPWAT simulations were started in the month of January.

Banana cultivation is concentrated in the Southern Districts of Stann Creek and Toledo. The total area under banana cultivation in 2010 was ~ 6,175 acres. This led to a produced a total production of 4.5 million boxes and a revenue of $ ~ 4.5 million USD (Banana Growers Association, 2011). Bananas are produced throughout the year and are exported each week. However, most of Belize's banana production is done in the latter quarter of the year (Banana Growers Association, 2011).

Belize's major export market for bananas is the European Union under the Economic Partnership Agreement (EPA) with the European Union. Under the EPA, Belize currently exports its bananas on a duty free quota free basis. Belize, as a member of the African, Caribbean and Pacific (ACP) Group exports its bananas under preferential (duty free) rates to the European Union (EU). However, Belize will have to compete among larger exporters of bananas such as the Latin Americans countries that produce on a larger scale at cost-efficient methods. In effect, this will allow for more bananas on the market to the EU which will eventually have a negative effect on prices on bananas (Banana Growers Association, 2011).

7.1 Banana Production and Export

Two varieties of banana are cultivated in Belize: 1) granine and 2) granine-meristem. For a new plantation of bananas, from planting date 1) granine takes 9 months for harvest and 2) granine-meristem takes 7 months (Personal Conversation: Mr. Miguel Angel Monroy – Meridian Banana Enterprise Ltd., October, 2013).

Each plant produces a sucker that replaces the original plant after harvest and that will produce the next harvest cycle of bananas for harvest. The banana plant produces a flower (conical) that is cut off after fruits appear and the fruits/bunches are then covered with bags (blue) to create a local micro-climate and to protect against insects. Planting by means of suckers is done all year round. Plant density: 800 to 900 plants per acre and row spacing are 5.6 to 5.8 feet. Soils are clays and sandy loams that are regularly fertilized with nitrogen, potash and phosphorous to maintain a high level of soil fertility. The more chemicals applied as fertilizer and fungicide, the better is the quality of the banana fruit in Belize. Rooting depth is 6 inches for clayey soils and 12 inches for sandy loam soils. After appearance of banana bunches, rubber bands are used to keep the individual banana fruits together and to promote symmetry (Personal Conversation: Mr. Miguel Angel Monroy – Meridian Banana Enterprise Ltd., October, 2013).

Good drainage is very important for banana production. Banana plants also consume a large amount of water, but drainage is crucial to protect against water logging at the roots of the plant In the dry season, irrigation, namely either centre pivot sprinklers below the banana trees that cover a radius of 40 to 50 feet radius or drip systems are used depending on weather and droughty conditions) (Personal Conversation: Mr. Miguel Angel Monroy – Meridian Banana Enterprise Ltd., October, 2013).

Diseases are major problem for banana production in Belize. Heavy rains lead to the incidence of funguses, mainly sigatoka that appear mostly from September to November. In order to control sigatoka, the affected leaves are cut off. But in order to maintain ample fruit production you need to have at least 5 leaves per tree (Personal Conversation: Mr. Miguel Angel Monroy – Meridian Banana Enterprise Ltd., October, 2013).

Banana yields in Belize, under ideal conditions are 850 to 900 boxes/acre/year (1 box = 40 lbs.). At harvest the banana plant with fruit attached is chopped and half-lowered so as to remove the blue protective bag and place sponges between bunches to avoid bruising. Color identification systems, using different colors of ribbons are used to identify the age of the fruit bunches for harvest and replacement. A harvest team comprises 3 people: 1) Cutter; 2) Bagger (to load on to hooks and cables) and 3) Puller (to manually pull banana bunches to packaging plant). Cables and hooks for transporting harvested banana bunches: are 240 feet apart and placed along rows that then lead to the main cable for transporting banana bunches (manual pull) to packaging plant. The puller manually pulls about 25 banana bunches at a time and probably up to 100 trips per day to give a total of 2,500 bunches harvested each day. The banana plant that is cut down is then chopped up and spread on field to provide organic fertilizer (Personal Conversation: Mr. Miguel Angel Monroy – Meridian Banana Enterprise Ltd., October, 2013).

The bunches of banana are then taken to the pack house for grading and packing. At the pack house individual bunches of banana are removed and placed in water tanks so as to water the fruit, to reduce the amount of latex flow and to removes insects such as spiders, scorpions, and cockroaches. At the packaging plant, teams of workmen and workwomen perform a number of quality control checks including removing bananas of low quality. Bunches are then dipped in chemicals (bankit and fungacil) in order to preserve crown and neck of banana in good condition), aloes to seal bruises on skin of banana and bacterol and chlorine to disinfect fruit before packaging for preservation. Banana bunches are then are graded according to size and quality, placed in plastic bags, sealed, labelled and packed in boxes and for transport to the shipment port (Personal Conversation: Mr. Miguel Angel Monroy – Meridian Banana Enterprise Ltd., October, 2013; Aisle Spy, 2012).

The harvested and packed banana fruits are then transported by ship and it takes up to 2 weeks before the boxes of bananas and uploaded at ripening depot in the UK and other foreign markets. The banana fruits put are then subjected to a ripening period of 6 to 7 days: ethylene is used in the ripening process. The fruits are then checked by quality control inspectors for scarring, coloring, insects and correct labelling before they are ready for selection by different buyers (Aisle Spy, 2012).

The cost of production of bananas in Belize, including labour and chemicals, is ~ $16,000.00 BZ/acre, which works out to $ 9.00 BZ to $10.00 BZ per box. Bananas sold at $ 20.00 BZ per box during the first 6 months of year because of higher production costs in the dry season for irrigation water use and at $ 15.00 BZ per box in the last 6 months of year that corresponds to the rainy season when production costs are lower due to less irrigation water use. But sometimes losses due to disease (sigatoka) and quality (crown rut, peel rut, neck rut and finger rut can lead to revenue losses (Personal Conversation: Mr. Miguel Angel Monroy – Meridian Banana Enterprise Ltd., October, 2013; Aisle Spy, 2012).

When bananas are exported to the EU, very stringent quality criteria have to be met: a quality criteria rating of 85 % for 30 quality criteria including length, coloration, stage of ripening, crown rut, peel rut, neck rut and finger rut has to be met to obtain top market price. But if the quality criteria rating are lower than 85 %, a lower market price is negotiated. However, if the quality criteria rating drops to 35 % or lower there is zero payment and loss of revenue (Personal Conversation: Mr. Miguel Angel Monroy – Meridian Banana Enterprise Ltd., October, 2013; Aisle Spy, 2012).

7.2 Climate and Climate Change and Banana Production

For bananas, climate change may significantly alter both yields as well as vulnerability to diseases, which would affect the food security and incomes of hundreds of Belizean farmers and workers. Studies have found that in the lowland tropics, such as the coastal areas of Belize where temperatures are already extremely high, even slight temperature increases could damage banana production or eliminate it altogether. Climate change could affect banana diseases as well, such as black leaf spot, also known as black sigatoka. The use of fungicides to control this disease accounts for a large percentage of the total investment in production of banana, a critical source of income for developing countries such as Belize (Climate Change Agriculture and Food Security, 2011).

7.3 CROPWAT Simulation of Banana Yields – Observed vs Simulated: 1st Year Production

Banana crops represent a collection of individual plants that vegetatively propagate at their own rhythm, with stabilised but unsynchronised production of inflorescences over time. Such agrosystems cannot be simulated with existing crop models due to the unsynchronized behavior of individual plants (Tixier et al. 2004). This section looks at irrigation requirements for bananas in the 1st year.

CROPWAT simulations of banana yield changes (%) are also limited to yield changes due to a lack of water at the rooting depth, whether from rainfall or irrigation (Steduto et al. 2012).

At first, simulated data using ECHAM5 and HadCM3Q11 climate model data coupled with the CROPWAT crop model is compared with observed banana yield reduction (%) due to lack of water and irrigation requirements (mm/year) data for the an area in the vicinity of Melinda Forest station in Stann Creek District for the current period, namely 2000-2009 (Table 5.22).

Table 5.22 shows that for the current period (2000-2009), when using observed data, yield reductions due to lack of water are minimal, with a mean value of 4.0 %. However, when using simulated data from both the ECHAM5 and HadCM3Q11 yield reductions due to lack of water is non-existent (Table 5.22)

This is very likely due to the fact that both the ECHAM5 and HadCM3Q11simulations of rainfall for the current period (2000-2009) in the vicinity if Melinda Forest station is slightly higher than the observed data as seen in Section 2 and therefore leads to zero yield reductions (Table 5.22).

Table 5.22: CROPWAT simulation of yield reduction (%) caused by lack of water for banana production - 1st year, with observed and modeled climatic data 2000-2009, Melinda Forest station

Year	Observed	ECHAM	HadAM3
1	2.4	0	0
2	3.7	0	0
3	1.2	0	0
4	4.1	0	0
5	4.8	0	0
6	8	0	0
7	2.4	0	0
8	4.9	0	0
9	4	0	0
10	4.3	0.1	0
Mean	**4.0**	**0.0**	**0.0**
σ	**1.8**	**0.0**	**0.0**

7.4 CROPWAT Simulations of Yield Reductions (%) for Bananas – 1st Year: Current vs Future

Furthermore, when assessing yield reductions of bananas due to lack of water when using simulated data from both the ECHAM5 and HadCM3Q11 yield reductions due to lack of water for both the current (2000-2009) and future (2060-2069) periods are more or less zero (Tables 5.23 and 5.24)

This is again very likely due to the fact that both the ECHAM5 and HadCM3Q11simulations of rainfall for both the current (2000-2009) and future (2000-20069) periods in the vicinity if Melinda Forest station are slightly higher than the observed data as seen in Section 2, and thus does not cause any water stress to reduce banana production (Tables 5.23 and 5.24).

Table 5.23: CROPWAT simulation of yield reduction (%) caused by lack of water for banana production - 1st year, for current (2000-2009) and future (2040-2069), and the changes (Δ) according to the ECHAM5 model, Melinda Forest station

Year	2000-2009	2060-2069	Δ
1	0	0	0
2	0	0	0
3	0	0	0
4	0	0	0
5	0	0	0
6	0	0	0
7	0	0	0
8	0	0	0
9	0	0	0
10	0.1	0	-0.1
Mean	**0.0**	**0.0**	**0.0**
σ	**0.0**	**0.0**	**0.0**

Table 5.24: CROPWAT simulation of yield reduction (%) caused by lack of water for banana production - 1st year, for current (2000-2009) and future (2040-2069), and the changes (∆) according to the HadCM3Q11 model, Melinda Forest station

Year	2000-2009	2060-2069	∆
1	0	0	0
2	0	0	0
3	0	0	0
4	0	0.1	0.1
5	0	0	0
6	0	0	0
7	0	0	0
8	0	0	0
9	0	0	0
10	0	0	0
Mean	**0.0**	**0.0**	**0.0**
σ	**0.0**	**0.0**	**0.0**

7.5 CROPWAT Simulations of Irrigation Requirements for Banana - 1 st Year Production: Observed vs Models

CROPWAT simulations of citrus yield changes also provide estimates of irrigation requirements to maximize citrus yields (Steduto et al. 2012). This section looks at irrigation requirements for bananas in the 1st year.

At first, simulated data using ECHAM5 and HadCM3Q11 climate model data coupled with the CROPWAT crop model is compared with irrigation requirements (mm) based on observed data for the an area in the vicinity of Melinda Forest station in Stann Creek District for the current period, namely 2000-2009 (Table 5.25).

Table 5.25 shows that for the current period (2000-2009), when using observed data, irrigation requirements are negative, meaning excess water, with a mean value of - 40.1 mm/year. However, when using simulated data from both the ECHAM5 and HadCM3Q11, irrigation requirements are now slightly positive: a mean value of 41.3 mm/year for ECHAM5 and 7.9 mm/year for HadCM3Q11 (Table 5.25).

This is very likely due to the fact that both the ECHAM5 and HadCM3Q11simulations of rainfall for the current period (2000-2009) in the vicinity if Melinda Forest station is slightly lower than the observed data as seen in Section 2 and therefore leads to higher irrigation water requirements (Table 5.25).

Table 5.25: CROPWAT simulation of Irrigation Requirement (mm) for Banana Production - 1st year, with observed and simulated (ECHAM5 and HadCM3Q11) data for the current (2000-2009) period, Melinda Forest station

Year	Observed	ECHAM5	HadCM3Q11
1	-111.3	23.2	22.5
2	-1.8	0	5.7
3	-170.9	88.5	0
4	-79.6	9	2.3
5	14.1	52.9	17.2
6	36.3	86.9	0
7	-73.3	0.2	0
8	-96.7	14.1	1
9	47.7	3.1	29.1
10	34.5	135.3	1.2
Mean	**-40.1**	**41.3**	**7.9**
σ	**75.7**	**47.4**	**10.9**

7.6 CROPWAT Simulations of Irrigation Requirements for Banana – 1 st Year: Current vs Future

When assessing irrigation requirements for banana due to lack or excess of water when using simulated data from the ECHAM5 model, the mean value of irrigation requirements the current period (2000-2009) is 41.3 mm/year while for the future period (2060-2069) the mean value is 21.2 mm/year, a change (Δ) of -20.1 mm/year (Table 5.26)

This is again very likely due to the fact that the ECHAM5 simulations of rainfall for the future (2060-2069) will be slightly wetter than the current period (2000-2009) in the vicinity of Melinda Forest station as seen in Section 2, and in spite of warmer temperatures and higher evaporation, the irrigation requirements will be lower in the future (Table 5.26)

Table 5.26: CROPWAT simulation of irrigation requirement (mm) for banana production – 1st year according to climatic data of ECHAM5 model, Melinda Forest station

Year	2000-2009	2060-2069	Δ
1	23.2	47.4	24.2
2	0	-15.8	-15.8
3	88.5	0	-88.5
4	9	0	-9
5	52.9	0	-52.9
6	86.9	17.4	-69.5
7	0.2	14.3	14.1
8	14.1	72.4	58.3
9	3.1	75.3	72.2
10	135.3	0.8	-134.5
Mean	**41.3**	**21.2**	**-20.1**
σ	**47.4**	**32.4**	**66.0**

But when assessing irrigation requirements for citrus due to lack or excess of water when using simulated data from the HadCM3Q11 model, the mean value of irrigation requirements for both the current period (2000-2009) future (2060-2069) periods are mostly positive: the mean value is 7.9 mm/year for the current period while for the future period the mean value is 13.7 mm/year, a change (Δ) of 5.8 mm/year (Table 5.21)

This is again very likely due to the fact that the HadCM3Q11 simulations of rainfall for the future (2060-2069) will be very moderately wetter than the current period (2000-2009) in the vicinity of Melinda Forest station as seen in Section 2, and when factoring warmer temperatures and higher evaporation, the irrigation requirements will be slightly higher in the future (Figure 5.27).

Table 5.27: CROPWAT simulation of irrigation requirement (mm) for banana production – 1st year according to climatic data of HadCM3Q11 model, Melinda Forest station

Year	2000-2009	2060-2069	Δ
1	22.5	0	-22.5
2	5.7	12.9	7.2
3	0	0	0
4	2.3	1.9	-0.4
5	17.2	15.2	-2
6	0	38.4	38.4
7	0	52.5	52.5
8	1	15.1	14.1
9	29.1	0.9	-28.2
10	1.2	0	-1.2
Mean	**7.9**	**13.7**	**5.8**
σ	**10.9**	**18.2**	**24.6**

7.7 CROPWAT Simulation of Banana Yields – Observed vs Simulated: 2nd Year Production

CROPWAT simulations of banana yield changes (%) are limited to yield changes due to a lack of water at the rooting depth, whether from rainfall or irrigation (Steduto et al. 2012). This section looks at irrigation requirements for bananas in the 2nd year.

At first, simulated data using ECHAM5 and HadCM3Q11 climate model data coupled with the CROPWAT crop model is compared with banana yield reduction (%) using observed data foe estimating lack of water and irrigation requirements (mm/year) for the an area in the vicinity of Melinda Forest station in Stann Creek District for the current period, namely 2000-2009 (Table 5.28).

Table 5.28 shows that for the current period (2000-2009), when using observed data, yield reductions due to lack of water are significant, with a mean value of 27.5 %. However, when using simulated data from both the ECHAM5 and HadCM3Q11 yield reductions due to lack of water is lower: 5.2 % (ECHAM5) and 4.1 % HadCM3Q11 (Table 5.28)

This is very likely due to the fact that both the ECHAM5 and HadCM3Q11simulations of rainfall for the current period (2000-2009) in the vicinity if Melinda Forest station is slightly higher than the observed data as seen in Section 2 and therefore leads to lower yield reductions (Table 5.28).

Table 5.28: CROPWAT simulation of yield reduction (%) caused by lack of water for banana production – 2nd year, with observed and modeled climatic data 2000-2009, Melinda Forest station

Year	Observed	ECHAM	HadAM3
1	25.2	6.6	2.1
2	29.7	0.8	10.2
3	29.5	4.5	4.2
4	33.6	0	11.6
5	16.2	15.8	1.6
6	32.1	0	1
7	20.4	12	1.5
8	34.8	0	6.6
9	24.3	0	0
10	28.9	12.2	1.8
Mean	**27.5**	**5.2**	**4.1**
σ	**5.9**	**6.1**	**4.1**

7.8 CROPWAT Simulations of Yield Reductions (%) for Bananas – 2nd Year: Current vs Future

Furthermore, when assessing yield reductions of bananas due to lack of water when using simulated data from both the ECHAM5 and HadCM3Q11 yield reductions due to lack of water for both the current (2000-2009) and future (2060-2069) periods are minimal (Tables 5.29 and 5.30)

This is again very likely due to the fact that both the ECHAM5 and HadCM3Q11simulations of rainfall for the future (2000-20069) period is higher compared to the current (2000-2009) period in the vicinity if Melinda Forest station as seen in Section 2, and this leads to a slight reduction in yields due to a lack of water: (-.1.5 % for ECHAM5 –Table 5.29 and – 0.9 % for HadCM3Q11 - 5.30).

Table 5.29: CROPWAT simulation of yield reduction (%) caused by lack of water for banana production – 2nd year, for current (2000-2009) and future (2040-2069), and the changes (∆) according to the ECHAM5 model, Melinda Forest station

Year	2000-2009	2060-2069	∆
1	6.6	0	-6.6
2	0.8	0	-0.8
3	4.5	11.4	6.9
4	0	6.7	6.7
5	15.8	3.1	-12.7
6	0	7.7	7.7
7	12	0.1	-11.9
8	0	8.3	8.3
9	0	0.8	0.8
10	12.2	0	-12.2
Mean	**5.2**	**3.8**	**-1.4**
σ	**6.1**	**4.3**	**8.8**

Table 5.30: CROPWAT simulation of yield reduction (%) caused by lack of water for banana production – 2nd year, for current (2000-2009) and future (2040-2069), and the changes (∆) according to the HadCM3Q11 model, Melinda Forest station

Year	2000-2009	2060-2069	∆
1	2.1	3.7	1.6
2	10.2	0	-10.2
3	4.2	4.5	0.3
4	11.6	20.1	8.5
5	1.6	0	-1.6
6	1	0	-1
7	1.5	0	-1.5
8	6.6	2.2	-4.4
9	0	0	0
10	1.8	1	-0.8
Mean	**4.1**	**3.2**	**-0.9**
σ	**4.1**	**6.2**	**4.7**

7.9 CROPWAT Simulations of Irrigation Requirements for Banana – 2nd Year Production: Observed vs Models

CROPWAT simulations of citrus yield changes also provide estimates of irrigation requirements to maximize citrus yields (Steduto et al. 2012). This section looks at irrigation requirements for bananas in the 2^{nd} year.

At first, simulated data using ECHAM5 and HadCM3Q11 climate model data coupled with the CROPWAT crop model is compared with irrigation requirements (mm) based on observed data for the an area in the vicinity of Melinda Forest station in Stann Creek District for the current period, namely 2000-2009 (Table 5.31).

Table 5.31 shows that for the current period (2000-2009), when using observed data, irrigation requirements are relatively high, meaning water deficits, with a mean value of 268.6 mm/year. However, when using simulated data from both the ECHAM5 and HadCM3Q11, irrigation requirements are now much lower: a mean value of 35.7 mm/year for ECHAM5 and 24.2 mm/year for HadCM3Q11 (Table 5.31).

This is very likely due to the fact that both the ECHAM5 and HadCM3Q11simulations of rainfall for the current period (2000-2009) in the vicinity if Melinda Forest station is slightly higher than the observed data as seen in Section 2 and therefore leads to lower irrigation water requirements (Table 5.31).

Table 5.31: CROPWAT simulation of Irrigation Requirement (mm) for Banana Production – 2^{nd} year, with observed and simulated (ECHAM5 and HadCM3Q11) data for the current (2000-2009) period, Melinda Forest station

Year	Observed	ECHAM5	HadCM3Q11
1	63	39.9	17.6
2	250.9	46	36.7
3	323.3	25.2	23
4	417.4	0.2	69.4
5	325.9	98.9	14.2
6	307.4	0	5.6
7	-17.1	79.4	4.4
8	416.7	0.6	60.3
9	171.1	3	1.9
10	426.9	63.3	8.4
Mean	**268.6**	**35.7**	**24.2**
σ	**153.0**	**36.1**	**23.9**

7.10 CROPWAT Simulations of Irrigation Requirements for Banana – 2nd Year: Current vs Future

When assessing irrigation requirements for banana due to lack or excess of water when using simulated data from the ECHAM5 model, the mean value of irrigation requirements for the current period (2000-2009) is 35.7 mm/year while for the future period (2060-2069) the mean value is 22.9 mm/year, a change (Δ) of -12.7 mm/year (Table 5.32)

This is again very likely due to the fact that the ECHAM5 simulations of rainfall for the future (2060-2069) will be slightly wetter than the current period (2000-2009) in the vicinity of Melinda Forest station as seen in Section 2, and in spite of warmer temperatures and higher evaporation, the irrigation requirements will be lower in the future (Table 5.32)

Table 5.32: CROPWAT simulation of irrigation requirement (mm) for banana production – 2nd year according to climatic data of ECHAM5 model, Melinda Forest station

Year	**2000-2009**	**2060-2069**	**Δ**
1	39.9	-42.1	-82
2	46	34.7	-11.3
3	25.2	187.1	161.9
4	0.2	-32.5	-32.7
5	98.9	-19.4	-118.3
6	0	33.2	33.2
7	79.4	0.6	-78.8
8	0.6	39.1	38.5
9	3	20.4	17.4
10	63.3	8.2	-55.1
Mean	**35.7**	**22.9**	**-12.7**
σ	**36.1**	**64.4**	**80.7**

But when assessing irrigation requirements for banana due to lack or excess of water when using simulated data from the HadCM3Q11 model, the mean value of irrigation requirements for the current period (2000-2009) is 24.2 mm/year while for the future period (2060-2069) the mean value is 33.7 mm/year, an increase (Δ) of 9.5 mm/year (Table 5.33)

This is very likely due to the fact that the HadCM3Q11 simulations of rainfall for the future (2060-2069) will be slightly drier than the current period (2000-2009) in the vicinity of Melinda Forest station as seen in Section 2, and when compounded with warmer temperatures and higher evaporation, the irrigation requirements will be higher in the future (Table 5.32)

Table 5.33: CROPWAT simulation of irrigation requirement (mm) for banana production – 2nd year according to climatic data of HadCM3Q11 model, Melinda Forest station

Year	**2000-2009**	**2060-2069**	**Δ**
1	17.6	19.9	2.3
2	36.7	2.1	-34.6
3	23	23.4	0.4
4	69.4	255.9	186.5
5	14.2	0	-14.2
6	5.6	-6.6	-12.2
7	4.4	18.7	14.3
8	60.3	36.9	-23.4
9	1.9	-3.2	-5.1
10	8.4	-10.6	-19
Mean	**24.2**	**33.7**	**9.5**
σ	**23.9**	**79.6**	**63.7**

One can therefore conclude from the above results that CROPWAT coupled with climate data of the ECHAM5 and HadCM3Q11 models produce simulations of yield reductions (%) due to lack of water and of irrigation requirements (mm/year) do not change appreciably when the current climate (2000-2009) is compared to the future (2060-2069) for banana production on the vicinity of Melinda Forest station in Stann Creek District. This is very likely due to the fact that both the ECHAM5 and HadCM3Q11 simulations of rainfall for the future (2060-2069) will be very slightly wetter than the current period (2000-2009) in the vicinity of Melinda Forest station as seen in Section 2, and in spite of warmer temperatures and higher evaporation, lack of water will have a minimal impact on banana yields. Furthermore irrigation requirements, if required, will be negligible under the future (2060-2069) climate.

These results are similar to those of Ramirez et al. (2013) using similar climate models, including ECHAM5 and HadCM3Q11, but forced by the SRES-B2 scenario (Ramirez et al. 2013). Furthermore, a recent study using similar climate scenarios indicated that the changes in area (km^2) modeled as suitable for conventional banana plantations under current conditions as opposed to future climate conditions (2060s) would decrease by ~ 2% for Belize, but would decrease by ~ 74 % for neighbouring Guatemala, which would provide Belize with a comparative advantage insofar as banana production and export is concerned (Machovina and Feeley, 2013).

8.0 Socio-economic Impacts

It is apparent from the foregoing that the agricultural sector of Belize would suffer mainly negative impacts from future (2060-2069) climate change. Yields of the major crops, namely sugarcane, rice, bananas, citrus and RK beans, are all expected to decrease. These decreases in crop yields would result from an increase in air temperature accompanied by higher evaporation rates, variable rainfall and increases or decreases in rainfall, depending upon the location in Belize.

In the case where there will be excess water in the soil, due to higher rainfall, production costs will also likely increase because new drainage infrastructure will be necessary, especially for crops such as bananas.

Rainfed agricultural production systems will also be affected by the adverse impacts of changing climate on the rainfall pattern. This would place a high demand on management techniques for agricultural production and extra inputs into agriculture thereby resulting in an increase in cost of production. Irrigation costs would rise in places where soil moisture would decrease. At the same time, soil erosion caused by flooding would increase input in fertilizer and pesticide to offset losses in organic material in soil, reduced soil fertility, plant diseases, pest occurrence and weed control.

9.0 Adaptation Options

It is expected that the agricultural sector of Belize will be seriously affected by future climate change. This creates the need to carry out adaptations in the sector, industry and markets, in producer strategies and in rural development strategies, with the objective of reducing social and economic costs.

Adaptation to climate change needs to be seen as an iterative process, where the likely state of the climate will not be at a stable equilibrium, rather an ongoing transient process (Stafford Smith et al. 2011). Therefore adaptation responses need to be viewed and shaped appropriately.

At the centre of climate change adaptation efforts are interventions aimed at enhancing adaptive capacity and stimulating adaptive actions.

Agricultural adaptation options are normally grouped according to four main categories that are not mutually exclusive: (1) technological developments, (2) government programs and insurance, (3) farm production practices, and (4) farm financial management (Smit and Skinner, 2002).

Technological adaptations are developed through research programs undertaken by federal and district governments, and through research and development programs of private sector industries. The development of new crop varieties including types, cultivars and hybrids, has the potential to provide crop choices better suited to temperature, moisture and other conditions associated with climate change. This involves the development of plant varieties that are more tolerant to such climatic conditions as heat or drought through conventional breeding, cloning and genetic engineering. Technological adaptation options have been proposed in crop development, to increase their tolerance to climate change and variability; weather and climate information systems, to provide future seasonal weather forecasts; and resource management to deal with of climate-related risks. Weather predictions over days or weeks have relevance to the timing of operations such as planting, spraying or harvesting. Farmers may use this information with respect to the timing of operations such as planting and harvesting, the choice of production activities such as crop varieties and the type of production, such as irrigation or dry-land agriculture (Smit and Skinner, 2002; Bárcena et al. 2013, Ramirez et al. 2013).

Government programs involve financial management activities such as the use of use of crop insurance and agricultural subsidies (Smit and Skinner, 2002).

Farm production practices involve changes in farm operational practices, which may be stimulated or informed by government programs or industry initiatives. Farm production adaptations include farm-level decisions with respect to farm production, land use, land topography, irrigation, and the timing of operations Changing farm production activities have the potential to reduce exposure to climate-related risks and increase the flexibility of farm production to changing climatic conditions. Production adaptations could include the diversification of crop varieties, including the substitution of plant types, cultivars and hybrids, designed for higher drought or heat tolerance and that have the potential to increase farm efficiency in light of changing temperature and moisture stresses. Altering the intensity of chemical fertilizers and pesticides, capital and labour inputs has the potential to reduce the risks in farm production to climate change, but may increase the cost of production (Smit and Skinner, 2002; Bárcena et al. 2013, Ramirez et al. 2013).

Farm financial adaptation options are farm-level responses using farm income strategies, both government supported and private, to reduce the risk of climate-related income loss. Government agricultural support and incentive programs greatly influence farm financial management decisions. Farm financial adaptations involve decisions with respect to crop insurance and income stabilization programs (Smit and Skinner, 2002; Bárcena et al. 2013, Ramirez et al. 2013).

However these adaptation options may face a variety of challenges and barriers in Belize. These barriers to adaptation to climate change will include: economic resources, technical knowledge, and adaptive capacity in the agriculture sector. Climate change may therefore present possible opportunities and priorities for the modernization of agriculture in Belize by enabling effective and proactive adaptation to climate change.

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Section 6: Fisheries Sector

1.0 Introduction

The fishing industry of Belize has contributed significantly to the development of the country by providing direct employment to fishermen, and processing plant personnel. In addition it has added to foreign exchange earnings strengthening the country's economy. The fishing industry is divided into two main sectors, namely, the wild capture fisheries and the aquaculture sector. The wild capture fisheries sector is predominantly a small-scale fishery, which is carried out mainly within the shallow protected waters of the main Barrier Reef (reef flat and reef slope) including the three atolls (Turneffe Island, Glovers Reef and Lighthouse Reef). The shrimp fishery, mostly an industrial fishery, is generally carried out in the central and southern part of the country. The aquaculture sector has had an increase in production on a yearly basis, due to the increase in number of operating farms; it has significantly become one of the most important sectors in Belize. The aquaculture sector contributes significantly to the employment and income of rural communities besides the generation of foreign exchange earnings. Additional benefits of shrimp farming and aquaculture development in Belize includes; business opportunities for ancillary services such as freight haulage, customs brokerage, and rural areas development.

The Fishing Industry contributes significantly to the economy of Belize mostly from exports of lobster, conch, and shrimp. The Fisheries Sub-sector contributed 2.2% to Belize's Gross Domestic Product (GDP) in 2008 (Statistical Institute of Belize, 2008). Fisheries export statistics, for the year 2008, reflected earnings valued at Bze $43.6 million with Lobster contributing Bze $14.0 million, Conch Bze $6.5 million and Farmed Shrimp and Fish Bze $22.8 million (Belize Fisheries Department, 2008).

The sector is characterized as a commercially artisanal industry except for the industrial trawl fishery of shrimp and employs approximately 2,759 active fishermen in 2009. The artisanal fishing fleet consist of 628 boats which are composed of open boats, sail sloops and canoes. The industry is considered to be lucrative and successful mainly because of the good prices obtained on the foreign market and because most fishermen belong to one of the four main cooperatives. They play a dominant role in the industry and are entirely owned by local investors and fishermen that are the main shareholders (Wade, 2010).

The Belize Fishing Industry has been successful because of its ability to adapt to both local and global changes thus allowing it to capitalize on the benefits of certain policies or maintain the level of operations and activities in the sector necessary for its continued growth. It is envisaged however that the proliferation of more robust policies geared directly or indirectly towards the sector could have profound implications on the integrity and continued success of the fishing industry (Wade, 2010).

Practically all the fishing is done in the shallow waters of the barrier reef and the shallow waters of the three atolls. There are nearly 160 miles of barrier reef and 180 miles of reef around the outer atolls. The shallow lagoon between the mainland coast and barrier reef and inside the coral atolls provide ideal habitats for the development of often extensive seagrass beds which provide breeding or feeding areas for numerous commercially valuable species including lobster, conch and many fish species (Wade, 2010).

Ninety percent of the Lobster, Conch and Farmed Shrimp produced in Belize are sold directly to foreign export markets. The other ten percent is sold on the local market to consumers and the tourism sector. Most of the finfish landed is also sold locally and consumed by Belizeans and tourist visitors to Belize (Wade, 2010).

2.0 General Description of the Marine Fisheries

Belize is home to a rich and diverse marine eco-system. The Mesoamerican Barrier Reef System, stretching the full length of the country's coastline, is the largest unbroken coral reef complex in the Western hemisphere and a World Heritage Site. These natural resources are critically important to the economy and communities of Belize and need to be protected from the increasing pressures placed on them from unsustainable practices and from the impacts of climate change.

2.1 Wild Capture Fisheries Sector

The wild capture fisheries sector is comprised of commodities such as spiny lobster, queen conch, pink shrimp, finfish, aquarium fish, aquatic invertebrates and stone crab. The spiny lobster, queen conch and pink shrimp (penaeus dourarum) are the most important ones with respect to production and economic value (Villanueva, 2012)

2.2 Lobster fishery

Over the past few years the lobster fishery has dominated the fishing industry by becoming the highest and the most important income earner small-scale fishery in Belize. On an average 500,000 lbs. of lobster tail are exported annually. It is a seasonal fishery, kept as “open access” for eight months of the year (Villanueva, 2012)

2.3 Conch fishery

Conch over the past years has remained the second most commercially important commodity harvested from the wild by divers. This fishery is a small-scale and seasonal fishery and fishing is undertaken in all six fishing areas in Belize for nine months of the year. Usually conch is caught along the fore-reef, and the inner lagoons, and is fished exclusively by diving, because the species is sedentary. As a result the annual active fishermen exclusively dive the species at depths ranging between five feet to ninety feet. Wooden sailing sloops measuring up to 30 feet are used in the conch fishery (Villanueva, 2012).

This fishery is an artisanal and seasonal fishery and fishing is undertaken in all six fishing areas in Belize for nine months of the year (See Figure 1). Conch over the past years has remained the second most commercially important commodity harvested from the wild by divers. Usually conch is caught along the fore-reef, and the inner lagoons of the atolls, and is fished exclusively by diving, because the species is sedentary. As a result the annual active fishermen exclusively dive the species at depths ranging between five feet to ninety feet. Skiff and wooden sailing sloops measuring up to 30 feet are used in the conch fishery. These sloops are equipped with sails and auxiliary engines (15-40 HP). They carry up to 8 small canoes and as many as 10 fishermen and remain out at sea for 6 to 12 days. The conch season in Belize opens from 1st October-30th June of each year allowing fishermen to harvest conch from the main fishing grounds. Other regulations also exist to protect the conch fishery (Source: Villanueva, 2012).

2.4 Marine Shrimp Fishery

The Marine Shrimp Fishery can be divided into the Industrial Trawl Fishery and the Coastal Artisanal Fishery. The Artisanal shrimp fishery is a small fishery; it is limited to fishing activities in the southern portion of the country where small skiff and canoes are utilized. The Industrial Trawl fishery consists of trawlers designed like those used in the Gulf of Mexico (Villanueva, 2012).

Shrimp trawling activities has been regulated by the Belize Fisheries Department, where the close season (15thMarch-14thJuly) is dependent upon the results obtained from consistent independent surveys, however there have been times where operations have stopped voluntarily as a result of the small non-profitable catches taken. The most commonly caught species are the *Penaeus duorarum* (pink shrimp), penaeus aztecus (brown shrimp) and *Penaeus schmitti* (white shrimp) (Villanueva, 2012).

In Belize the number of exporters entering this fishery is controlled and therefore it has remained on a small scale. This fishery is a multi-billion dollars business worldwide and is based on both wild capture fishery and cultured species, however, due to environmental concerns there has not been much expansion in this fishery. As a matter of fact there is no longer marine shrimp fishery on an industrial scale due the banning of trawling in Belizean waters (Ministry of Agriculture and Fisheries, 2013).

2.5 Finfish Fishery

The finfish fishery continues to be an important fishery for many coastal communities in Belize, for example, Belize City, Hopkins and Placencia. Most of the finfish landed by independent fishermen and cooperative members are sold locally at the markets, hotels and to private individuals and therefore goes as unreported landings. In addition most cooperatives do not receive finfish unless a reasonable and profitable quantity is landed, since it is not economically feasible for them to process a small quantity. Finfish are caught by hand-lining, spearing, long-lining, gillnetting and trapping using fish pots. Snappers, groupers, mackerels and jacks are the most desirable species for export, however, it should be noted that the *Lutjaniae* family make up the largest single family of exported fish (Villanueva, 2012).

2.6 Marine Aquarium Fishery

In Belize the number of exporters entering this fishery is controlled and therefore it has remained on a small scale. This fishery is a multi-billion dollars business worldwide and is based on both wild capture fishery and cultured species, however, due to environmental concerns there has not been much expansion in this fishery. A number of small companies export ornamental fishes to the U.S.A. and Germany (Villanueva, 2012).

Presently, there are four companies exporting ornamental fishes to the U.S.A. and Germany. Four (4) exporter's licenses were issued in 2011. The companies that are presently exporting aquarium fishes and aquatic invertebrates are Circle M Development Ltd., Colson Bay Investment Ltd., Tropical Export Co. Ltd. and Tropical Aquarium Marine Life Belize Company (Villanueva, 2012).

2.7 Other Commodities

Other fisheries commodities that are produced and exported in smaller quantities include stone crab claws and squid.

2.8 Fishing Areas

Fishing in Belize is restricted to three distinct bottom environments. Different fish species are caught in the shallow water of the Barrier Reef and the three atolls, mangrove root systems, and sea-grass beds. The Belizean fishing area is divided into six fishing zones (See Figure 6.1).

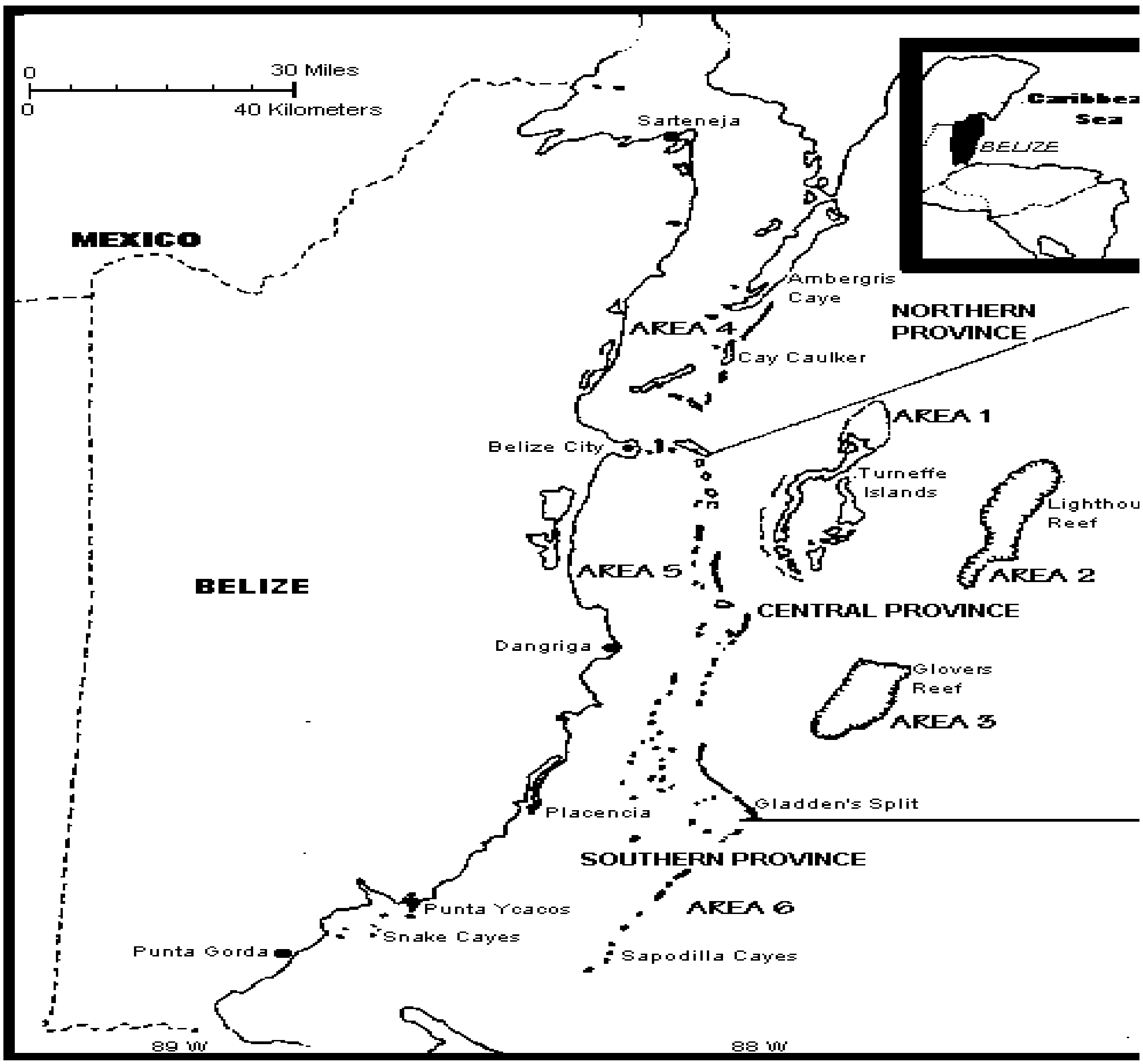

Figure 6.1: Fishing Zones of Belize

3.0 Aquaculture

The aquaculture industry in Belize formally began in the early 1980's with the development of ten acres of experimental ponds in Southern Belize by a private company, namely General Shrimp Limited. The commercial success of this endeavor has led to the rapid expansion of this sector, most notably the culture of the Pacific White Shrimp (Litopenaeus vanammei). The aquaculture sector is now firmly established as a significant contributor to the Belizean economy in terms of generating foreign exchange earnings (Aquaculture Industry Profile – Belize, 2008).

Although aquaculture in Belize has been almost exclusively based on the farming of penaeid shrimps, the culturing of other species has been attempted in the past. These include the husbandry of: the Nile Tilapia (Oreochromis niloticus), the freshwater Australian Red Claw Lobster (Cherax quadricarinatus), the Redfish (Sciaenops ocellatus), and a number of African Rift Lake ornamental finfish species such as Haplochromis sp., Labeochromis sp., Melanochromis sp., Tropheus sp., Psuedotropheus sp. and Awlenocara sp. However, with the exception of Tilapia, the culturing of these species met with commercial failure, except for the Tilapia (Aquaculture Industry Profile – Belize, 2008).

There has been a recent interest in marine cage culture of other viable species such as the Florida Pompano (Trichinous carolinus) and the Cobia (Rachycentron canadum). In 2006, the first Cobia cage culture operation was established in Belize, namely Marine Farms Belize Limited. In 2007, the farm began its first exports to the US market. This farm has fully established phase I of its operations and is now investing into a Cobia hatchery near Dangriga area, as well as a processing plant near Belize City (Aquaculture Industry Profile – Belize, 2008).

3.1 Shrimp Aquaculture

There are presently a number of shrimp farms operational in Belize. These farms were utilizing four distinct husbandry systems, including semi-intensive high stocking and multi harvesting farming systems; semi-intensive farming systems with lower stocking densities and multi harvesting; intensive farming systems with one stocking and one harvest per cycle after four to five months and super-intensive farming systems with one stocking and one harvest per cycle after four to five months (Aquaculture Industry Profile – Belize, 2008).

3.2 Tilapia Aquaculture

Fresh Catch Belize Limited, the only commercial tilapia farming facility in Belize, utilized a semi-intensive farming system with one nursery and two different grow out stages. These were (Aquaculture Industry Profile – Belize, 2008):

Nursery Phase: Stocking density of 40 fingerlings/m^2 with a crop cycle of 120 days and harvest weight between 100-120 grams;

Grow-out Phase I: Stocking density of 13 fingerlings/m^2 with crop cycle of 120 days and harvest weight of 350 grams;
Grow-out Phase II: Stocking density of 4 fingerlings/m^2 with crop cycle of 120 days and harvest weight of 850 grams.

However, Tilapia aquaculture on an industrial scale has been dormant in recent years and Fresh Catch Belize Limited is in receivership (Ministry of Agriculture and Fisheries, 2013).

3.3 Cobia Aquaculture

As for the marine cage farming of Cobia, which is the most recent emerging cultured species in Belize and the region, is based on a semi-intensive culture system comprising of one nursery phase followed by two grow-out stages which are described below:
Nursery Phase: involves the utilization of 5 m circumference cages with a crop cycle of 4-6 weeks and harvest weight of 100 grams;
Grow-out Phase I: utilization of 60 m circumference cages circumference cages with a crop cycle of 3-4 months and harvest weight of 1 – 1.5 kilograms;
Grow-out Phase II: utilization of 100 m circumference cages with a crop cycle of 6-8 months and harvest weight of 5-6 kilograms.

But, Tilapia aquaculture on an industrial scale has also been dormant since 2010 due to the destruction of the marine cages by hurricane Richard (Ministry of Agriculture and Fisheries, 2013).

3.4 Location of Aquaculture Operations

The ten (10) shrimp farms that are operational are situated along the coastal plain, with the land system been classified as the Toledo Polenta or TP Land System. There is one farm located in the Ladyville area (Caribbean Shrimp Farm), two farms in the Dangriga area (Paradise Shrimp Farm, Melinda Mariculture), two farms located between All Pines and the lower reaches of the Placencia Lagoon (Haney's Shrimp Farm, Belize Aquaculture Limited) and the other five farms situated in the Mango Creek area (Royal Mayan Shrimp Farm, Texmar Shrimp Farm, Crustaceans Shrimp Farm, Aquamar Shrimp Farm and Bel-Euro Shrimp Farm) (Aquaculture Industry Profile – Belize, 2008).

The operation of Fresh Catch Belize Limited is located near La Democracia in proximity to the Coastal Road. As for Marine Farms, the cage farming facility is situated near the Robinson Point Cays and its hatchery operations about one mile north of Dangriga at the facilities previously owned by Tao San Mariculture Shrimp Farm (Aquaculture Industry Profile – Belize, 2008).

4.0 Fishermen communities/Socioeconomic importance

The fishing industry of Belize provides direct employment for 2,759 licensed fishermen (2009): More than 50% of these fishermen are between the ages of 15 and 35 years and most of these fishers originate from impoverished rural and coastal communities. Also, the fishermen cooperatives employ 102 fulltime employees and the aquaculture farms employ employees (562 full time, 206 part time) who are responsible for processing, packaging and administrating the daily activities (Wade, 2010).

In most coastal and rural communities, young Belizeans have encountered reduced opportunities in recent times to pursue further education. Most of the fishers and plant workers are only equipped with a primary school education. In some instances, youngsters are removed from school to fish commercially with their fathers and brothers to supplement the family income (Wade, 2010).

The erosion of the traditional preferential markets for Belize's sugar in the European Union and in the United States of America coupled with the market low prices have forced many young sugarcane farmers in northern Belize to abandon their sugarcane fields and enter the fishing industry. Over the next 3 - 5 years, more sugarcane farmers are expected to enter the industry and thus increase the total number of active fishers significantly. There are five fishermen cooperative and fifteen aquaculture establishments operating in the country (Wade, 2010)

4.1 Total Number of Fishermen and Boats

Presently there are over 3,184 registered part-time and full-time fishermen and 1,377 registered fishing vessels that are involved in the fishing industry. In 2011 there were 2,582 licensed fishermen, which show an increase of 4.5% compared to 2010. It was also recorded that 752 vessels were licensed in 2011, which showed an increase of 7.0 % compared to 2010 (See Table 6.1) (Ministry of Agriculture and Fisheries, 2013).

Table 6.1: Belize licenses issued to fishers and boats (2000 -2012)

TABLE OF ISSUED LICENSES													
Year	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
Fishers	**1872**	**1707**	**1947**	**2009**	**1731**	**2026**	**2131**	**2110**	**2267**	**2759**	**2472**	**2582**	**2759**
Boat	**750**	**608**	**708**	**689**	**621**	**652**	**653**	**593**	**643**	**628**	**703**	**752**	**717**

5.0 Fisheries Production and Revenues

5.1 Lobster Production

Lobsters landed at the fishing cooperatives are in the form of tails and head meat. Lobster tails production by the fishermen cooperatives has maintained fairly stable over the last five years ranging between 420,000 and 501,000 lbs. with over 611,160 lbs. of lobster tails and 64,187 lbs. of head meat been produced in 2011. This showed an increase of 22.1 % in lobster tail and 19.6 % in lobster head meat production compared for the year 2010. This represented 36.1% of the total wild marine commodities produced by the fishing cooperatives. The lobster season in Belize opens from 15th June-14th February of each year allowing fishermen to harvest lobster from the main fishing grounds. In addition there are other regulations that govern the sustainable existence of the lobster fishery (See Figure 6.22). Figure 2 shows lobster tails and lobster head meat production from the fishing cooperatives over the years 1977-2013. The decrease in lobster production in 2008 was due to the fact that fishermen in northern and central Belize lost a lot of their traps and shades to Hurricane Dean (August, 2007) (Figure 6.2) (Ministry of Agriculture and Fisheries, 2013).

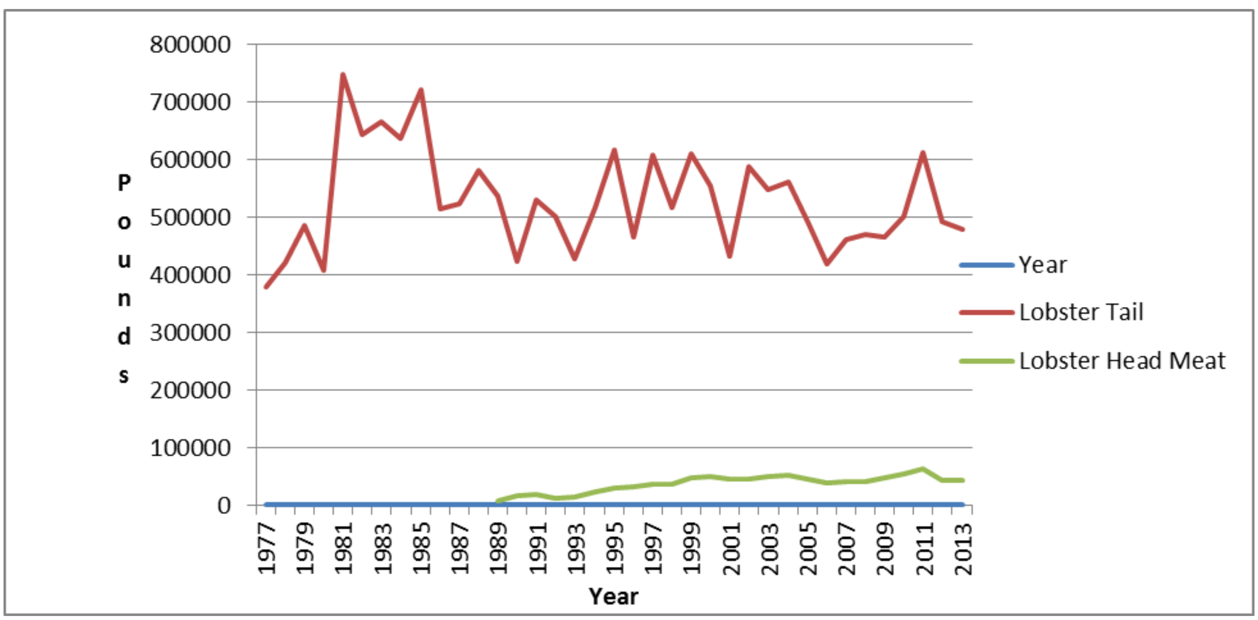

Figure 6.2: Belize lobster tails and head meat production (1977-2013) (Source: Ministry of Agriculture and Fisheries, 2013)

5.2 Lobster Exportation

Presently there are five fishermen cooperatives operating in the country. These cooperatives are owned by Belizeans and employed about 110 employees who are responsible for processing, packaging and administrating the daily activities. The table below (Table 6.2) shows the different fishermen cooperatives with their location and number of producing and non-producing members (Source: Villanueva, 2012).

Table 6.2: Fishing cooperatives membership for 2011 (Source: Villanueva, 2012)

COOPERATIVE	LOCATION	PROD.	NON-PROD.	TOTAL
Northern	Belize City	611	416	1027
National	Belize City	400	131	531
Caribena	San Pedro	15	121	136
Placencia	Placencia Village	19	32	41
Rio Grande	Punta Gorda	12	30	42

The two major fishing cooperatives, Northern and National Fishermen Cooperative, have a processing plant that processed fishery products for exportation. Placencia and Rio Grande Fishermen Cooperative deliver their fishery products to either one of these major fishing cooperative. Over the past years lobster tails exports have maintain fairly stable between 400,000 pounds and 600,000 pounds. In 2011 the fishing cooperatives exported 557,320 lbs. of lobster tails to the U.S.A. valued at $16.9 M Bze. This showed an increase in export weight of 28.4 % and an increase in foreign exchange earnings of 29.7 % compared to 2010. This increase in foreign exchange earnings was due to better lobster prices ($31.00 per lbs.) on the international market. Also $116,100.00 Bze was earned on 19,350 lbs. of processed lobster head meat exported to the U.S.A. This showed a decrease of 65.5 % in export earnings and 66.9 % in export weight for lobster head meat compared to 2010. Belize enjoys duty–free access for all exports to the U.S.A. market under the Caribbean Basin Initiative (CBI). Almost all of the lobster production is exported, mainly as lobster tails, to the US for earnings in $US (Figures 6.3 and 6.4) (Ministry of Agriculture and Fisheries, 2012).

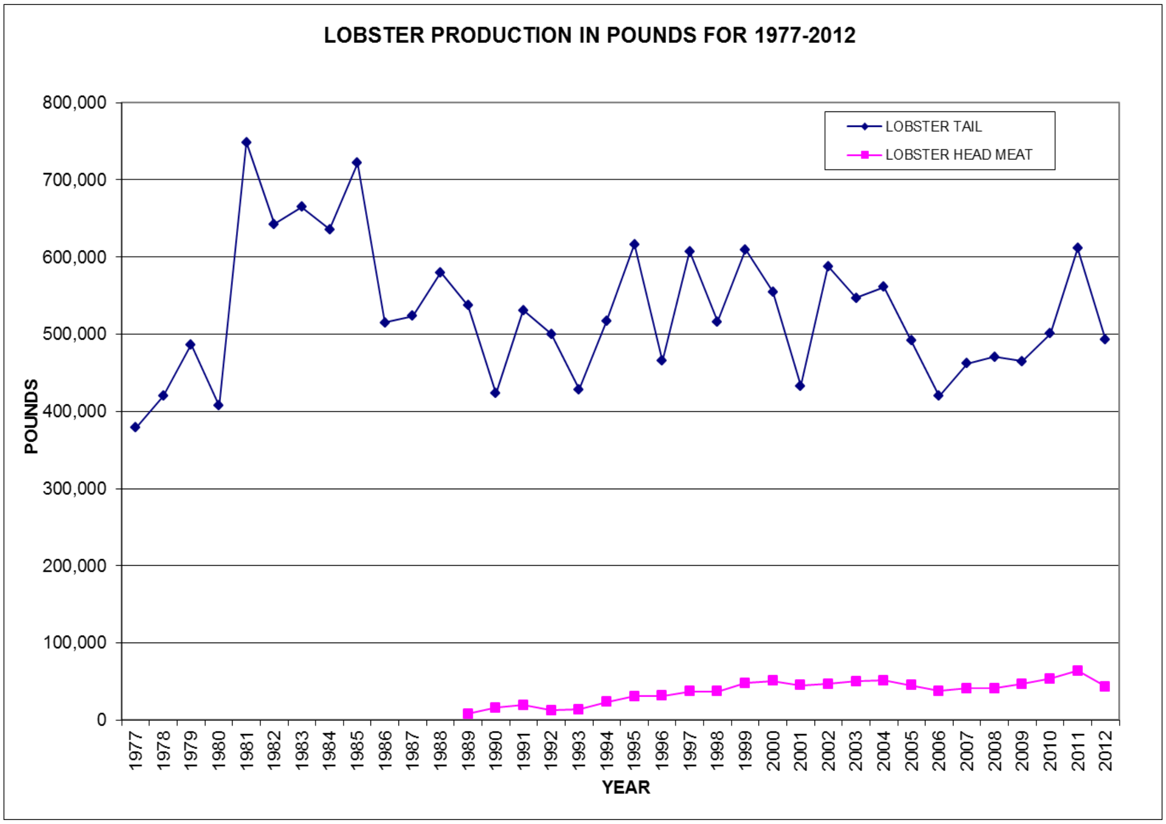

Figure 6.3: Lobster production in pounds and & US (1977-2012) (Source: Ministry of Agriculture and Fisheries, 2012)

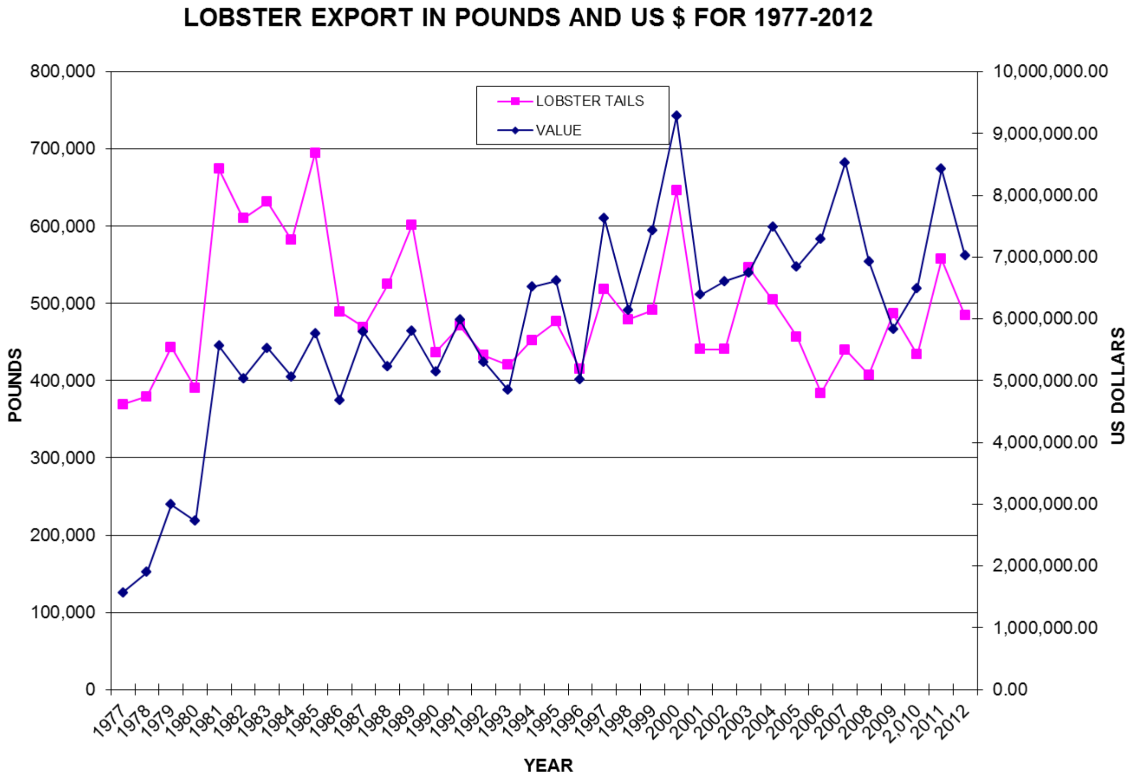

Figure 6.4: Lobster exports in pounds and $US (1977-2012) (Source: Ministry of Agriculture and Fisheries, 2012)

5.3 Conch Production

Conch production by the five Fishermen Co-operatives has maintained fairly stable over the past 5 years ranging between 575,070 lbs. and 856,000 lbs. with over 856,425 lbs. produced in 2011. This showed an increase of 21.4 % in production compared for the year 2010. This represented 45.8 % of the total wild marine commodities produced. The conch season in Belize opens from 1st October-30th June of each year allowing fishermen to harvest conch from the main fishing grounds. The general increase in conch production is due to the allocation of increasing amounts of annual quotas (75 % of maximum sustainable yield). The following Figure 6.5 shows conch production from the fishing cooperatives over the period 1977-2013, respectively (Source: Ministry of Agriculture and Fisheries, 2013).

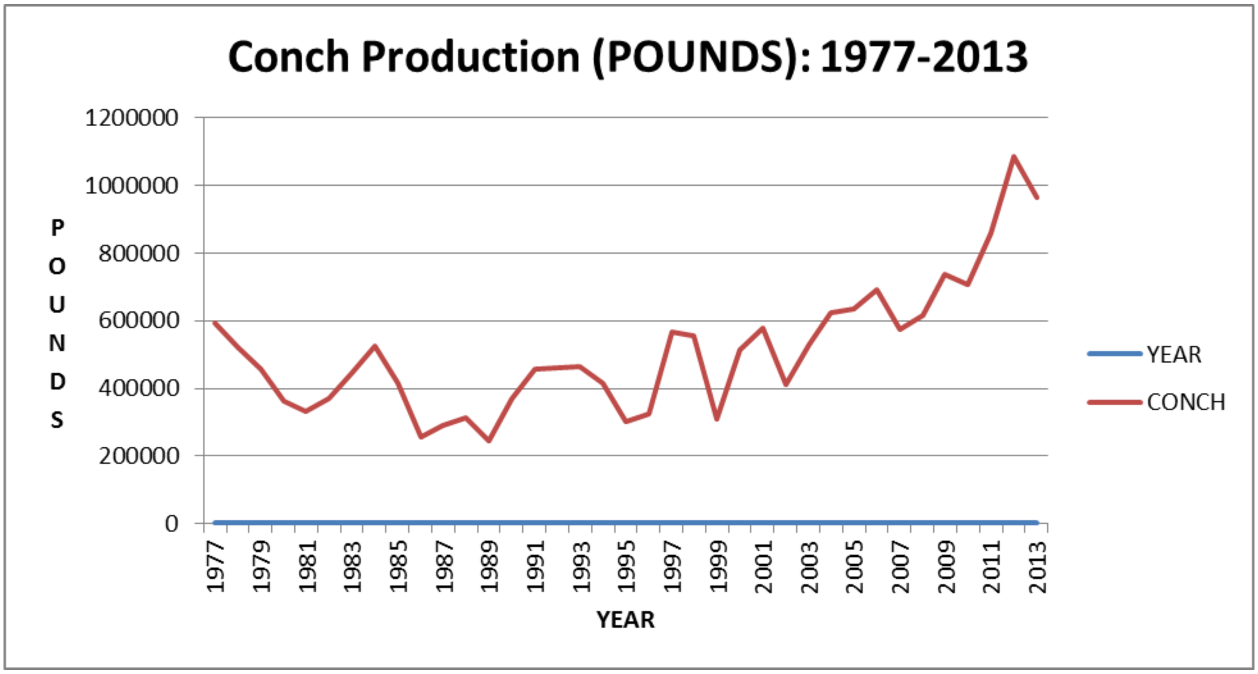

Figure 6.5: Conch production for the period 1977-2013 (Source: Ministry of Agriculture and Fisheries, 2013)

5.4 Conch Exportation

In 2011 the fishing cooperatives exported 791,350 lbs. of market cleaned conch meat to the U.S.A. valued at $8.2 M Bze. This showed an increase in foreign exchange earnings of 2.4 % and 9.0 % in export weight for conch meat compared to 2010. The following Figure 6.6 shows conch exports and earnings from the fishing cooperatives over the period 1977-2012, respectively (Source: Ministry of Agriculture and Fisheries, 2012).

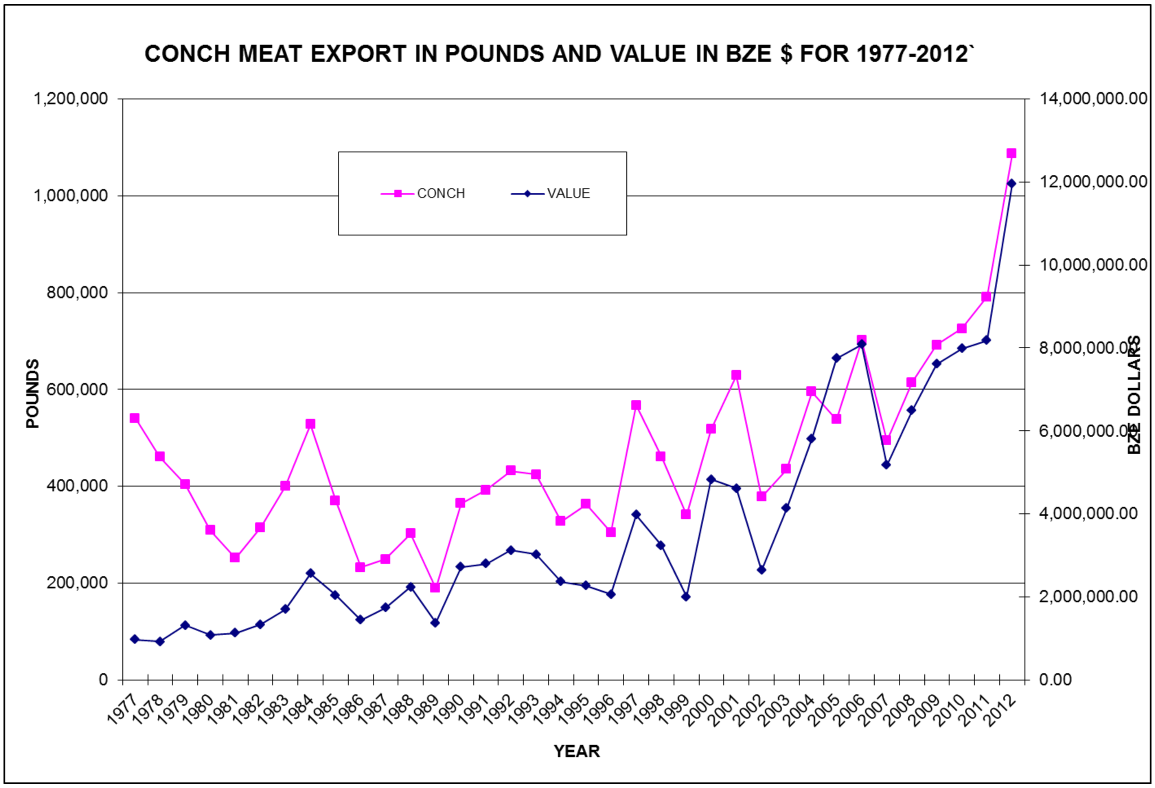

Figure 6.6: Conch meat exports in pounds and $US (1977-2012) (Source: Ministry of Agriculture and Fisheries, 2012)

5.5 Marine Shrimp Production

The production of marine shrimp over the past years has shown a steady decrease due to the amount of trawlers operating and the taking of recruitment stocks. The artisanal shrimp fishery in 2010 produced 4,480 lbs. of marine shrimp showing a decrease of 83.8% in production compared to 2009. This production represented 0.33% of the total wild marine commodities produced for the year 2010. Most shrimp produced by the Rio Grande Fishermen Cooperatives in 2010 were exported. The following Figure 6.7 shows shrimp production from the fishing cooperatives over the over the period 1977-2013, respectively (Source: Ministry of Agriculture and Fisheries, 2013).

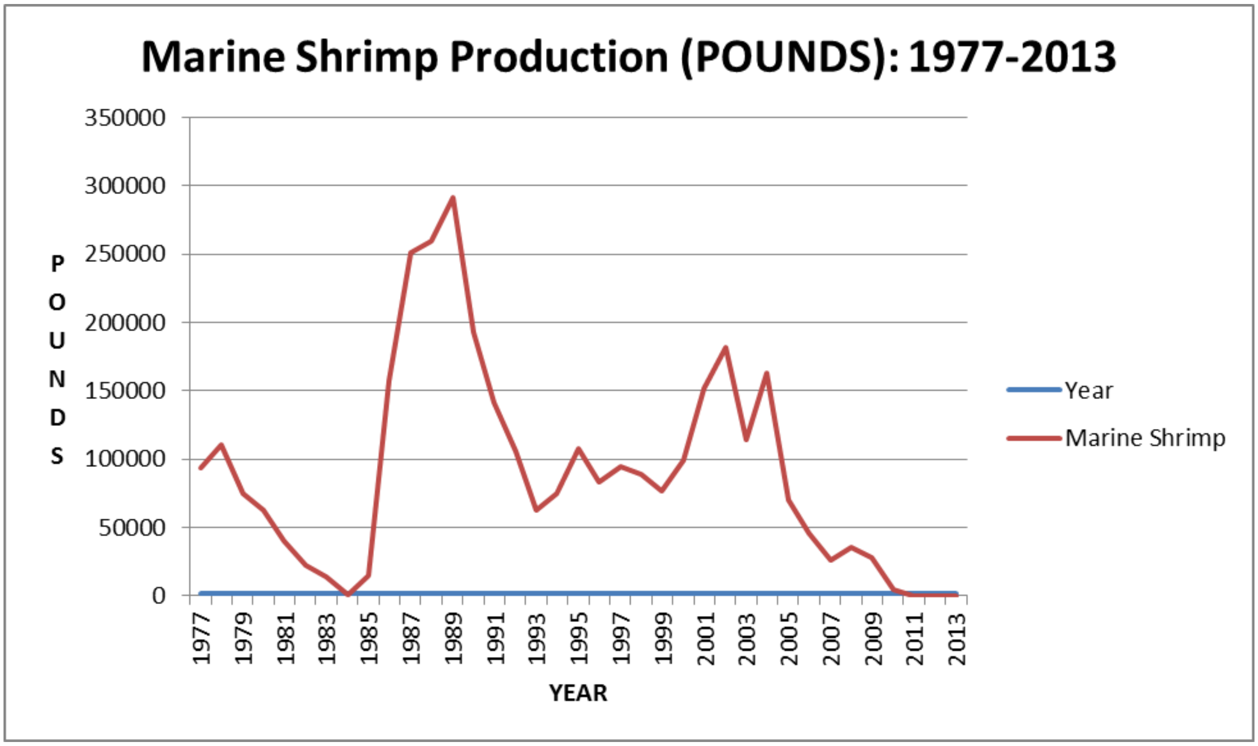

Figure 6.7: Marine shrimp production (1977-2013) (Source: Ministry of Agriculture and Fisheries, 2013)

5.6 Marine Shrimp Exportation

Due to uneconomical low catches, resulting most likely from overfishing marine shrimp fishery was halted in 2011 and therefore there was no exportation of marine shrimp. The following Figure 6.8 shows shrimp export and earnings from the fishing cooperatives over the over the period 1977-2012, respectively. As mentioned previously, profitability and environmental concerns and the banning of trawling in Belizean waters has led to the decline in marine shrimp and export in recent years. The small amount of marine shrimp captured from 2011 to the present has been on an artisanal level (Source: Ministry of Agriculture and Fisheries, 2013).

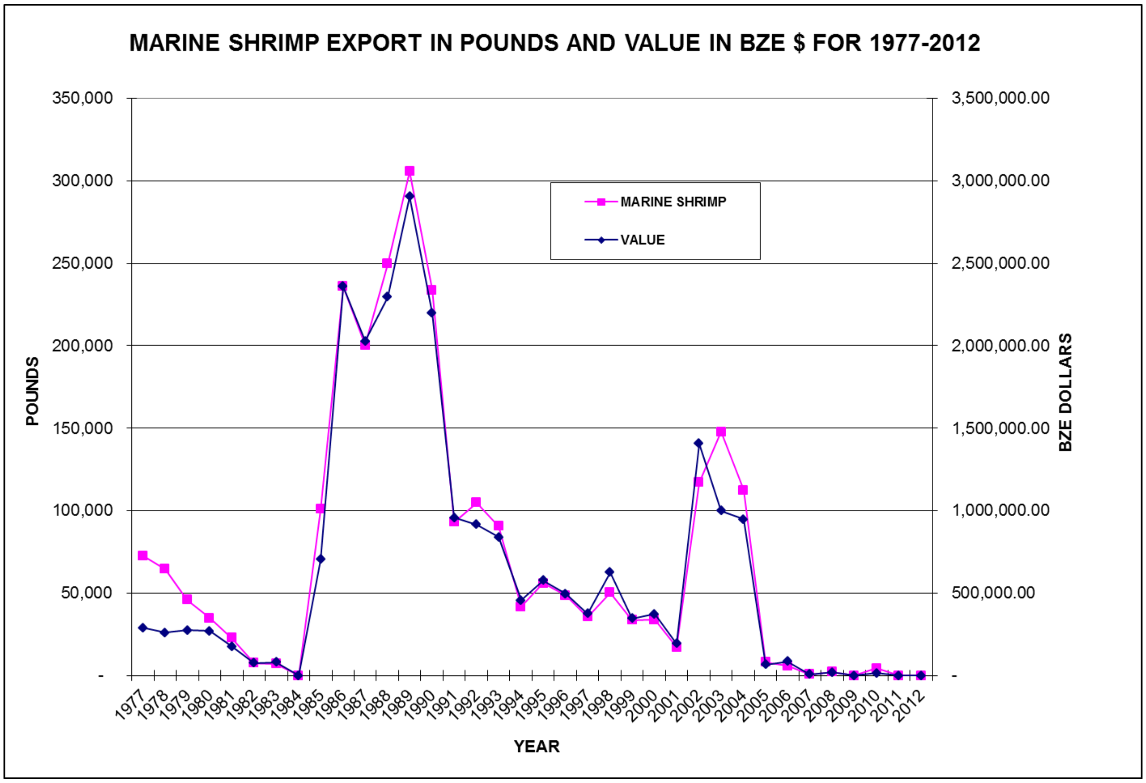

Figure 6.8: Shrimp exports and revenues for period 1977- 2012 (Source: Ministry of Agriculture and Fisheries, 2012)

5.7 Finfish Production

Whole fish and fish fillet production by the fishermen cooperatives for 2011 amounted to 268,340 lbs. and 17,090 lbs., respectively. This showed an increase of 115.1% for whole fish and 50.0 % for fish fillet production compared for the year 2010. Finfish production represented 15.3 % of the total wild marine commodities harvested by the fishing cooperatives. Deep-sea fishing outside the Barrier Reef, although practiced by a few fishermen, could be productive but local fishermen are reluctant to make the necessary investment until it has been shown to be economically feasible. The following Figure 6.9 shows whole fish and fish fillet production over the period 1977-2013 from the fishing cooperatives countrywide respectively (Source: Ministry of Agriculture and Fisheries, 2013).

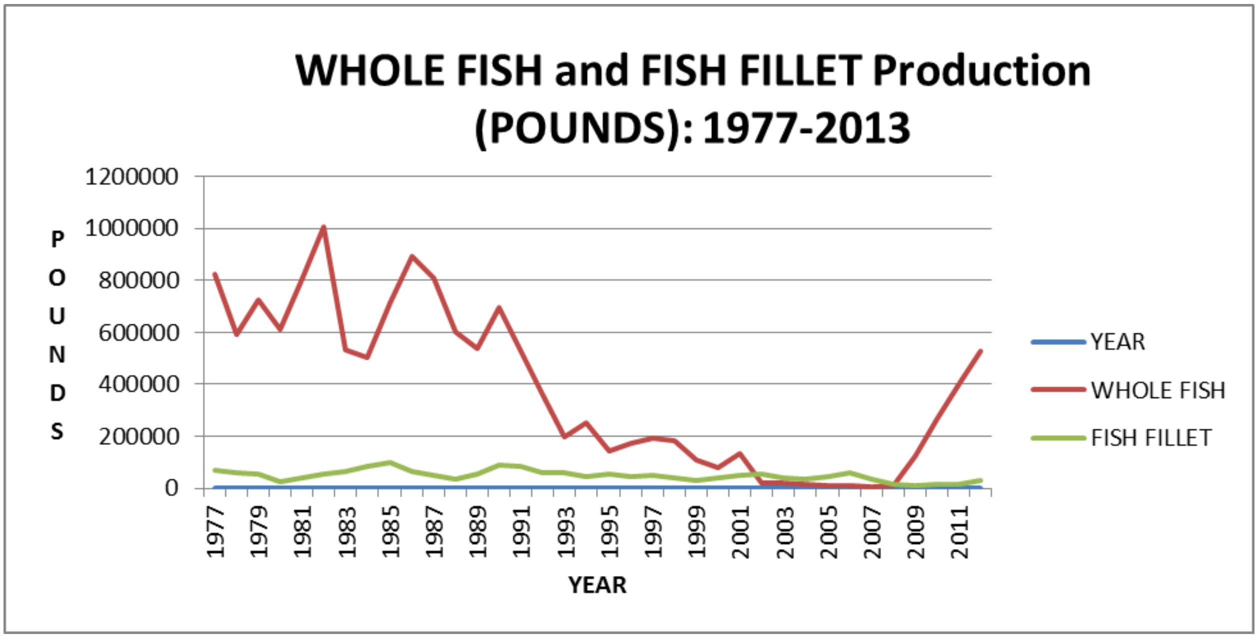

Figure 6.9: Finfish and fish fillet production for period 1977-2013 (Source: Ministry of Agriculture and Fisheries, 2013)

5.8 Finfish Exportation

In 2011 Rainforest Co. Ltd. exported about 224,000 lbs. of whole fish earning in foreign exchange about $672,000 Bze. BRIFRA also exported 9,033 lbs. of fish valued $26,622.83 Bze. For the year 2011 only Placencia and Rio Grande Fishermen Cooperative received whole fish from its members. The following Figures 6.10 and 6.11 show whole fish, fish fillet, fresh shark and salted fish exports from the fishermen cooperatives and fish exporters over the 1977-2012 period and earnings (BZE $) (Source: Ministry of Agriculture and Fisheries, 2012).

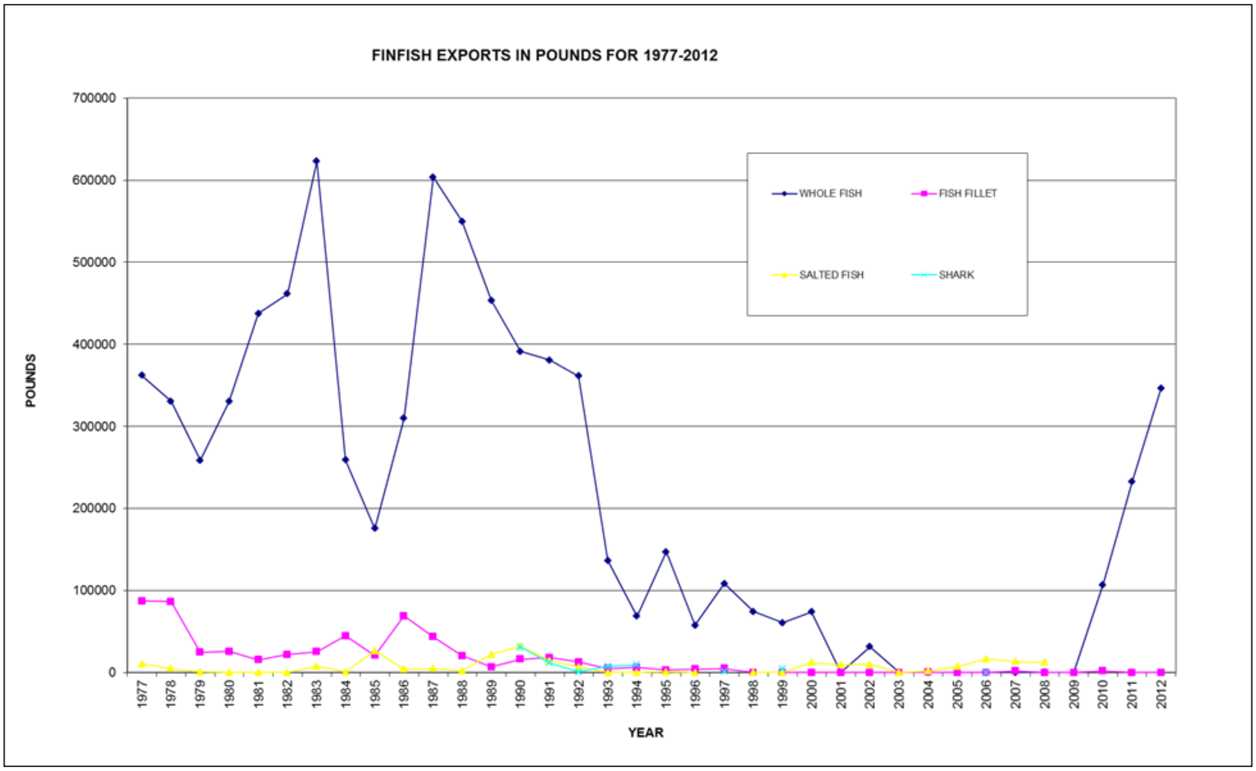

Figure 6.10: Finfish exports for the period 1977-2012 (Source: Ministry of Agriculture and Fisheries, 2012)

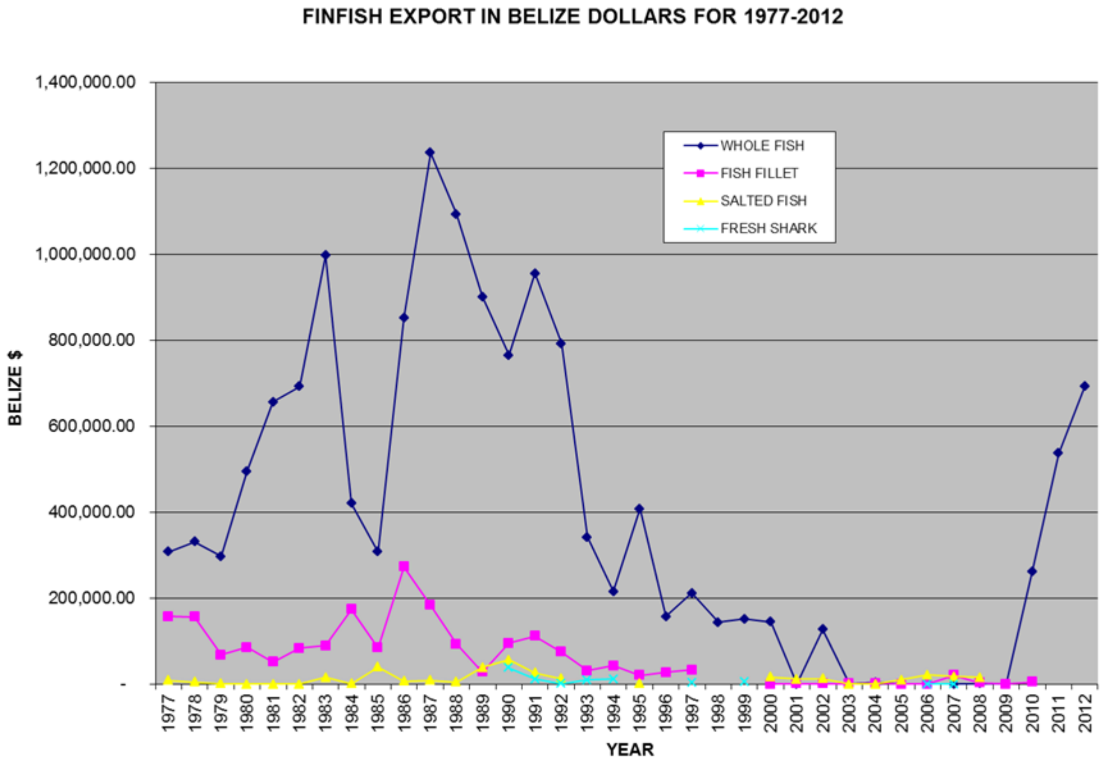

Figure 6.11: Finfish exports and earnings (BZE$0 for the period 1977-2012 (Source: Ministry of Agriculture and Fisheries, 2012)

5.9 Aquarium fish exportation

Thirty-four thousand eight hundred and sixty nine (34,869) fishes valued at $262,460.00 Bze were exported for the year 2009 (Source: Statistical Institute of Belize). In spite of setbacks, the aquarium trade of Belize continues in 2013 with only three exporters (Colson Bay Investments, Tropical Fish Exports and Marine Life Belize. Marine Life Belize had the highest exportation of invertebrates (79,774 specimen) and Colson Bay Investments the highest exportation of fish (11,174). The total combined value for the aquarium trade was $150,000.00. These exporters harvest the aquarium species from the Turneffe Atoll and along the Belize Barrier Reef avoiding areas visited by tourists. The following Table 6.3 (Villanueva, 2012) and Figure 6.12 (Ministry of Agriculture and Fisheries, 2013) show aquarium fish and aquatic invertebrates exports and earnings over the past ten and fourteen years respectively.

Table 6.3: Export figures for aquarium fishes from 2000-2009 (Villanueva, 2012)

EXPORT FIGURES FOR MARINE AQUARIUM FISHES FROM 2000-2009				
Year	**Aquarium Fish (No.)**	**Value (Bze $)**	**Aquatic Invert (No.)**	**Value (Bze $)**
2000	6,127	93,487.73	10,226	57,975.98
2001	2,796	37,629.20	8,731	57,306.40
2002	3,186	35,145.24	0	0
2003	8,270	39,148.71	350	2,450.00
2004	61,874	180,367.00	0	0
2005	115,222	216,737.00	0	0
2006	48,100	102,831.00	-	-
2007	62,034	230,355.66	0	0
2008	38,207	240,000.00	0	0
2009	34,869	262,460.00	0	0
2010	N/A	N/A	N/A	N/A

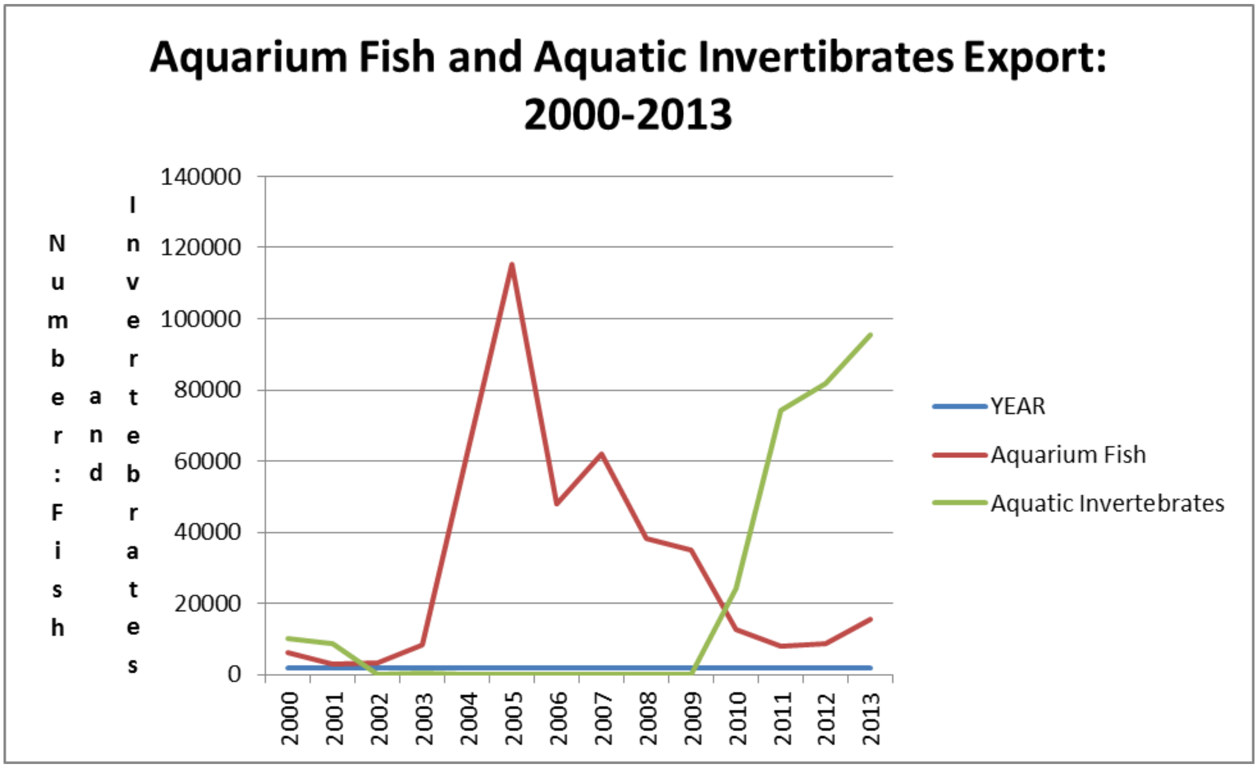

Figure 6.12: Belize aquarium fish and aquatic invertebrates exports (2000-2009) (Villanueva, 2012)

5.10 Other Commodities: Stone Crab Claws

Three thousand three hundred and seven (3,307) pounds of king crab claws was produced by the National Fishermen Cooperative in 2011. This production represented 0.18 % of the total wild marine commodities landed. This showed an increase of 14.8 % in king crab claws production compared to 2011. No stone crab or king crab claws were exported in 2011. The Rio Grande Fishermen Cooperative produced 49,833 pounds of sea cucumber in 2011. This showed an increase of 177.6 % in sea cucumber production compared to 2010. The following Figures 6.13 and 6.14 show stone crab claws production and export for Northern Fishermen Cooperative over the past years (1981-2011) and earnings (1981-2012) (Villanueva, 2012; Ministry of Agriculture and Fisheries, 2013).

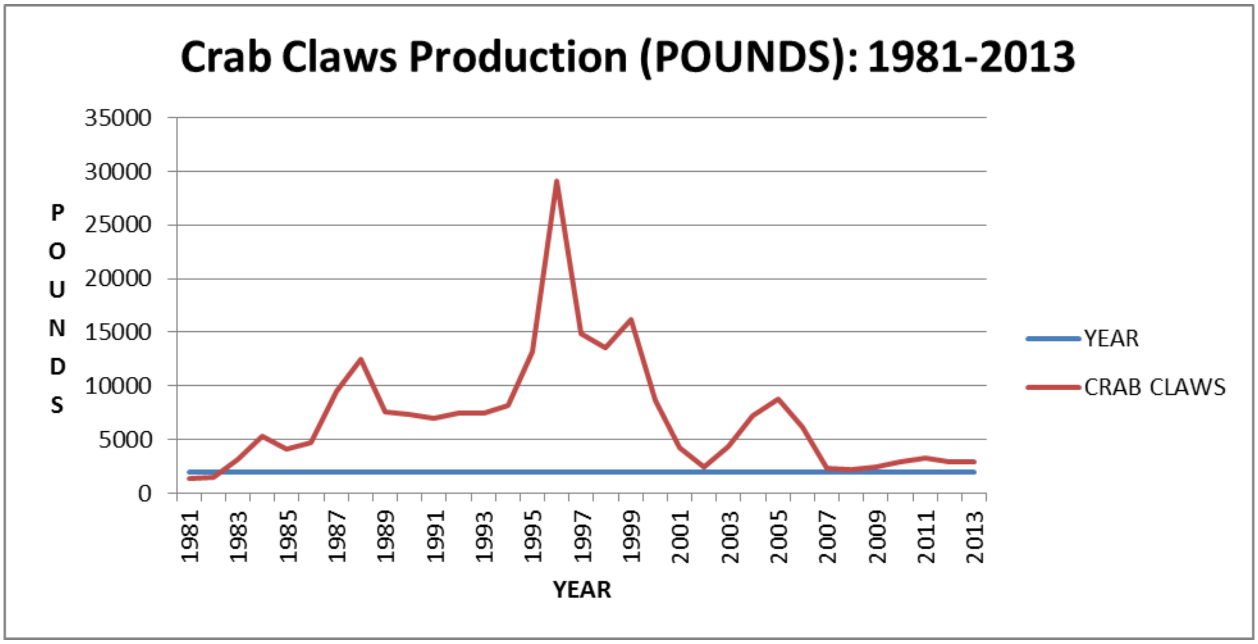

Figure 6.13: Stone Crab claws production (1981-2013) (Ministry of Agriculture and Fisheries, 2013)

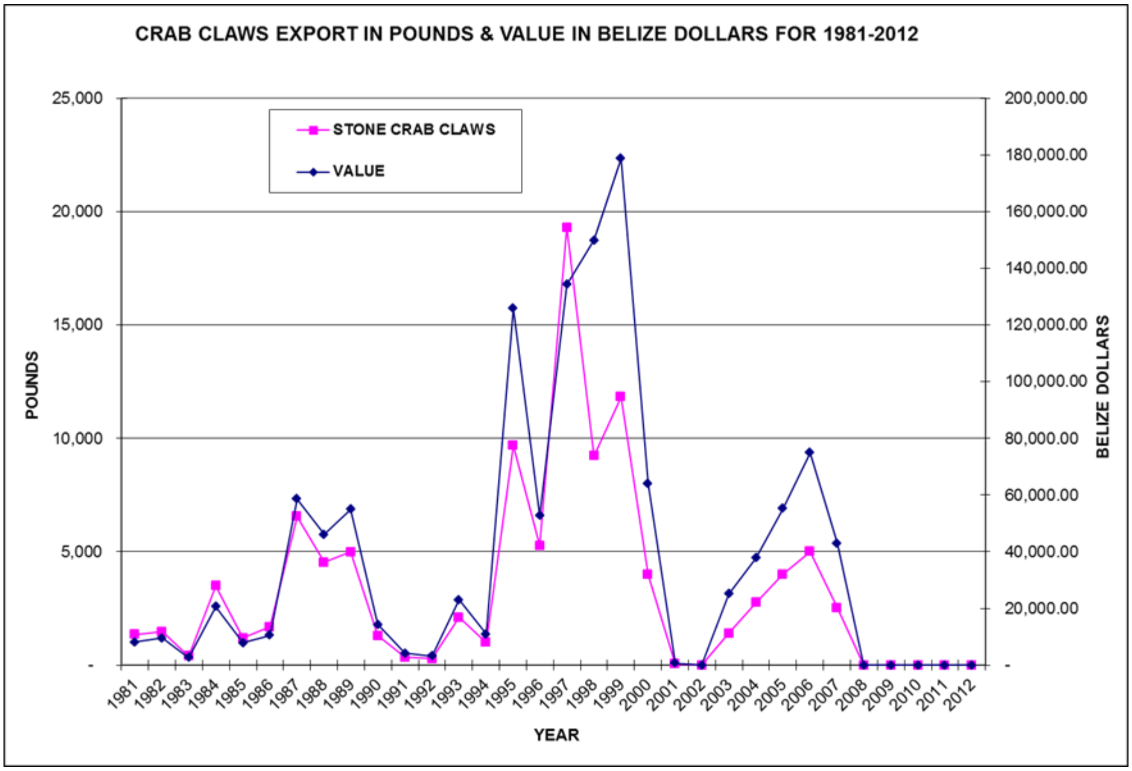

Figure 6.14: Crab claws exports (pound and dollars) for period 1977-2012 (Source: Ministry of Agriculture and Fisheries, 2012)

5.11 Other Commodities: Sea Cucumber

The Sea Cucumber fishery of Belize, though recent, is vibrant and has received high interest from fishermen and prospective exporters. However, due to the slow growth of the organism and habitat specificity, the fishery only had seventy-four licensed fishermen and four exporters. One hundred fifty-four thousand nine hundred pounds of wet weight sea cucumbers was exported in 2011 (Figure 6.15).

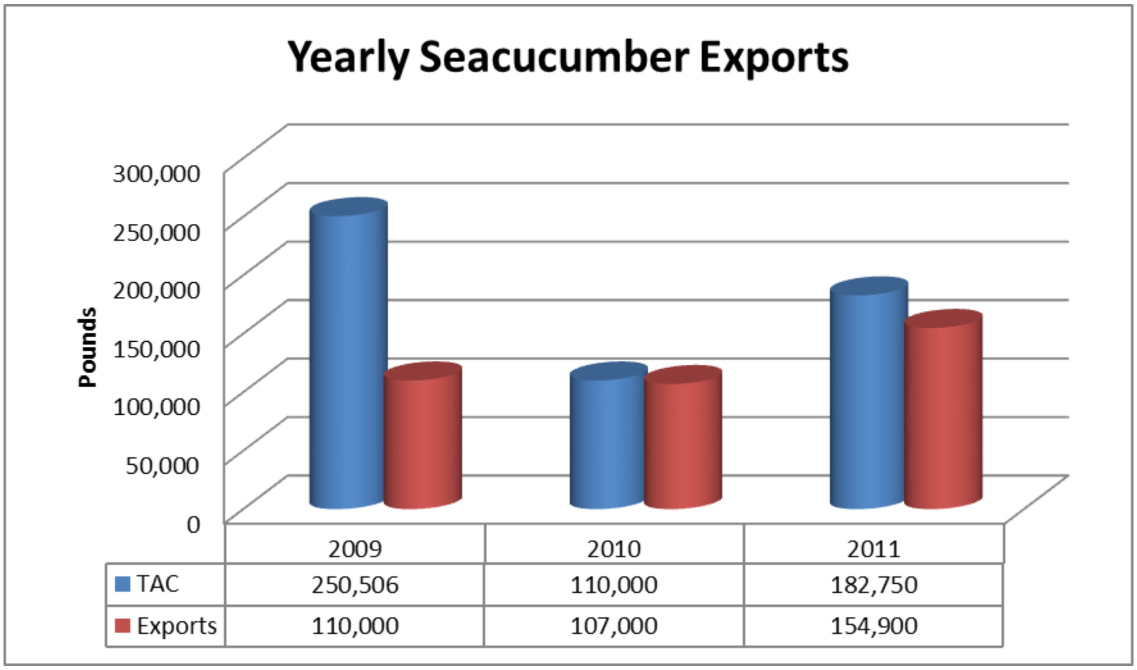

Figure 6.15: Sea Cucumber Catch (TAC) and Exports – 2009-2011(Source: Ministry of Agriculture and Fisheries, 2013)

5.12 Other Commodities: Seaweed

In recent years, fishermen in Belize are encouraged to cultivate seaweed as an alternative to over-fishing and a means of bringing in extra cash. In Belize, seaweed is primarily used to make a local beverage (sea moss) but in the last few years many new products containing seaweed have appeared on the regional market. Belize is in a unique position because it is home to one of the most marketable of Caribbean seaweeds. The main seaweed harvested in Belize is eucheuma, which reportedly grows quickly and stays clean on the farm lines. This seaweed can also be harvested in a very short period of time and has been the most successful species grown so far. Mariculture of seaweed is also helpful to the environment and is a positive type of aquaculture (Ambergris Caye .com Forum).

5.13 Other Commodities: Red Drum Fish

Trials in red drum farming in Belize date back possibly to the 1990s. During 2012 and 2013, Blue Water International – Belize Ltd. (BWIB), a subsidiary of Blue Water International (USA), ran a pilot project in Belize. Then as recently as January 2014, the Department of the Environment (DoE) of Belize held consultations on a proposed red drum fish farm in Belize. The marine cage farming of red drum (Sciaenops ocellatus), also known as "redfish," is being promoted by Blue Water International, just a few miles offshore of Belize City. The proposed site is located within a study area of about 100 acres and is approximately 6.5 miles east from Belize City, 4.75 miles south south-east of Stake Bank Caye, and 0.21 miles south of the south east corner of the Swallow Caye Wildlife Sanctuary. It is adjacent to the lower western side of the Drowned Cayes."

BWIB claimed that the red drum, which can grow to 5-6 feet long and weigh as much as 50 pounds, is not a local specie, but belongs to the same family as grunts, which are caught locally. BWIB claims that at the end of the pilot project (2012-2013), the results indicated that redfish fingerlings could grow to market size in 11-12 months in the warm tropical waters of Belize. It added that, "these growth cycles are achieved in half the time it normally takes redfish to grow to market size in the U.S. onshore farming operations" (Amandala Newspaper, January 14, 2014).

6.0 Fisheries Habitats

Fisheries require healthy habitats to survive and reproduce. Essential fisheries habitats in Belize include all types of aquatic habitats, namely wetlands, coral reefs and seagrasses where fish spawn, breed, feed, or grow to maturity (Figure 6.16).

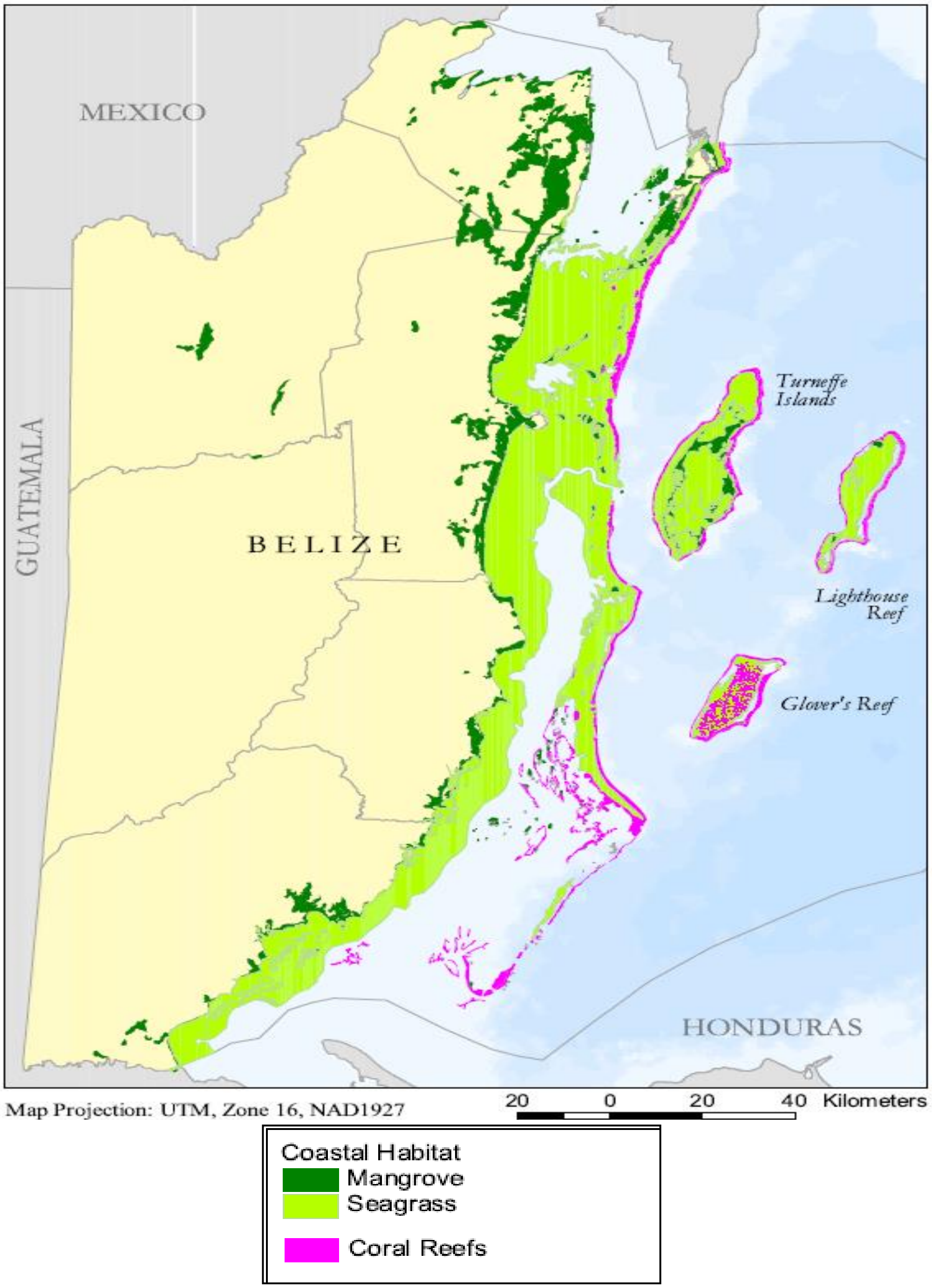

Figure 6.16: Major Fisheries Habitats in Belize

6.1 Coastal Wetlands: Mangroves

Mangrove environments provide a range of vital ecosystem goods and services (Polidoro et al., 2010). Mangrove habitats in particular perform a host of commercial and subsistence uses as well as providing natural coastal protection from erosion and storm events (Ellison, 2009; Waycott et al., 2011). Sea-level rise is reported as the most significant climate change threat to the survival of mangroves and the loss of seaward edge of mangroves and this can be attributed to ongoing sea-level rise and the inability of mangroves to tolerate the increased inundation at the seaward margin when sedimentation rates in mangroves forests are unable to keep pace with sea level rise (McKee et al., 2007; Ellison, 2009; Waycott et al., 2011).

6.2 Seagrasses

The response of sea grass to climate change stress is likely to be complex, regionally variable and potentially manifest in quite different ways even in the same location over foreseeable temporal time frames. Studies have shown that several species of sea grasses are sensitive to heat and light stress (Campbell et al., 2006) In fact studies of climate change impacts on sea grasses suggests increasing atmospheric CO_2 concentrations are likely to initially increase productivity and biomass of sea grass meadows. However, light reduction on account of rising sea levels may be a limiting factor to sea grass growth due to increased depth. Furthermore, sea level rise may significantly increase suspended sediment loads and turbidity in the water column, thereby negatively impacting benthic photosynthetic species such as sea grasses. Otherwise, temperature stress is most commonly reported as the main expected climate change impact on sea grasses (Campbell et al., 2006; Connolly, 2009; Waycott et al., 2011).

6.3 Coral Reefs

Coral reef ecosystems are one of the most important resources of coastal communities like Belize. Coral reefs provide habitats for a host of marine species upon which many coastal communities are deeply dependent for subsistence diets as well as underpinning key beach and reef-based touristic economic activity (Bell et al., 2011). The sensitivity of coral reef ecosystems to climate change is well documented (e.g. Stokes et al., 2010; Lough and van Oppen, 2009). Furthermore, consideration also has to be given to the immediate interdependence of human wellbeing in coastal communities.

Increased coral bleaching due to thermal stress and reduced calcification rates due to increasing CO_2 concentration are expected to affect the function and viability of living reef systems (Cantin et al., 2010). Higher temperatures have also been implicated in negative affects to spawning of adult reef species (Donelson et al., 2010). Unprecedented bleaching events have also been recorded in some of the most pristine, uninhabited locations (Alling et al., 2007; Williams et al., 2010). A recent reef survey around nearby Barbados following a Caribbean regional bleaching event revealed the most severe bleaching ever recorded with approximately 70% of corals impacted (Oxenford et al., 2008).

In Belize, the combination of disturbance events and chronic stresses has caused a decline in live coral cover and parallel increases in macroalgae on many reefs. The Acropora species have suffered a dramatic reduction in live cover since the late 1970s as a result of white band disease, and the region-wide die-off of the long-spined sea urchin grazer (Diadema antillarum). In 1998, the most severe coral bleaching event on record occurred, along with the catastrophic impacts of Hurricane Mitch that produced torrential rains, flooding, and destructive waves that caused considerable mechanical damage to reefs. The combination of bleaching, hurricane damage, and increasing chronic local stresses, has resulted in dramatic reductions in coral cover: 62% in southern Belize; 55% in the north; 45% on the atolls; and 36% on central reefs. Long-term data exist for a few sites in Belize; live coral cover on shallow patch reefs in Glovers Reef atoll has decreased from 80% in 1971, to 20% in 1996, and to 13% in 1999. The inner fore-reef region at Carrie Bow Caye had 30-35% coral cover in the 1970s, but declined to 12- 21% in 1995. Similarly on the fore-reef at Channel Caye (3-15 m depth), an inner-shelf faroe, live coral declined from 85% in 1986 to 60% in 1996, primarily because of disease and loss of staghorn corals (Acropora cervicornis), with partial replacement by thin leaf lettuce coral (Agaricia tenuifolia). Subsequently, bleaching in 1998 devastated this reef, reducing coral cover to about 5% in 1999. In 1992, the coral cover on the barrier reef off Ambergris Caye and Gallows Reef (near Belize City) was 25% and 20% respectively. In 1993, the coral cover on the shallow Mexico Rocks patch reef off Ambergris Caye was 84%, but dropped to 66% in 1995 primarily as a result of the 1995 coral bleaching event. Prior to 1998, most impacts on reefs in Belize were from diseases and hurricanes, although regional increases in nutrient concentrations and sedimentation, loss of Diadema, moderate over-fishing, and bleaching were also likely contributors. The combined impacts of mass coral bleaching and Hurricane Mitch in 1998 exacerbated the rate of reef decline (Mcfield et al., 2006).

The following Figure 6.17 summarizes coral bleaching in Belize waters for bleaching seasons 2008-2012. It shows that for October/November there was significantly less bleaching in 2010 than in 2008. Other years were not significantly different. Observations from Figure 6.17 indicate:

The 2011-2012 bleaching season was impacted corals most and more than 20% coral colonies were affected for two months, namely, September and October;
Three peaks occurred in 2008-2009 during the months of October, December and April;
The mildest bleaching season was 2010-2011 which exhibited a peak in September but percent affected did not exceed 10%.

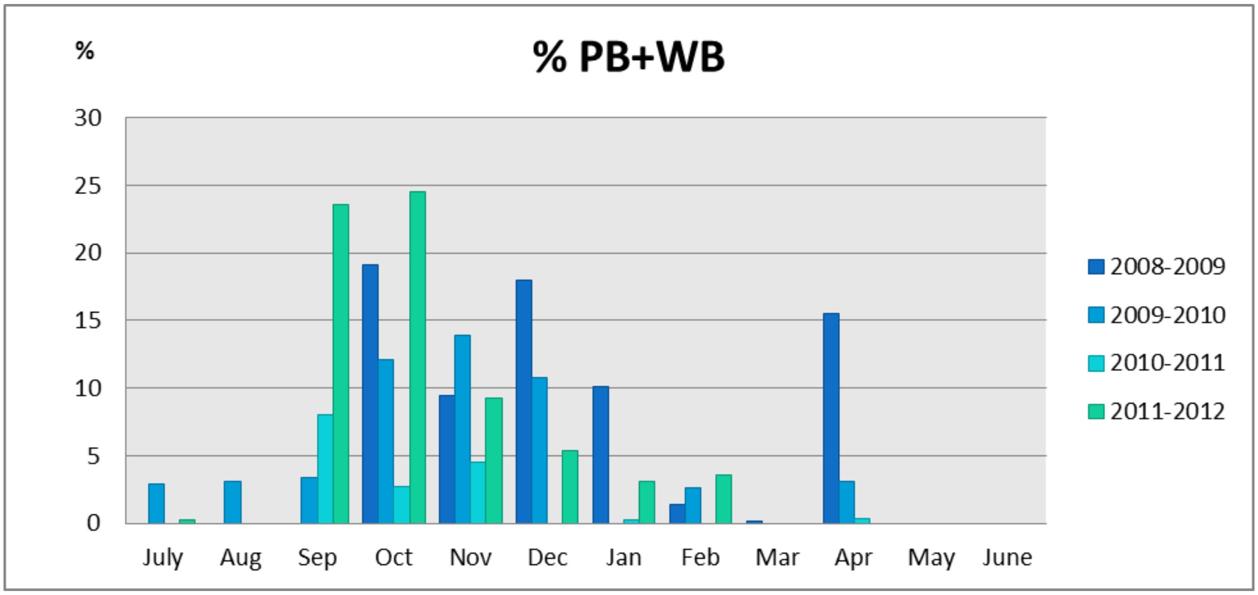

Figure 6.17: Summary of % part bleached (PB) or whole bleached (WB) coral colonies in Belize (Source: Searle et al., 2012)

However, studies have shown that coral reef resilience is enhanced in the absence of additional environmental stress such as declining water quality. In Belize chronologies of growth rates in massive corals Montastraea faveolata over the past 75–150 years showed that the bleaching event in 1998 was unprecedented in the past century but that the severity of the response also appeared to stem from reduced thermal tolerance resulting from the direct interactive effects of human coastal development (Carilli et al., 2010).

The loss of coral reef habitat has dire implications to coastal fisheries resources and more so in coastal communities like Belize where reef based subsistence and tourism activities are so intimately linked to the wellbeing and economies of these countries (Bell et al., 2011).

7.0 Climate Change Impacts on Fisheries

In view of the projected changes in air temperature, especially and changes in sea level and ocean acidity, one can expect mostly negative impacts on the fisheries sector of Belize. On a global scale, the ocean warming is largest near the surface, and the upper 75 m warmed by 0.11 °C per decade over the period 1971–2010. Furthermore, ocean acidification as expressed by the pH of ocean surface water has decreased by 0.1 since the beginning of the industrial era, corresponding to a 26% increase in hydrogen ion concentration IPCC, 2013).

In this section we compare current (2003-2012) and future (2060-2069) decadal temperature and rainfall for three locations in the major fishing zones of Belize, namely Ambergris Caye representing Zone 1, Belize City representing Zones 2 and 3 and Placencia representing Zones 3 and 6 (See Figure 6.1).

At first, examining the Ambergris Caye station the closest weather station to Zone 1, mean monthly near-surface air temperatures are expected to increase by > 1 ^{0} C in all months of the year in the future (2060-2069) and this would very likely also lead to warmer near surface ocean temperatures which can influence fish populations, fish varieties and zooplankton that provide food for fishes. Mean monthly rainfall, that has less of an impact on fisheries are also expected to increase in general, especially in the high tourist months (November to May) and this may impact negatively on tourism fishing (Figure 6.18).

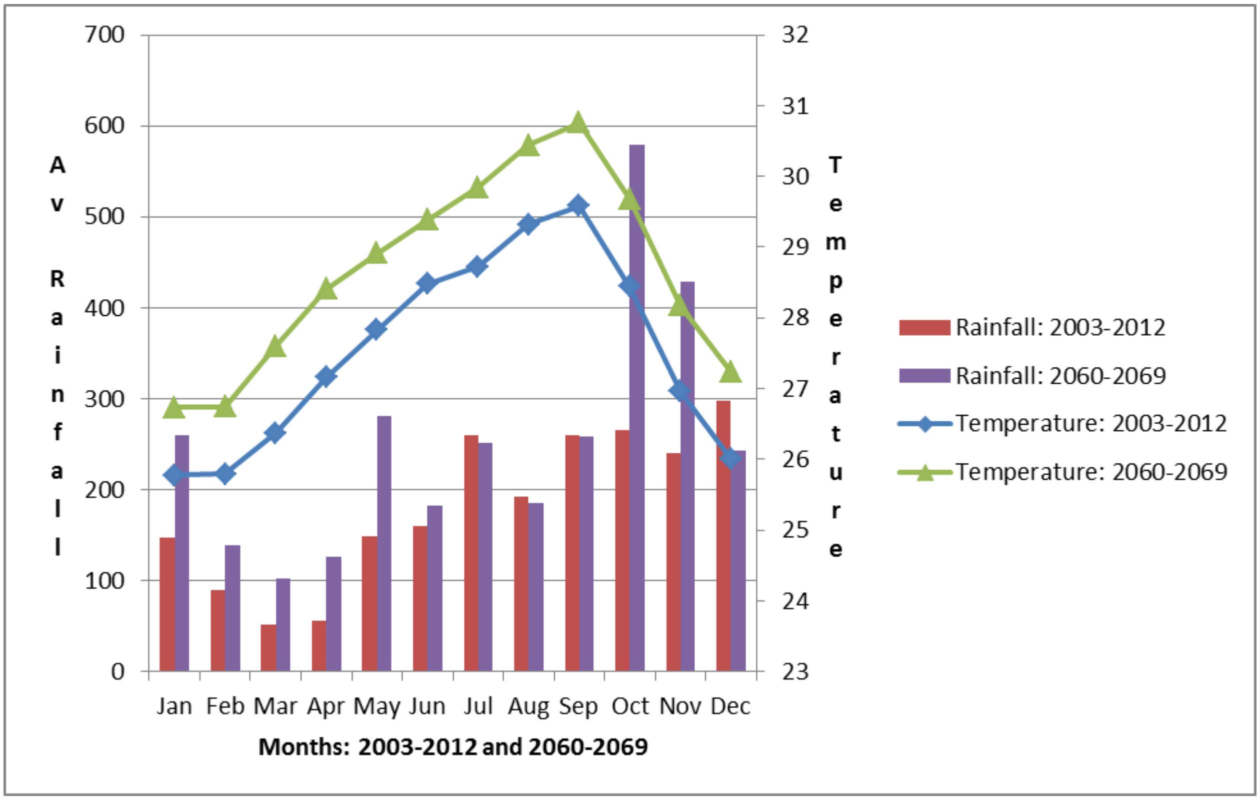

Figure 6.18: Current (2003-2012) Mean Monthly Temperature (0C) and Average Monthly Rainfall (mm/month) for the Ambergris Caye area according to the ECHAM5 model data

Next, examining the Belize City location (Zones 2 and 3), mean monthly near-surface air temperatures are expected to increase by ~1 ^{0} C in all months of the year in the future (2060-2069) and this would again very likely also lead to warmer near surface ocean temperatures which can influence fish populations, fish varieties and zooplankton that provide food for fishes. Mean monthly rainfall, that has less of an impact on fisheries are however expected to decrease in general and this may create more favorable conditions for tourism fishing (Figure 6.19).

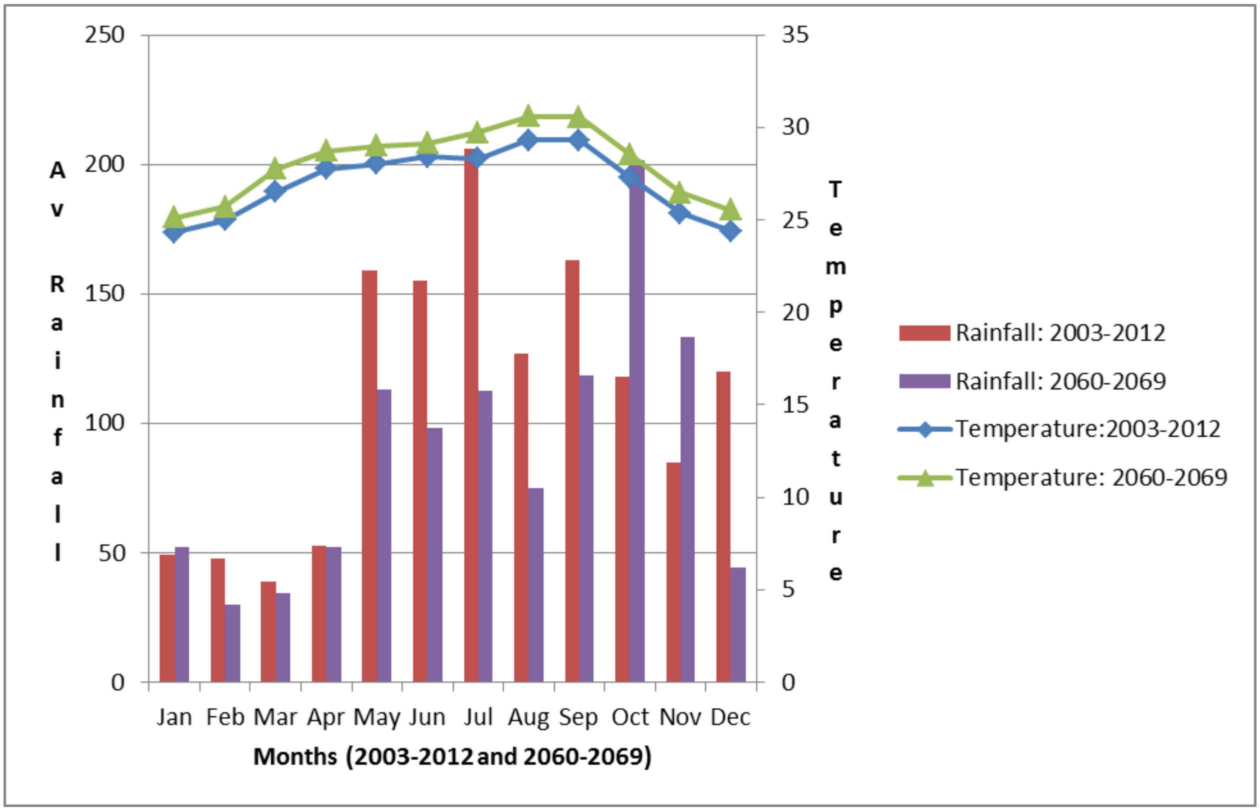

Figure 6.19: Current (2003-2012) Mean Monthly Temperature (0C) and Average Monthly Rainfall (mm/month) for the Belize City area according to the ECHAM5 model data

Finally, examining the Placencia location (Zones 3 and 6), mean monthly near-surface air temperatures are again expected to increase by > 1 ^{0} C in all months of the year in the future (2060-2069) and this would very likely also lead to warmer near surface ocean temperatures which can influence fish populations, fish varieties and zooplankton that provide food for fishes. Mean monthly rainfall that has less of an impact on fisheries however does not change much except for the month of October, which is outside the main tourist season and would therefore have little or no may negatively on tourism fishing (Figure 6.20).

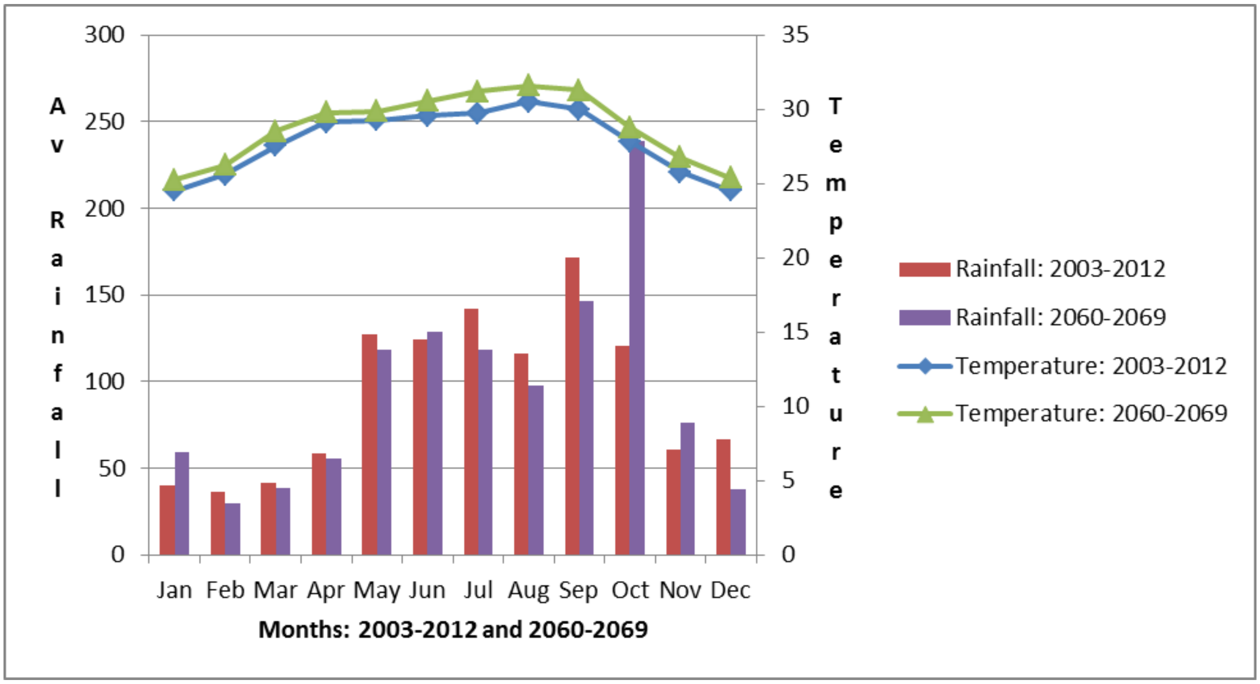

Figure 6.20: Current (2003-2012) Mean Monthly Temperature (0C) and Average Monthly Rainfall (mm/month) for the Placencia area according to the ECHAM5 model data

8.0 Non-climate Factors

Fisheries stocks in Belize not only supply locals with an important food source but also generate income and livelihoods for fishermen. In addition, commercial fisheries have traditionally been important foreign exchange earners for many nations, particularly coastal ones such as Belize.

However, fish stocks in the Belize are overexploited. The largest pressure on Belize's fisheries stocks are from overfishing, including illegal fishing. In Belize there have been large-scale declines in fisheries production and exports in recent years (See Figure 6.22).

Another indicator of higher pressure on Belize's fisheries stocks are reports that fish that used to be considered of lesser quality for consumption were targeted for capture. Fish in this category included herbivorous fish such as parrotfish. Such fish are critical regulators of coral reef ecosystems and coral cover build-up, as they graze on macro algae that compete with corals. These fish species were being caught due to a continued decline in large, preferred commercial fish species such as the groupers, and are usually filleted (Belize Environmental Outlook, 2010).

However, the Belize Fisheries Department has taken the necessary steps to stop this practice. The Nassau Grouper has been regulated by imposing a closed season and limitations of fish size. Furthermore Parrotfish and other grazers have been fully protected since 2009 (See Figure 6.21).

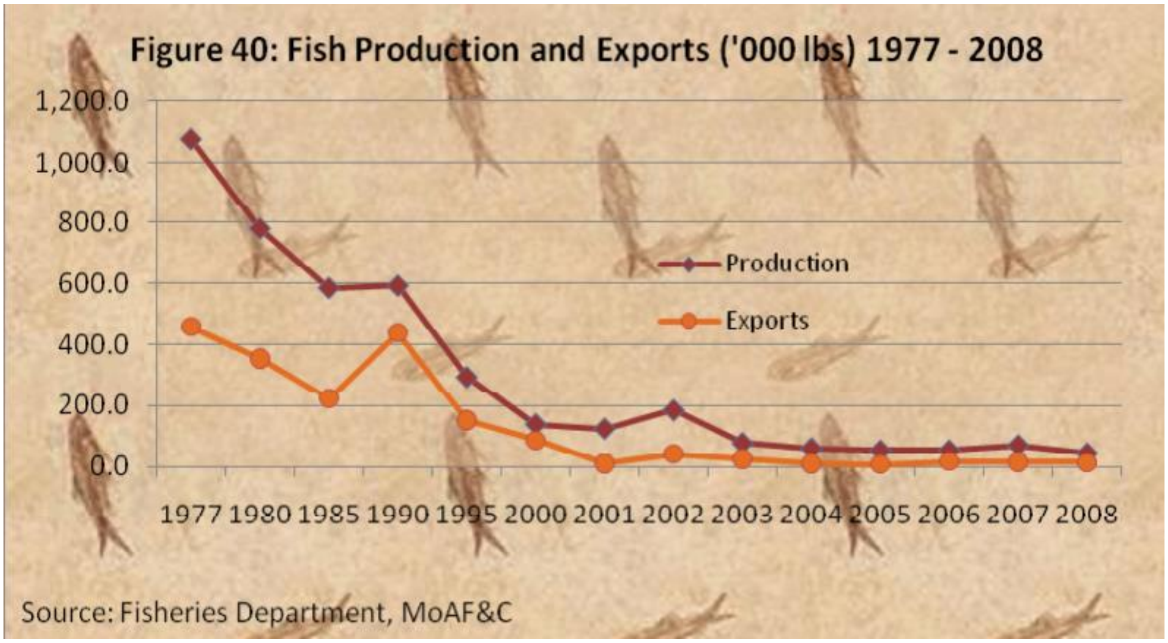

Figure 6.21: Belize Fish Production and exports: 1977-2008 (Source: Belize Environment Outlook, 2010)

As for large fish, the Nassau Grouper is on the IUCN Red List of Endangered Species and the Goliath Grouper is categorized as critically endangered by the IUCN Red List. Nassau Grouper is particularly vulnerable to depletion as large numbers meet during predictable times in spawning aggregations. Similarly, Goliath Grouper is a species that is also vulnerable, mostly because this species must inhabit mangrove habitats as juveniles and is therefore especially sensitive to unsustainable coastal development (Belize Environmental Outlook, 2010).

Furthermore, the growing resident and tourist population will continue to place increased pressure on Belize's fisheries and that more opportunities for direct sales will be available making the enforcement of size regulations more difficult. In addition to the disappearance of large species like groupers recent reports indicate that there is a great scarcity of apex predators such as sharks and rays. These species are also considered to have critical ecosystems roles and play an important role in regulating coral reef functioning. They are believed to be good indicators of fishing pressures and "in coral reef habitats, of high fish biomass and a functional ecosystem". Surveys conducted on fisheries in Belize reveal that these once abundant species are in decline. They are being hunted not only by Belizeans, but also by non-Belizeans (Belize Environmental Outlook, 2010).

Employment, income and foreign exchange generation through capture fishing will continue to decline if an adequate fisheries management regime is not implemented. It is likely then that the role of aquaculture will continue to increase, perhaps eventually replacing capture fisheries. This, however, can add pressure to coastal ecosystems through land-use changes. It is also likely that as long as there are still viable fisheries stock people will continue to fish legally or illegally. Therefore, apart from the economic losses, the health of the coastal and reef ecosystems may be lost as fisheries stocks decline beyond recovery. If this were to happen, Belize will not only lose its wild fisheries stocks but also the other ecosystem services that the coasts and reefs provide (Belize Environmental Outlook, 2010).

9.0 Adaptation: Fisheries Sector

The implementation of an appropriate fisheries management policy as a measure to promote reef ecosystem resilience and fisheries sustainability appears to be a sound strategy for Belize. The resources for capture fisheries are largely already fully or overexploited in Belize. Overfishing is widely regarded as the primary pressure on marine fishery resources but other human activities including rapid coastal zone development, land-based pollution and other activities are also negatively impacting the status and production of fisheries in Belize.

Climate change adds another compounding influence on the fisheries sector of Belize. The vulnerability of fisheries and fishing communities to climate change in Belize will depend on their exposure to its physical and ecological effects, their dependence on the fishery and their sensitivity to physical effects, and their adaptive capacity.

Adaptive responses to climate change in fisheries could include:

- management approaches and policies that strengthen the livelihood asset base, improved understanding of the existing response mechanisms to climate variability to assist in planning adaptation;
- recognizing and responding to new opportunities brought about by climate change;
- monitoring biophysical, social and economic indicators linked to management and policy responses and adoption of multi-sector adaptive strategies to minimize negative impacts such as instituting Government regulations on fishing seasons (Figure (6.22)

A wide range of management tools and strategies have been developed to manage fisheries. However, this array of tools is necessary but not sufficient for adaptation to climate change in fisheries. The standard tools for fisheries management were developed to control fishing mortality and to maintain adequate levels of recruitment to fishery stocks but without necessarily addressing the needs for resilience to change or to be able to function under changing climates (Grafton, 2010) He further proposes that these conventional management tools must be used within processes that:

- have a core objective to encourage ecosystems that are resilient to change;

- explicitly take into account uncertainties about future conditions and the effect of adaptation, and make use of models and other tools to explore the implications of these future and uncertain conditions.

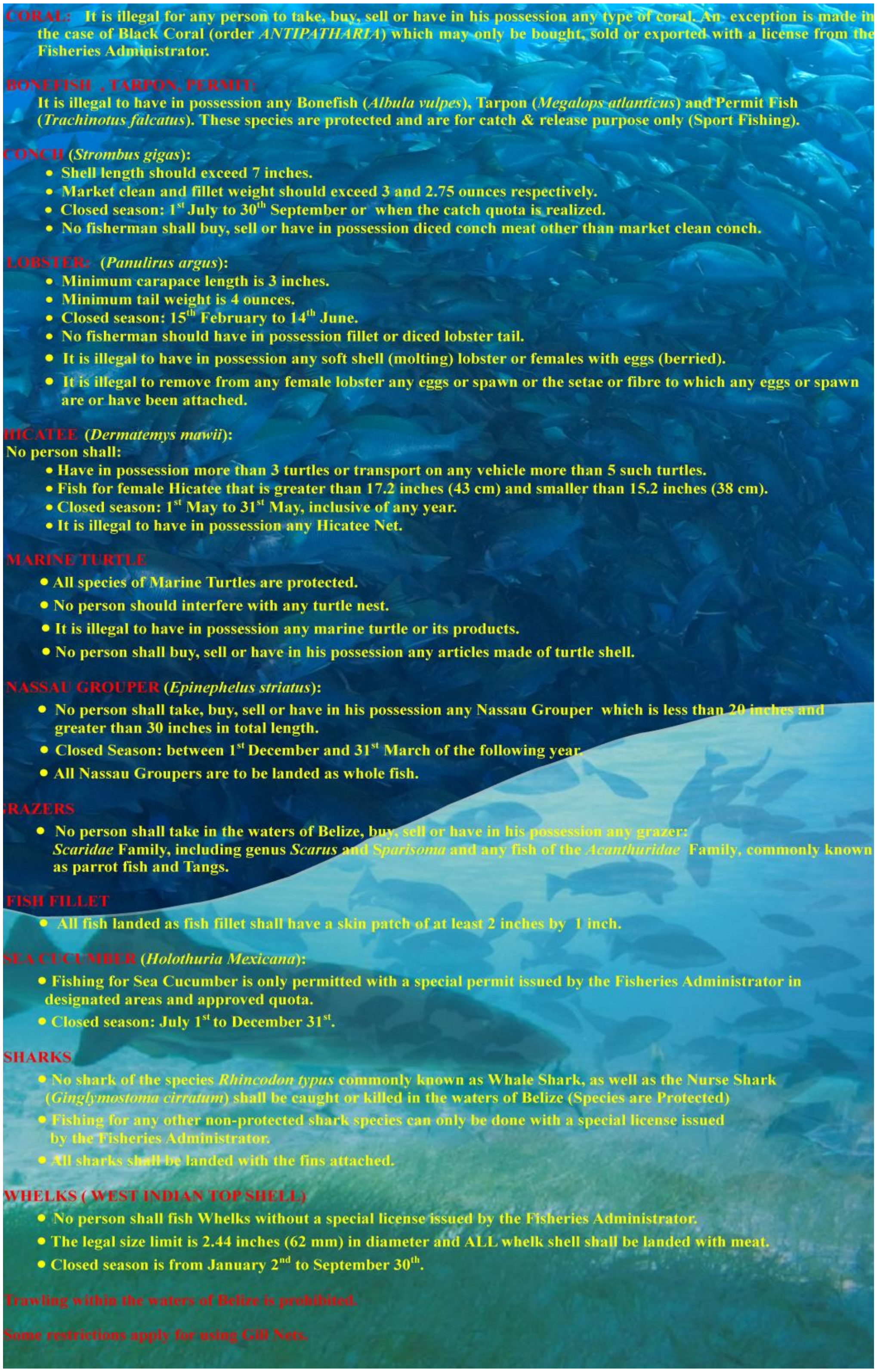

Figure 6.22: Fisheries Regulations (Belize Fisheries Department

There are also opportunities for fisheries to contribute to mitigation efforts in fisheries. Complementary adaptive responses include occupational flexibility, changing target species and fishing operations, protecting key functional groups, developing early warning systems for extreme events and the establishment of insurance schemes. Governance and management of fisheries will need to follow an ecosystem approach to maximize resilience of the ecosystem, and to be adaptive and flexible to allow for rapid responses to climate induced change (Grafton 2010).

In contrast to capture fisheries, aquaculture is estimated to be the fastest-growing animal-food-producing sector in Belize. Adaptive responses in aquaculture include the use of improved feeds and selective breeding for higher temperature tolerance strains to cope with increasing temperatures and shifting to more tolerant strains of molluscs to cope with increased acidification. Better planning and improved site selection to take into account expected changes in water availability and quality; integrated water use planning that recognizes and takes into account the water requirements and social and economic importance of fisheries and aquaculture in addition to other sectors; and improving the efficiency of water use in aquaculture operations are other adaptation options. In some near-shore locations like Placencia, there may be a need to shift property lines as the mean high water mark is displaced landwards by rising sea level (FAO Paper, 2009).

There are no simple, generic recipes for adaptation. But separate inter-related actions that could be taken to adapt fisheries and aquaculture in Belize to climate change could include (Bell et al. (2011) :

- economic development and government revenue;
- maintaining the contribution of fish to food security;
- maximizing sustainable livelihoods.

Furthermore, actions and policies for adaptation in fisheries and aquaculture should also complement those for other sectors. The greater the number of different production systems to which communities have access, the greater the chance that some systems available to them will not be negatively impacted and that some may even benefit from climate change. Similar case-by-case, integrated planning will be required in all other regions and at scales from community to regional to achieve clearly defined adaptation goals (Bell et al.2011).

In 2011, the Belize Fisheries Advisory Board and the Cabinet of Ministers authorized the use of Managed Access at two pilot sites to determine the viability and impact. Under this program, fishermen are expected to personally benefit from an increased in their individual production; which should provide the incentive for their commitment to comply and conform with the fisheries management measures being instituted in line with sustainable livelihoods and the supporting bio-ecological stocks and ecosystems. Fishermen will play an integral role in the management, monitoring and decision-making process of the Managed Access or Catch Shares program. This will in effect enhance their rightful roles as co-managers of the fisheries resources in the specific areas. This is critical given the enormous task and financial and material resources required by the Government in ensuring the sustainable use and development of the nation's fisheries resources. This program was also designed to improve enforcement efforts by placing greater surveillance and reporting responsibilities in the hands of the fishers themselves. It will provide the necessary incentives to instill greater sense of ownership of the fishery resource by the fishermen which bodes well for their commitment and support in restoring and maintain the health and abundance of the stocks (Ministry of Agriculture and Fisheries (2013).

After eighteen months of operations at Port Honduras Marine Reserve (PHMR) and Glover's Reef Marine Reserve (GRMR), the results from two separate independent evaluations, biological data, and surveys of fishermen are proving that Managed Access is working. Managed Access is creating more incentives for fishermen to comply with regulations, and illegal fishing is declining (Ministry of Agriculture and Fisheries (2013) :

- Managers have reported an approximately 50% decline in illegal trans-boundary fishing at PHMR, and an estimated 90% at GRMR;
- Enforcement data from Belize Fisheries Department is showing declines in the taking of undersized product, fishing in the closed season, and fishing in no-take zones. Better compliance with the no-take zones as a result of managed access is leading to better recovery and spillover of fish into General Use Zones;
- There is 100% compliance with the new licensing policy, and over 80% compliance with data submission at both sites – a remarkably high rate;
- Managed Access fishermen report that Managed Access is working for them and according to a survey of fishermen:
- A large majority of fishermen at both sites feel that they personally have benefitted from Managed Access, and are seeing increased yields, particularly following the start of the 2012 conch season;
- A large majority of Managed Access fishermen from both sites were of the opinion that Managed Access would increase security of livelihoods;
- 100% of Managed Access fishermen interviewed from Glovers Reef Marine Reserve considered that the Managed Access regime would increase sustainability of the marine resources;
- 83% of the Port Honduras Marine Reserve fishermen interviewed stated that their catch had increased.

These trends indicate that PHMR and GRMR are on the path to experiencing a recovery in their fisheries, a healthier ecosystem, and more opportunity for fishermen. The most telling indicator is that a majority of Managed Access fishermen at both sites agreed that the policy should be rolled out at a national level. Currently, the stance of the department is to roll-out managed access to the entire Marine Reserve Network including Lighthouse Reef Atoll. The fisheries department is also looking into the possibility of partnering with a social marketing group of experts called RARE that will assist the department in changing fishermen behavior and increasing the acceptance and endorsement of managed access expansion to other sites.

The results of the assessment of the implementation of managed access at the pilot sites were completed in January 2013. The report indicated that managed access has showed success at both sites. With this assessment the Belize Fisheries Department felt confident of the management tool implemented and now seeks to expand this management tool to the entire marine reserve network (nine Marine Reserves and one National Monument). In order to lead the expansion, the Belize Fisheries Department sought to assemble a coalition from the NGOs, scientific community and Fisher organizations that will work with the Government of Belize. The strategy for implementing the expansion of Managed Access included (Ministry of Agriculture and Fisheries (2013) :

- Creating a management plan for the proliferation of Managed Access at each location that is supported by all stakeholders including the Government of Belize, fishermen and the fishing industry, scientists, and the NGO community;
- Creating a cohort of Belizean Managed Access experts through a comprehensive training and capacity building program;
- Ensuring that Managed Access and its proliferation has the support of political leaders and policymakers;
- Promoting the benefits of Managed Access through a national outreach campaign to ensure widespread support from fisherman and other key stakeholders;
- Building capacity for and mobilizing fishermen through training and a community organizing program;
- Creating economic development opportunities including alternative livelihoods and premium seafood marketing;
- Acquiring the necessary infrastructure and materials to implement and operate managed access.

However, the Fisheries Department of Belize will be developing species specific management plans for lobster and conch starting in 2014.

Another example of providing an alternative livelihood for fishermen is found in Sarteneja, a key stakeholder community of the Belize Barrier Reef (www. gefsgp.org: GEF Project, 2007).

The Sarteneja Fishermen Association (SFA) is a community-based membership organization, with a membership of over 110 artisanal fishermen, based from the fishing community of

Sarteneja, in Corozal District. The SFA was registered on 19th September 2007, and seeks to provide alternatives for fishermen who wish to leave fishing, reducing the dependence of the community on the declining lobster and conch resources of the Belize Barrier Reef Reserve System - World Heritage Site.

Sarteneja has long been recognized as one of the major impacting communities on the Belize Barrier Reef Reserve System World Heritage Site, an area of exceptional biodiversity threatened by overfishing.

It is recognized at local, national and international level that the artisanal fishing industry is in decline, with too many fishermen seeking a declining and potentially unsustainable fisheries resource. With the majority of fishermen of Sarteneja leaving school at primary level and a lack of training in other work programs, it is hoped that this initiative will provide alternative livelihoods for the Sarteneja fishermen (www. gefsgp.org: GEF Project, 2007).

As for adaptation in the aquaculture sector a recent report by the Caribbean Regional Fisheries Mechanism (CRFM) and the Food and Agriculture Organization (FAO) on 'Climate change adaptation and disaster risk management in fisheries and aquaculture in the CARICOM region' aims is to develop a short-term strategy and action plan for integrating Disaster Risk Management DRM, and Climate Change Adaptation (CCA) and fisheries and aquaculture, with a focus on small-scale fisheries (SSF) and small-scale aquaculture (McConney et al., 2013).

This short-term strategy and action plan is built upon, and integrates into, core policy documents. The regional policy context is primarily the 'Regional Framework for Achieving Development Resilient to Climate Change' (the Regional Framework) that articulates CARICOM's strategy on climate change.

Several policy instruments need to be taken into account specifically for ecosystem approaches to fisheries and aquaculture. These documents contribute to a vision such as: regional society and economy that is resilient to a changing climate and enhanced through comprehensive disaster management and sustainable use of aquatic resources.

The Caribbean Community Climate Change Centre (CCCCC) Regional Framework contains five strategy elements and twenty goals or similar statements. Some are more relevant to fisheries and aquaculture, using an ecosystem approach, than others. Several aspects are developed in the Implementation Plan (IP), mainly under the heading of coastal and marine matters. This strategy and action plan incorporates fisheries and aquaculture more prominently into the IP as requested by the CRFM in order to strengthen the existing linkages to mutual advantage (McConney et al., 2013).

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Section 7: Tourism Sector

1.0 Introduction

The tourism industry in Belize is developing at a fairly fast rate, engaging a wide range of tourism operators and employment of significant numbers of Belize's population. Moreover, the tourism sector in Belize is one of the most important for the country's economy.

Belize's tourism industry is the largest contributor to the gross domestic product and the largest source of foreign exchange. Tourism was the largest income earner in 2005 and 2006, accounting for nearly BZ $350 and 400 million in earnings, respectively. This is equates to 16% and 17% of the GDP, respectively (Belize Tourism Board (BTZ): Travel and Tourism Statistics Digest, 2012)

A changing climate, along with sea level rise, would result in loss of beaches, properties and public infrastructure and will make Belize less attractive as a tourist destination. The loss of beaches and coastline due to erosion, inundation and coastal flooding and loss of tourism infrastructure, natural and cultural heritage would reduce the amenity value for coastal users (IPCC AR4, 2007).

One meter rise in sea level would impact 30% of Belize's wetlands (The Impact of Sea Level Rise on Developing Countries: A Comparative Analysis, February 2007) and none of the remnant Cayes in Belize will have a source of potable water (First National Communication to the Conference of the Parties of the United Nations Framework Convention on Climate Change, January 2000). Additionally, some coastal areas in Belize will experience high levels of saltwater intrusion and rising water tables, thereby reducing water quality. Decline in water quality due to salinization of aquifers would lead to higher costs of water because Cayes and other coastal areas would need to invest in desalinization plants.

The overall effect of changing climate on Belize's tourism industry would be a loss of employment and higher insurance costs for properties in vulnerable area (The Impact of Sea Level Rise on Developing Countries: A Comparative Analysis, February 2007).

An assessment of the economic vulnerability of Belize's tourism industry to climate change mentioned that reef-based activities attract more than 80 percent of foreign tourists. Coral mortality from climate change and other human-induced impacts may reduce the appeal of visitors that would like to participate in underwater recreational activities. The assessment further suggested that perceptions of reef quality may be an important factor in the assessment of the vulnerability of tourism demand to climate change in Belize (Richardson, 2007).

Climate change and climate-driven sea level rise will, in most likelihood, have important and severe impacts on the tourism industry of Belize. Increases in air temperature (2 ^{0}C to 4 ^{0} C) towards the end of the century may make conditions unbearable, especially for the elder retired tourist population, the major age group of tourists. Variability in precipitation that is also projected will very likely lead to extreme conditions, namely increasing drought in the dry season and torrential rains and flooding in the rainy season and to water and food shortages or higher prices if imported. Tropical storms and hurricanes, compounded by sea level rise, are also likely to increase in numbers and intensity, and apart from flooding and erosion of recreational beaches they will also very likely cause flooding and damage to transport and other infrastructure.

These projected changes in climate will have indirect secondary and tertiary effects on supply-based and demand-based systems upon which the tourism industry of Belize is dependent. Supply-based systems include: loss of beaches, loss of coral reefs due to temperature-induced bleaching, loss of food supply chains and loss of coastal infrastructure. Demand-based systems on the other hand include weather conditions in country of origin of tourists (mainly North America and Europe), perception issues such as security from extreme weather events and pricing policies for transport lodging and entertainment (See Figure 7.1).

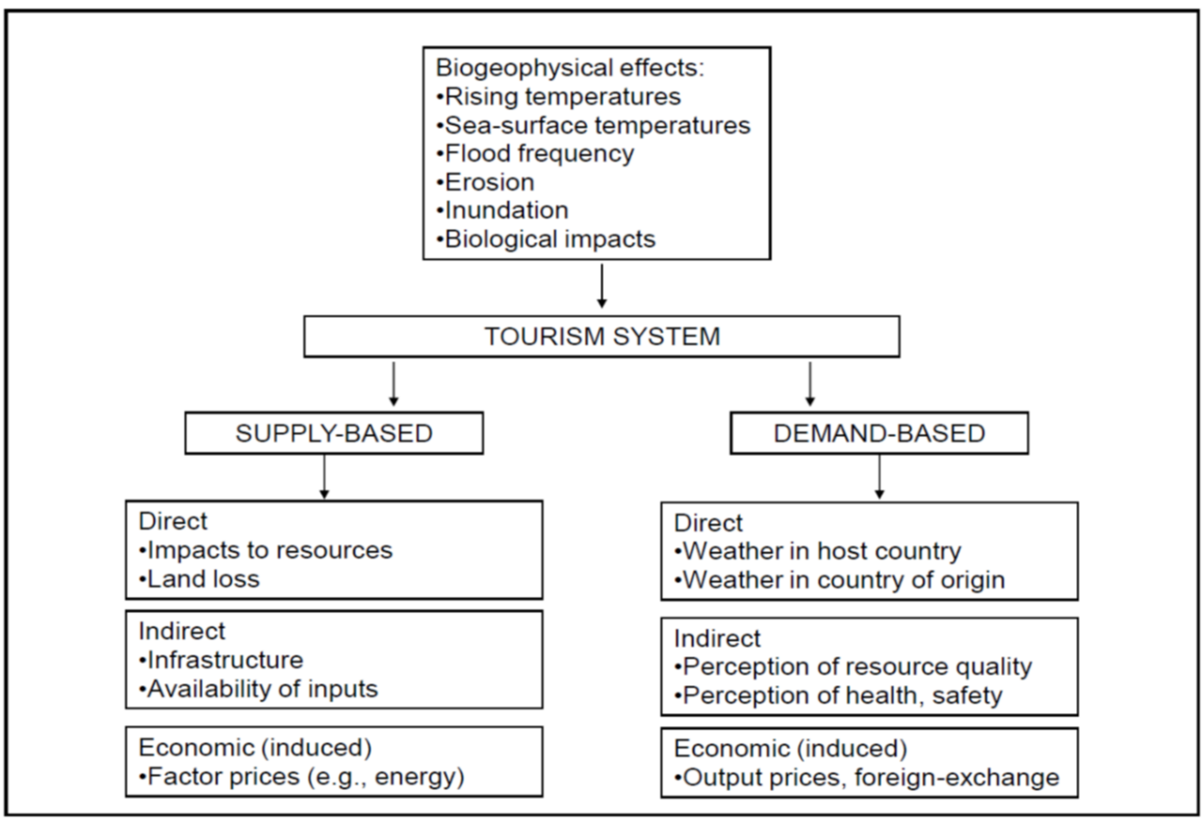


Figure 7.1: Framework for Tourism Sector Vulnerability Assessment (Source: Richardson, 2007)

2.0 Contribution of Tourism to the Economy of Belize: GDP and Employment

The direct contribution of the Travel and Tourism Industry to the GDP (Gross Domestic Product) of Belize includes contributions by industries that deal directly with tourists, including hotels, travel agents, airlines and other passenger transport services, as well as the activities of restaurant and leisure industries that deal directly with tourists. It also includes, for example, the activities of the restaurant and leisure industries directly supported by tourists.

The percentage direct contribution of the Tourism Sector increased steadily from ~ 12 % in 2002 and peaked at 27 % in 2009. However there was a drop off after 2009 due to the economic slowdown in North America and Europe, the major visitors. In 2012 the percentage again approached 27 % and projections for 2022 are over 30 % (See Figure 7.2: World Travel and Tourism Council, 2012).

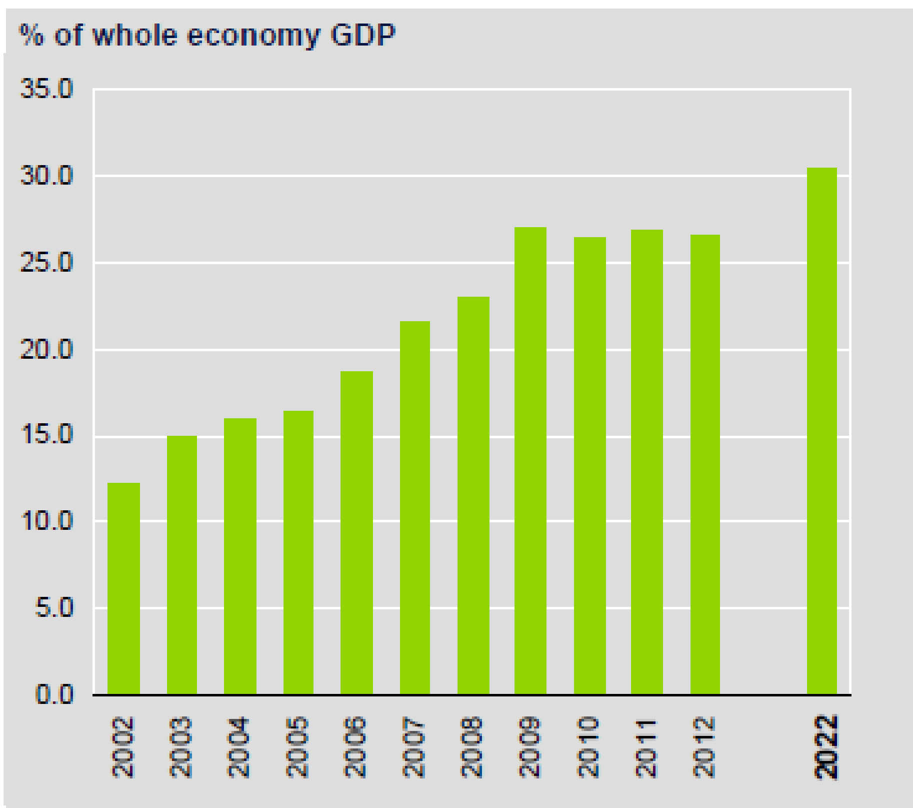


Figure 7.2: Percentage contribution of the Travel and Tourism Sector to the GDP of Belize (2002-2012) and projections to 2022 (Source: World Travel and Tourism Council (2012)

In line with the trend in GDP the number of jobs generated by the Tourism Sector of Belize increased steadily from ~ 7,000 (~7.5 %) in 2002 and peaked at ~ 16,000 (13.5 %) in 2007. However there was a drop off after 2007 due to the economic slowdown in North America and Europe, the major visitors. In 2012 the total number of jobs rebounded to ~ 15,000 (11.5 %) and projections for 2022 are over 22,000 jobs ~ 12 % (See Figures 7.3 and 7.4: World Travel and Tourism Council, 2012).

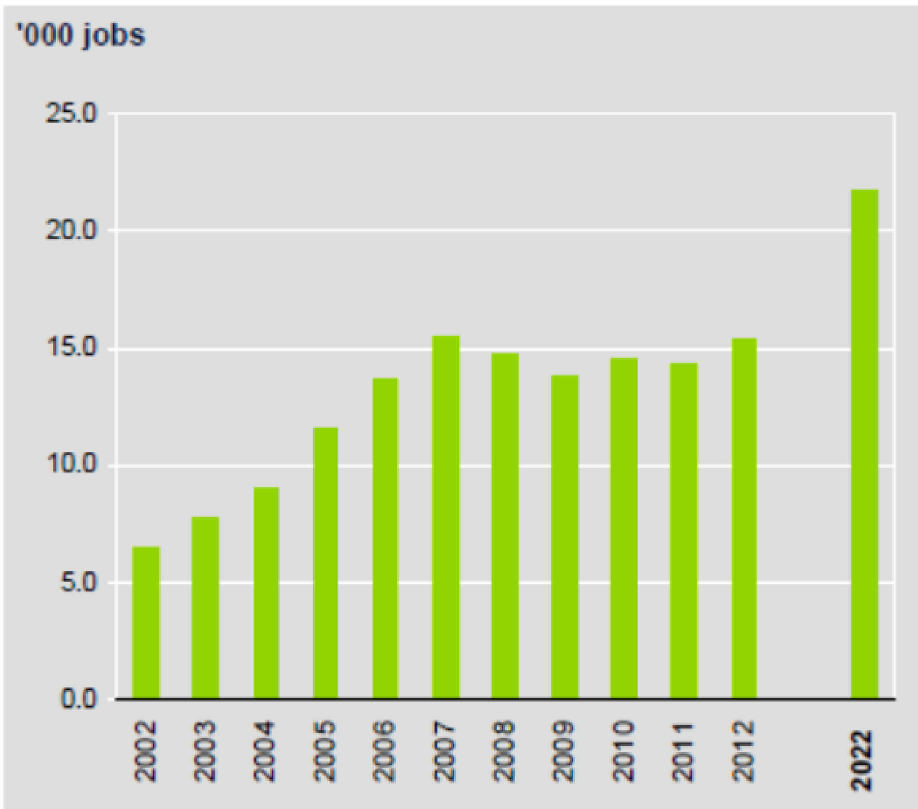


Figure 7.3: Contribution to the Number of Jobs (‘000) generated by the Travel and Tourism Sector (%) of Belize (2002-2012) and projections to 2022 (Source: World Travel and Tourism Council (2012)

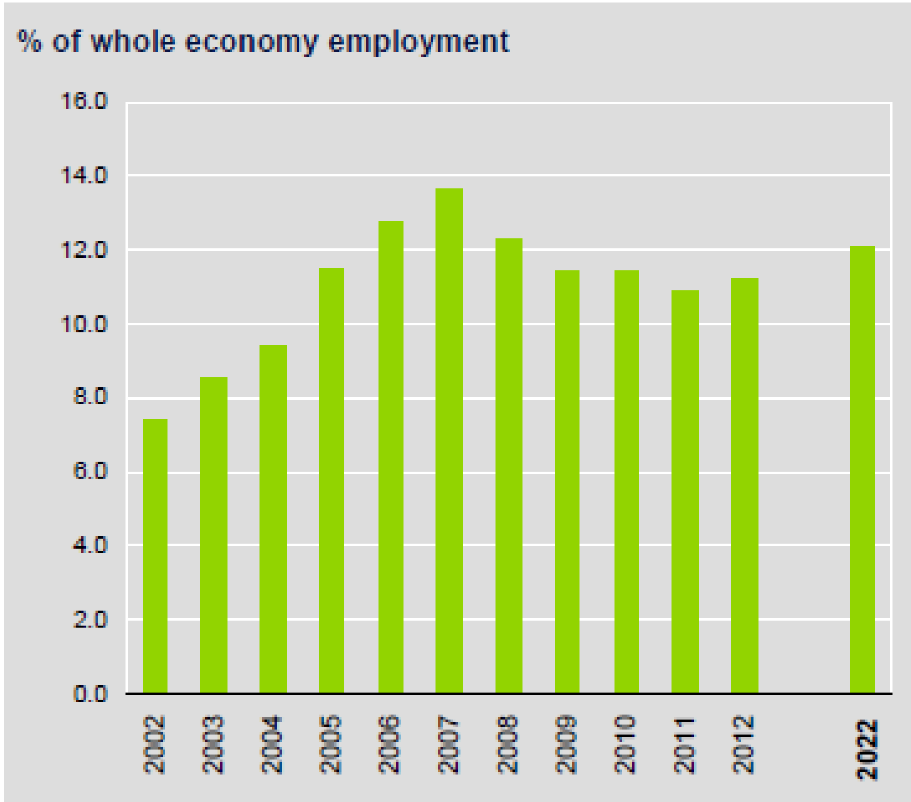


Figure 7.4: Percentage contribution of the Travel and Tourism Sector to the percentage (%) of employment of Belize (2002-2012) and projections to 2022 (Source: World Travel and Tourism Council (2012)

The total contribution of Travel and Tourism to GDP and jobs is nearly three times greater than its Direct contribution when one adds the Indirect and Induced contributions **(**World Travel and Tourism Council, 2012).

Indirect contribution represents the contribution to GDP and jobs of the following three factors:
Capital investment which includes capital investment spending by all sectors directly involved in the Travel and Tourism industry. This also constitutes investment spending by other industries on specific tourism assets such as new visitor accommodation and passenger transport equipment, as well as restaurants and leisure facilities for specific tourism use.
Government collective spending includes general government spending in support of general tourism activity. This can include national as well as regional and local government spending. For example, it includes tourism promotion, visitor information services, administrative services and other public services.
Supply-chain effects include purchases of domestic goods and services directly by different sectors of the Travel and Tourism industry as inputs to their final tourism output.

Induced contribution on the other hand relates to the broader contribution to GDP and employment of spending by those who are directly or indirectly employed by Travel and Tourism.

Using the year 2012 as an example, it can be seen that the total number of jobs created by the Travel and Tourist Industry in Belize was ~ 40,000 jobs (~ 31 %) of which, ~ 15,000 jobs (~ 11 %) were direct, 16,000 jobs (14 %) were indirect and ~ 9,000 (~ 6 %) were induced (See Figures 7.5 and 7.6: World Travel and Tourism Council, 2012).

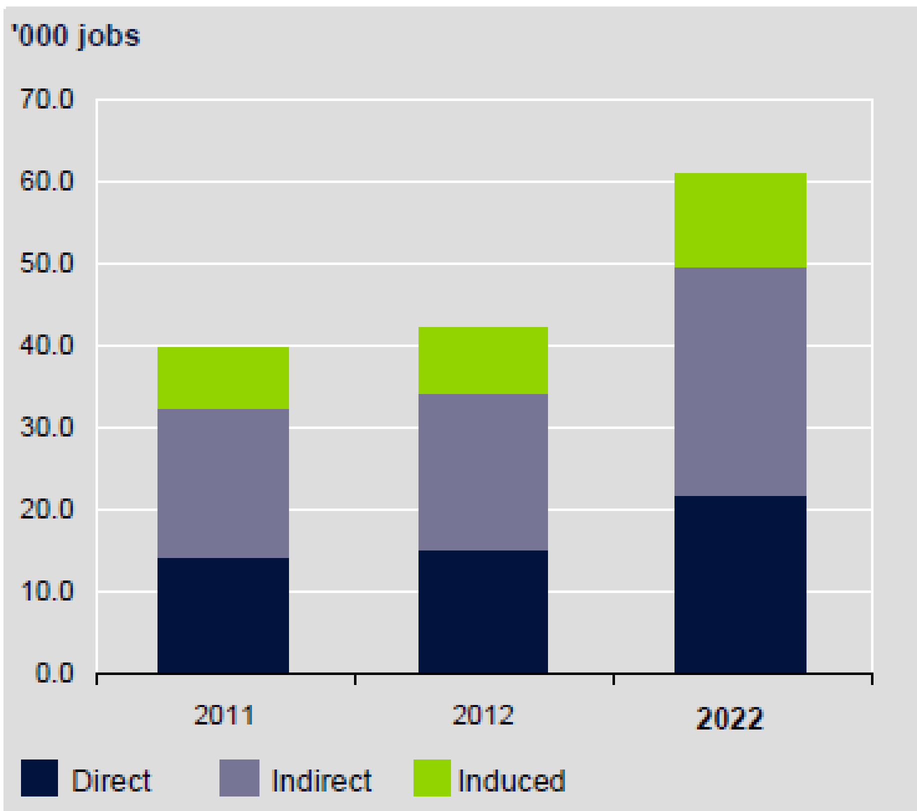


Figure 7.5: Direct, Indirect and Induced Contributions to Employment ('000 jobs) by the Travel and Tourism Sector of Belize (2011-2012) and projections to 2022 (Source: World Travel and Tourism Council (2012)

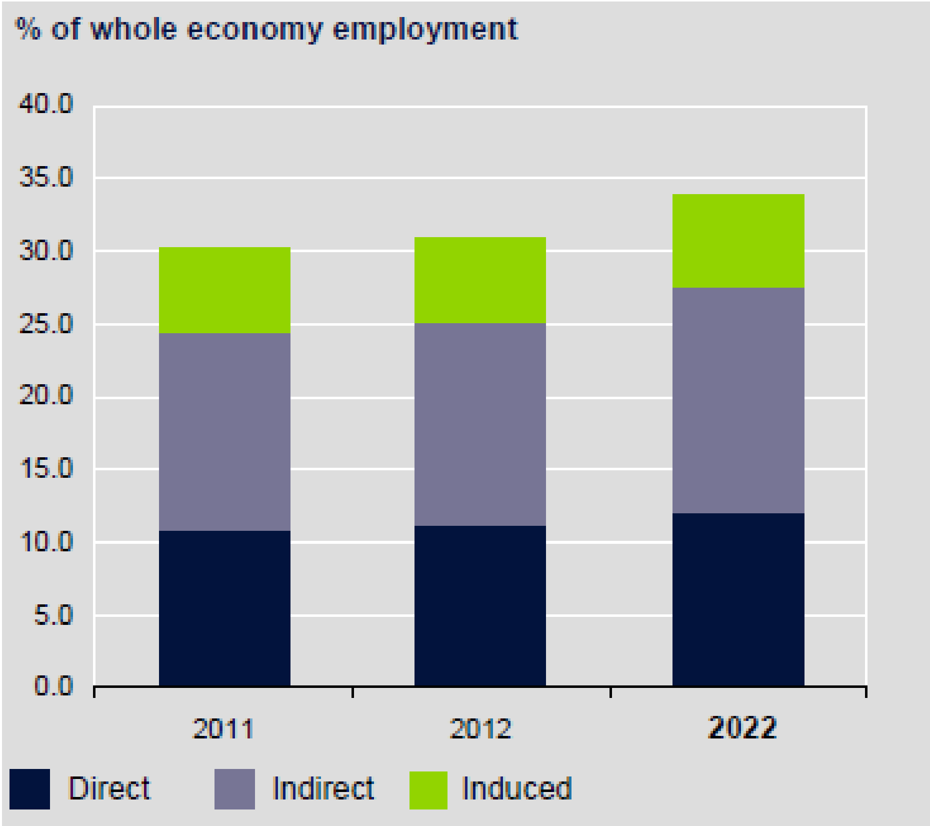


Figure 7.6: Direct, Indirect and Induced Contributions to Employment (%) by the Travel and Tourism Sector of Belize (2011-2012) and projections to 2022 (Source: World Travel and Tourism Council (2012)

Foreign Visitor Exports (LHS) spending which is linked to Foreign Tourist Arrivals (RHS) within Belize is expenditures by international tourists for both business and leisure trips (gifts, clothing, jewelry, alcohol and cigarettes...), including spending on transport.

The Foreign Tourist Arrivals (RHS) in Belize increased steadily from ~ 200,000,000 in 2002 and peaked at ~ 250,000,000 in 2007. However there was a drop off after 2007 due to the economic slowdown in North America and Europe, the major visitors. In 2012 the Foreign Tourist Arrivals (RHS) again rose to ~ 260,000,000 and projections for 2022 are to ~ 350,000,000 (See Figure 7.6: World Travel and Tourism Council, 2012).

Likewise, Foreign Investor Exports (LHS) in Belize increased steadily from ~ 300,000,000 (Constant 2011 BZD) in 2002 and peaked at ~ 620,000,000 (Constant 2011 BZD) in 2007. However there was a drop off after 2007 due to the economic slowdown in North America and Europe, the major visitors. In 2012 the Foreign Visitor Exports (LHS) again rose to ~

575,000,000 (Constant 2011 BZD) and projections for 2022 are to ~ 800,000,000 (Constant 2011 BZD) (See Figure 7.7: World Travel and Tourism Council, 2012).

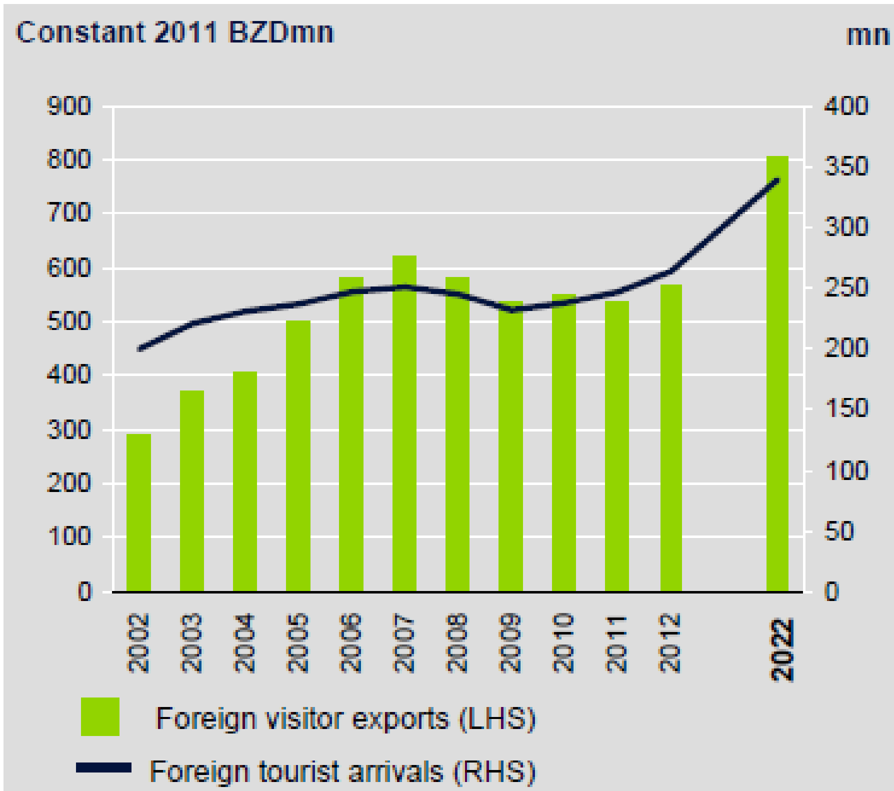


Figure 7.7: Foreign Visitor Exports (LHS) and Foreign Tourist arrivals for the Travel and Tourism Sector of Belize (2011-2012) and projections to 2022 (Source: World Travel and Tourism Council (2012)

Total tourist expenditures in Belize climbed and ranged from 311.4 million $BZD in 2003 to 639.1 million $BZD in 2012 (See Figure 7.8). Bur again there was a dip in total tourist expenditures between 2008 and 2011, bottoming out at 422.2 million $BZD in 2009 (See Figure 7.8).

The greatest portion of tourist expenditures was for holiday and leisure followed by business and the highest daily expenditures were from American tourists followed by Canadian and European tourists (See Table 7.1).

Figure 7.8: Total tourist expenditure (million $BZD: 2003-2012) (Source: Belize Tourism Board (BTZ): Travel and Tourism Statistics Digest, 2012)

Table 7.1: Average Daily Expenditure by Country/Region of Origin and purpose of visit, 2012

	Holiday /Leisure	Business	Visit Friends	Religion	DK/NS	Other	Total/ Average
USA	162.86	158.73	100.70	130.24	72.95	138.40	158.11
CANADA	133.99	133.13	82.60	129.64	219.07	167.96	132.55
EUROPE	94.56	134.72	81.08	100.00	0.00	68.17	94.53
CARIBBEAN	203.78	184.79	63.89	0.00	0.00	177.90	175.06
CENTRAL AMERICA	101.52	140.35	59.74	43.06	0.00	117.78	101.61
DK/NS	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other	105.40	148.24	81.19	25.00	0.00	123.67	106.76
TOTAL	148.28	154.92	94.81	126.61	114.70	136.72	145.27
Source: Statistical Institute of Belize (2012)							

As for the revenue generated by area, the highest percentage came from Ambergris Caye (46.1 %), followed by Cayo District (13 %), Placencia in Stann Creek District (11.8 %) and Belize District (10 %) (See Figure 7.9).

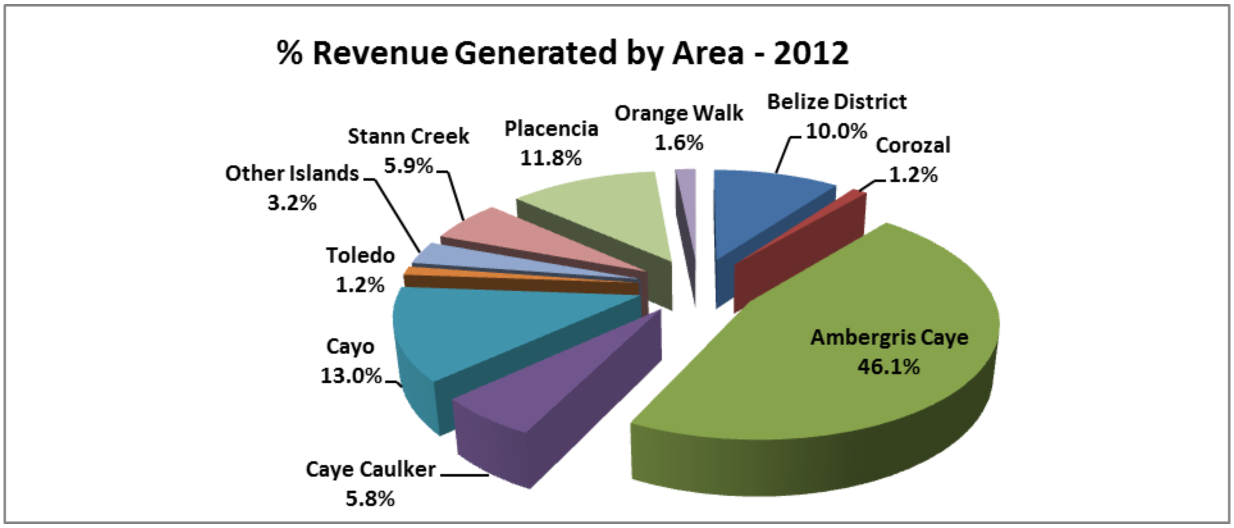


Figure 7.9: Percentage of Revenue generated by tourists according to area (2012) (Source: Belize Tourism Board (BTZ): Travel and Tourism Statistics Digest, 2012)

These tourist expenditures had spin-off economic benefits in terms of hotel employment rates. Again the highest percentage of hotel employment rates were in Ambergris Caye (25.8 %) followed by Belize District (25.3 %), Cayo District (16.8 %) and Stann Creek District (13.2 %, plus 6.4 % for Placencia) (See Figure 7.10 and Table 7.2).

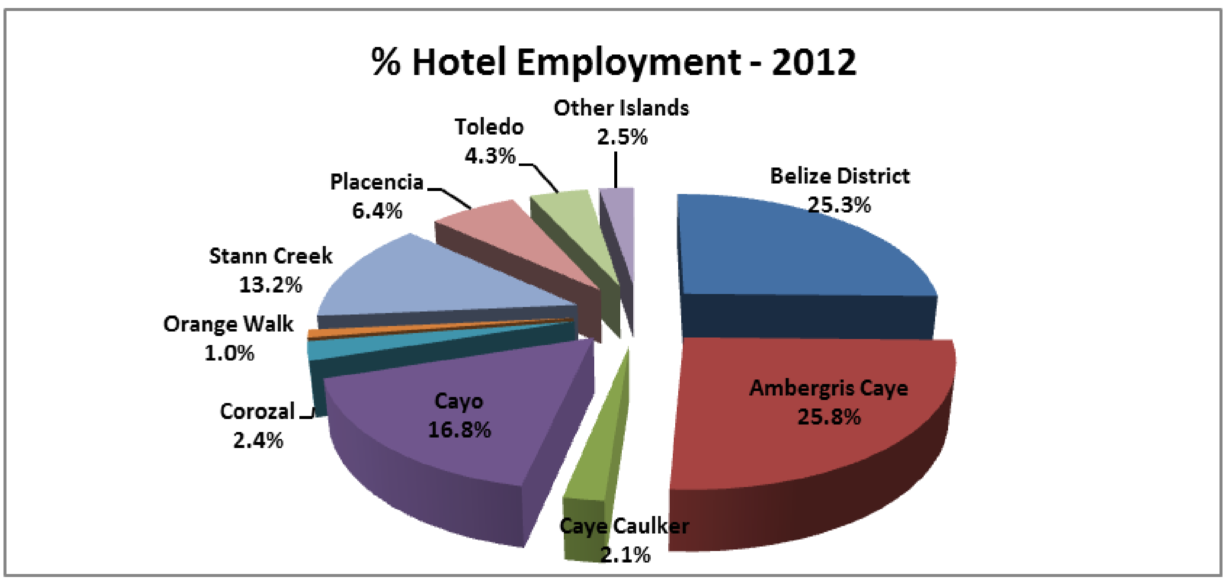


Figure 7.10: Percentage of Hotel Employment according to area (2012) (Source: Belize Tourism Board (BTZ): Travel and Tourism Statistics Digest, 2012)

Table 7.2: Hotel Employment by area (2003-2012) (Source: Belize Tourism Board (BTZ): Travel and Tourism Statistics Digest, 2012)

AREA	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	% Change
Belize District	1,313	1,220	1,319	1,366	1,322	1,237	1,224	1,214	2,005	2,007	0.1
Ambergris Caye	1,110	1,212	1,356	1,624	1,990	1,887	1,763	1,455	1,791	2,049	14.4
Caye Caulker	64	71	78	82	89	91	106	124	148	167	12.8
Cayo	736	800	997	922	1177	1375	1,208	1,185	1,254	1,334	6.4
Corozal	88	105	91	184	184	164	182	167	178	194	9.0
Orange Walk	69	60	60	72	101	98	107	95	80	82	2.5
Stann Creek	515	642	1209	1239	1,057	1,079	947	901	863	1046	21.2
Placencia	244	274	414	511	391	434	412	416	449	509	13.4
Toledo	41	24	20	67	105	137	167	168	399	343	-14.0
Other Islands	167	195	206	147	164	212	160	138	153	201	31.4
TOTAL	**4347**	**4603**	**5750**	**6214**	**6580**	**6714**	**6276**	**5863**	**7,320**	**7,932**	**8.4**
% change	**11.1**	**5.9**	**24.9**	**8.1**	**5.9**	**2**	**-6.5**	**-6.6**	**24.9**	**8.4**	

3.0 Tourist Arrivals

Statistics show that overnight tourist arrivals has grown steadily from ~ 220,000 tourists in 2003 to ~ 275,000 tourists in 2012, except for a slight decrease in tourist arrivals between 2008 to 2010, due to the economic slow-downs in North America and Europe, the major sources of tourists for Belize (See Figures 7.11, 7.12 and 7.13: Belize Tourism Board (BTZ): Travel and Tourism Statistics Digest, 2012).

Furthermore the vast majority of tourists visit Belize between the months of November and May, when it is cool or cold in North America and Europe and when the weather in Belize is the dry season together with an absence of tropical storms and hurricanes (See Figures 7.11, 7.12 and 7.13: Belize Tourism Board (BTZ): Travel and Tourism Statistics Digest, 2012). This is especially true for Canadian tourists (Figure 7.13). The spike in tourist arrivals in the summer months, namely June and July, from America and Europe is most likely due to Belizeans domiciled in these countries returning for family reasons during the summer school holidays (Figures 7.12 and 7.14).

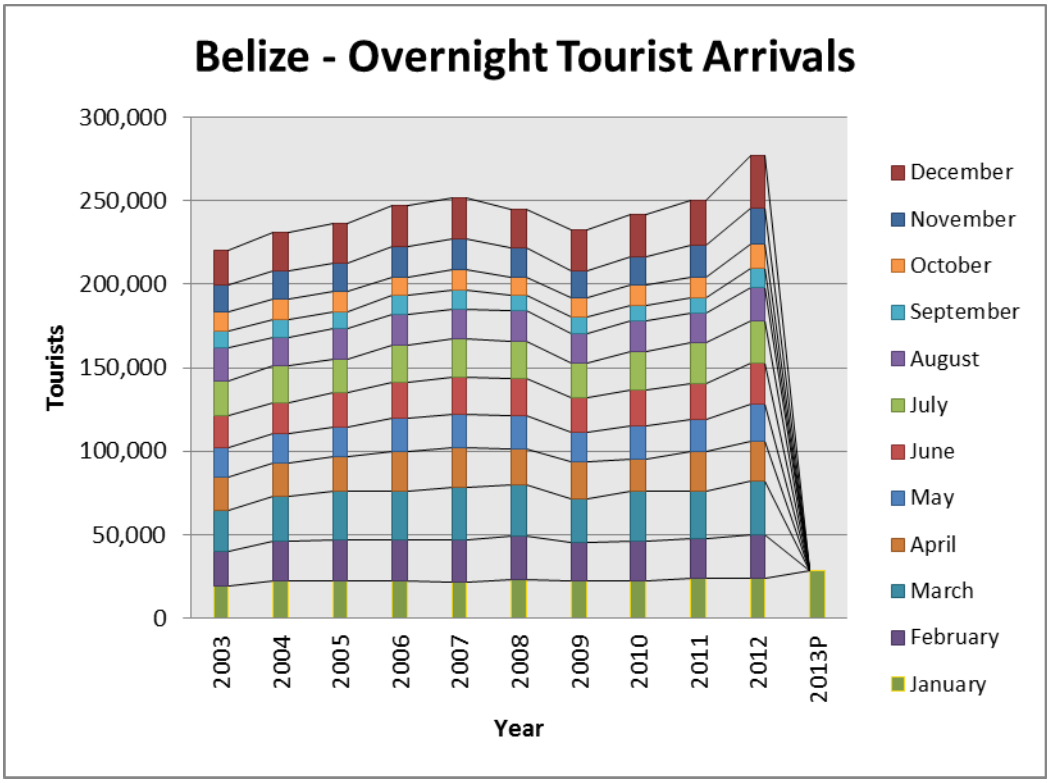


Figure 7.11: Monthly Overnight Tourist Arrivals in Belize (2003-2012) (2013-incomplete) (Source: Belize Tourism Board (BTZ): Travel and Tourism Statistics Digest, 2012)

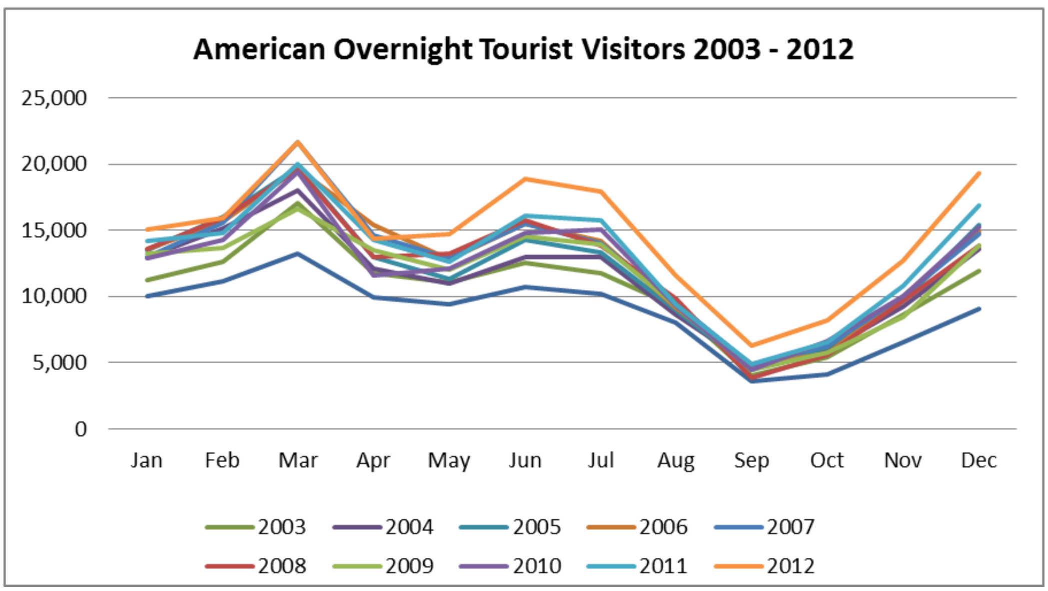


Figure 7.12: Monthly American Overnight Tourist Arrivals in Belize (2003-2012) (Source: Belize Tourism Board (BTZ): Travel and Tourism Statistics Digest, 2012)

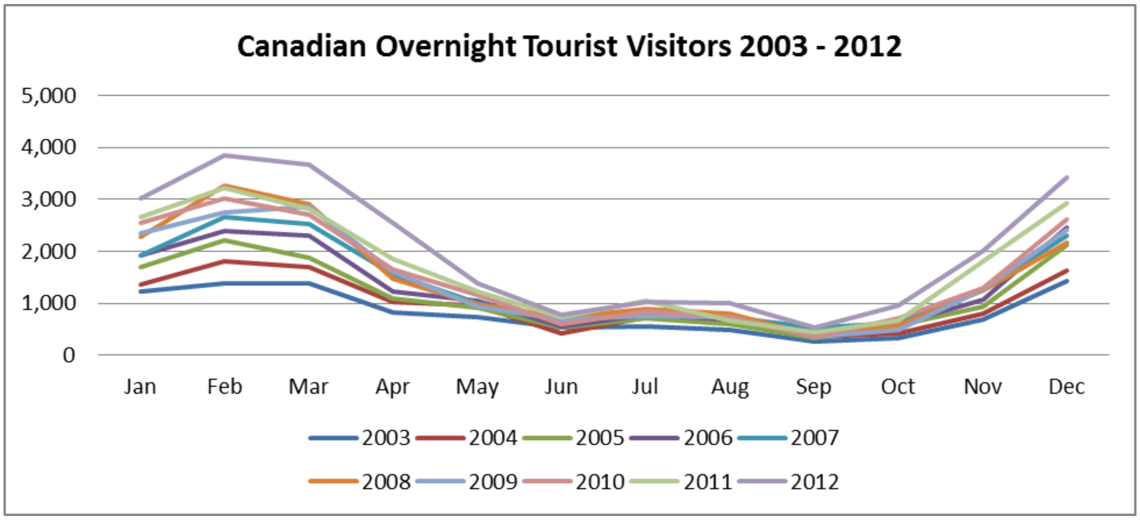


Figure 7.13: Monthly Canadian Overnight Tourist Arrivals in Belize (2003-2012) (Source: Belize Tourism Board (BTZ): Travel and Tourism Statistics Digest, 2012)

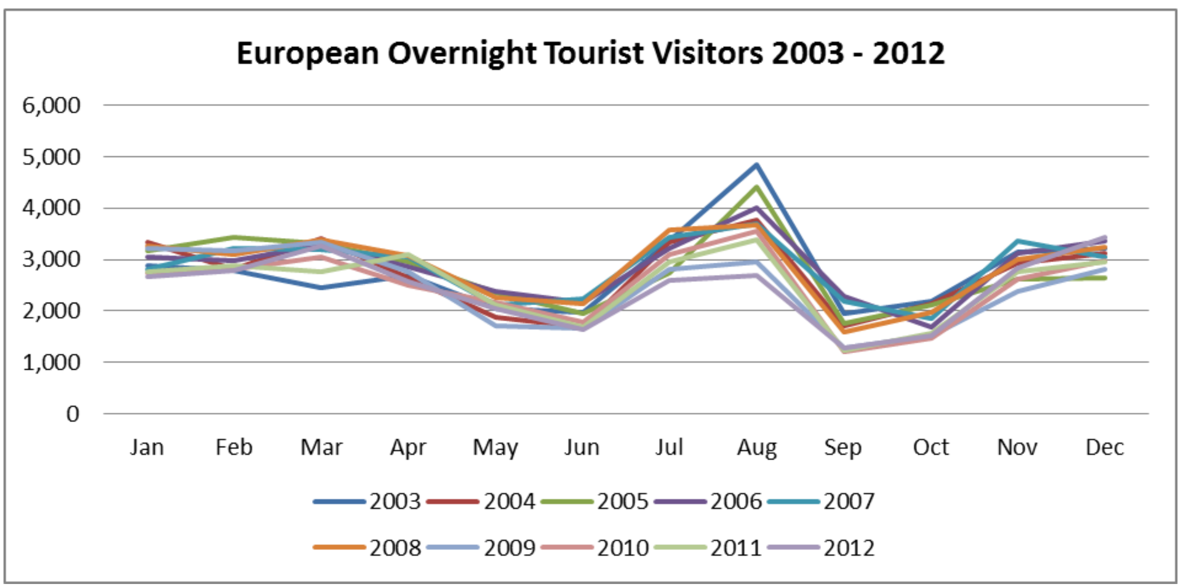


Figure 7.14: Monthly European Overnight Tourist Arrivals in Belize (2003-2012) (Source: Belize Tourism Board (BTZ): Travel and Tourism Statistics Digest, 2012)

As for the market share of tourists for a typical winter month (January, 2012), the vast majority of tourists come from America (62.2 %), followed by Canadians (12.5 %) and Europeans (11 %) (See Figure 7.15).

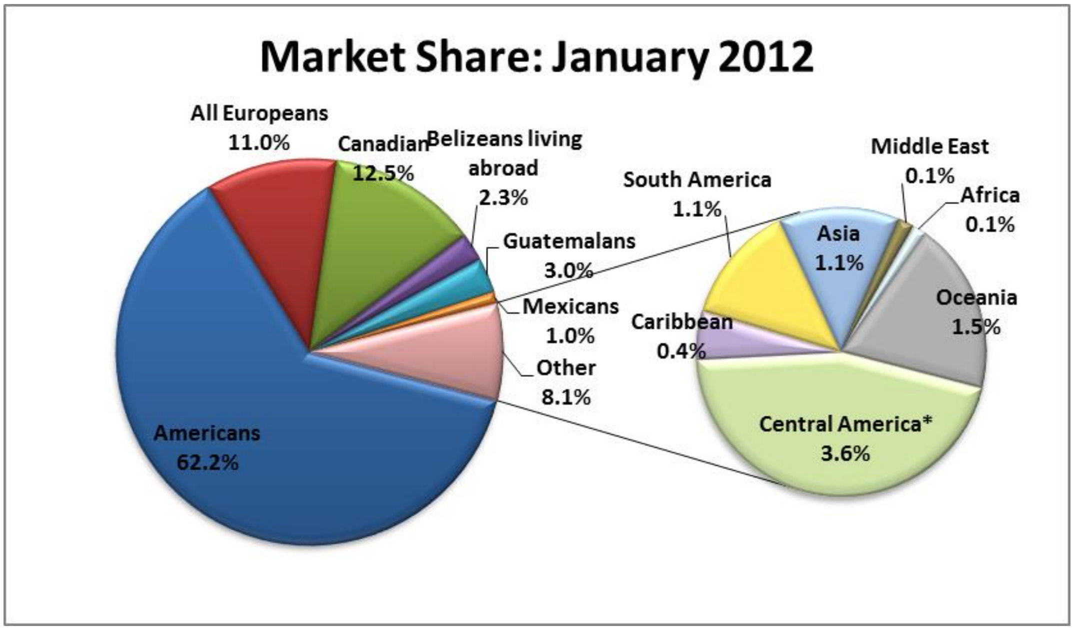


Figure 7.15: Market share of tourists from foreign countries (January 2012) (Source: Belize Tourism Board (BTZ): Travel and Tourism Statistics Digest, 2012)

Tourists visiting Belize arrive at the major international airport in Belize City namely, the Philip Goldson International Airport (PGIA). The then use local airline hubs or ferries to visit the Cayes or Placencia to the south in Stann Creek District (See Figure 7.16).

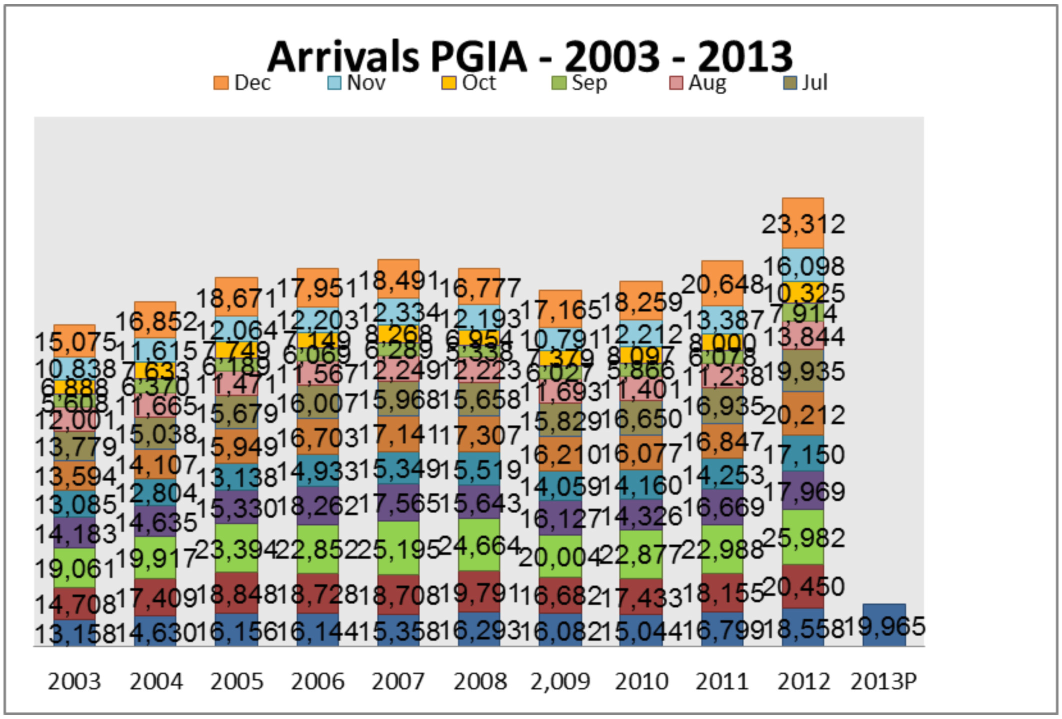


Figure 7.16: Tourist arrivals at Philip Goldson International Airport (PGIA) (2003-2012; 2013-incomplete (Source: Belize Tourism Board (BTZ): Travel and Tourism Statistics Digest, 2012)

Cruise ships are also an important mode of entry of tourists to Belize. It is again apparent that tourist arrivals by cruise ships are highest in the northern hemisphere winter months, namely from November to April. Furthermore, there was a downturn in tourist arrival rates between 2009 and 2011 on account of recessionary economies in North America and Europe (See Figure 7.17).

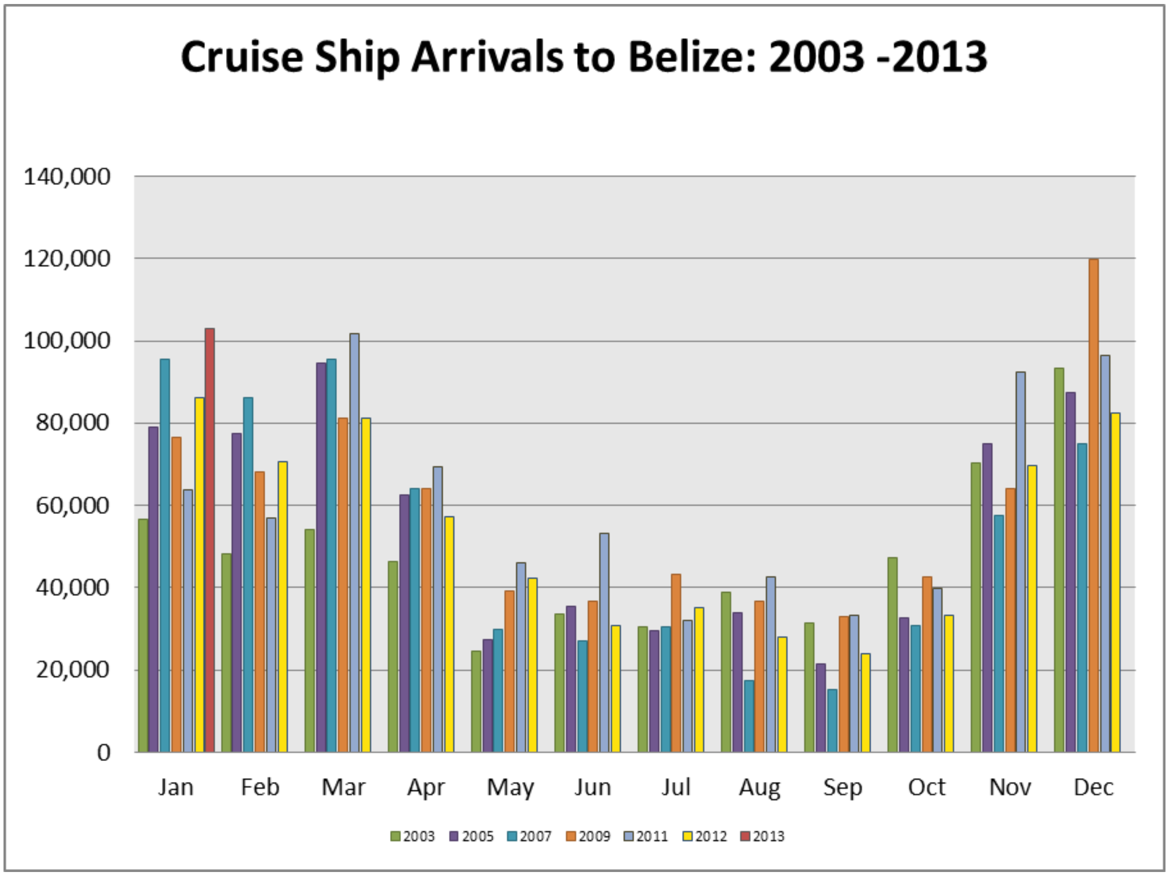
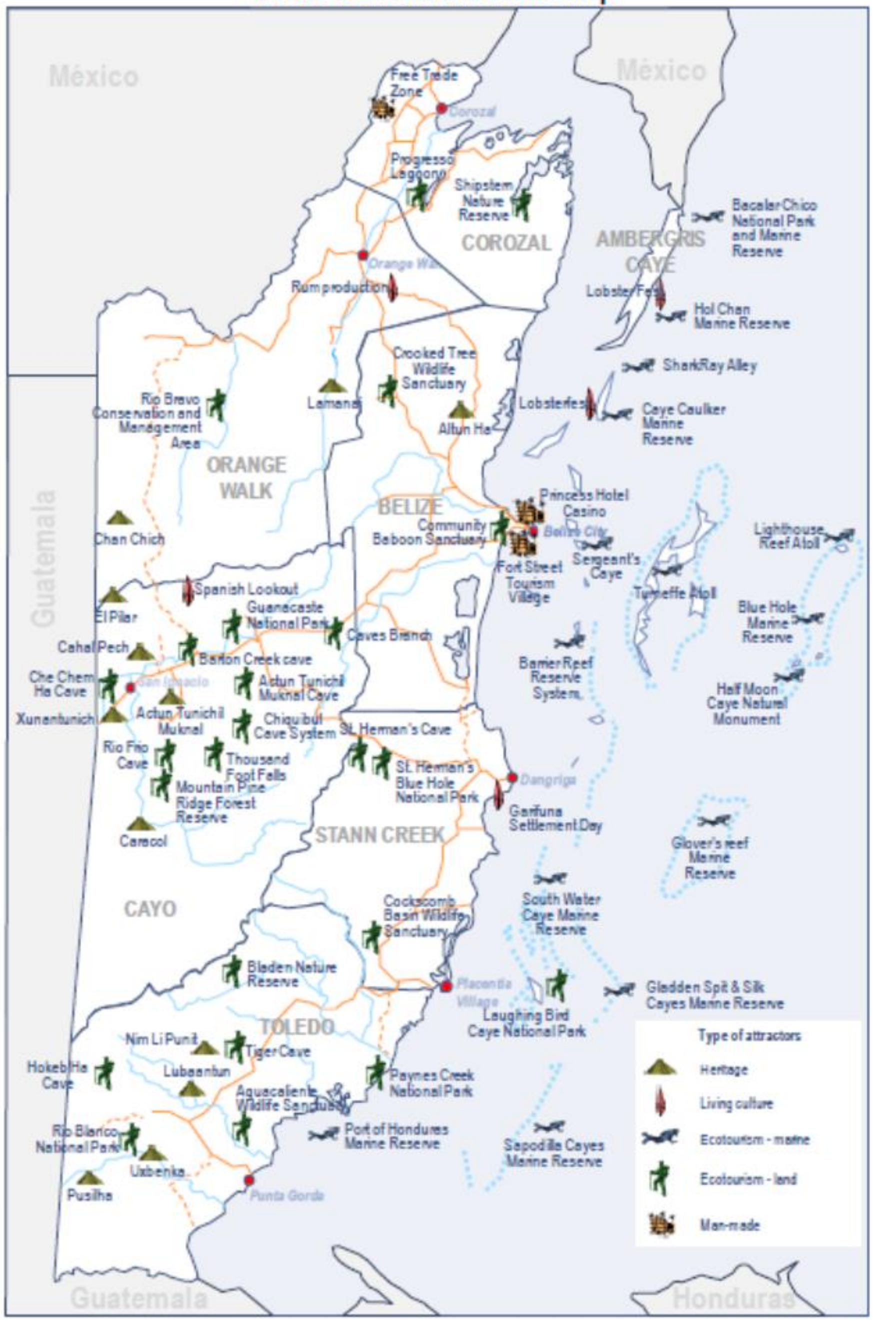


Figure 7.17: Cruise Ship tourist arrivals to Belize (2003-2012; 2013-incomplete) (Source: Belize Tourism Board (BTZ): Travel and Tourism Statistics Digest, 2012)

4.0 Tourist Attractions and Activities

Belize is endowed by a wide variety of attractions and activities for tourists coming mainly from America, Canada and Europe. Snorkeling (67.2 %), followed by caving (35.1 %), jungle trekking (33.4 %), island tours (26.2 %), diving (25.4 %) and fishing (23.7 %) are the most important tourist activities (Figures 7.18, 7.19 and 7.20 and Tables 7.3 and 7.4).

Belize Tourism Attractors Map



Source: T&L, 2010

Figure 7.18: Tourism Activities and Attractions in Belize (Source: Belize Tourism Board (BTZ): Travel and Tourism Statistics Digest, 2012)

Table 7.3: Participation in Activities by Country/Region of Origin (%)

	USA	CANADA	EUROPE	CARIBBEAN	CENTRAL AMERICA	OTHER	TOTAL
Diving	24.3%	28.5%	30.2%	6.7%	23.8%	27.3%	**25.4%**
Snorkeling	67.7%	71.9%	67.4%	20.0%	38.1%	58.6%	**67.2%**
Island Tour	25.9%	27.0%	26.2%	20.0%	9.5%	33.3%	**26.2%**
Caving	37.2%	40.7%	23.8%	6.7%	19.0%	19.2%	**35.1%**
Birding	10.7%	11.1%	8.7%	0.0%	0.0%	6.1%	**10.2%**
Gaming	1.4%	1.1%	1.3%	0.0%	0.0%	1.0%	**1.4%**
Other	19.1%	18.1%	7.7%	13.3%	28.6%	5.1%	**17.3%**
Fishing	25.7%	23.7%	15.1%	6.7%	9.5%	14.1%	**23.7%**
Sailing	15.5%	18.9%	17.8%	6.7%	14.3%	22.2%	**16.3%**
Canoe/Kayaking	22.5%	19.6%	14.4%	6.7%	4.8%	10.1%	**20.6%**
Jungle trekking	34.8%	40.0%	26.8%	6.7%	14.3%	16.2%	**33.4%**
Cultural Event	14.8%	11.1%	14.8%	0.0%	4.8%	4.0%	**13.9%**
DK/NS	6.4%	6.3%	8.1%	46.7%	38.1%	15.2%	**7.4%**
Total	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**

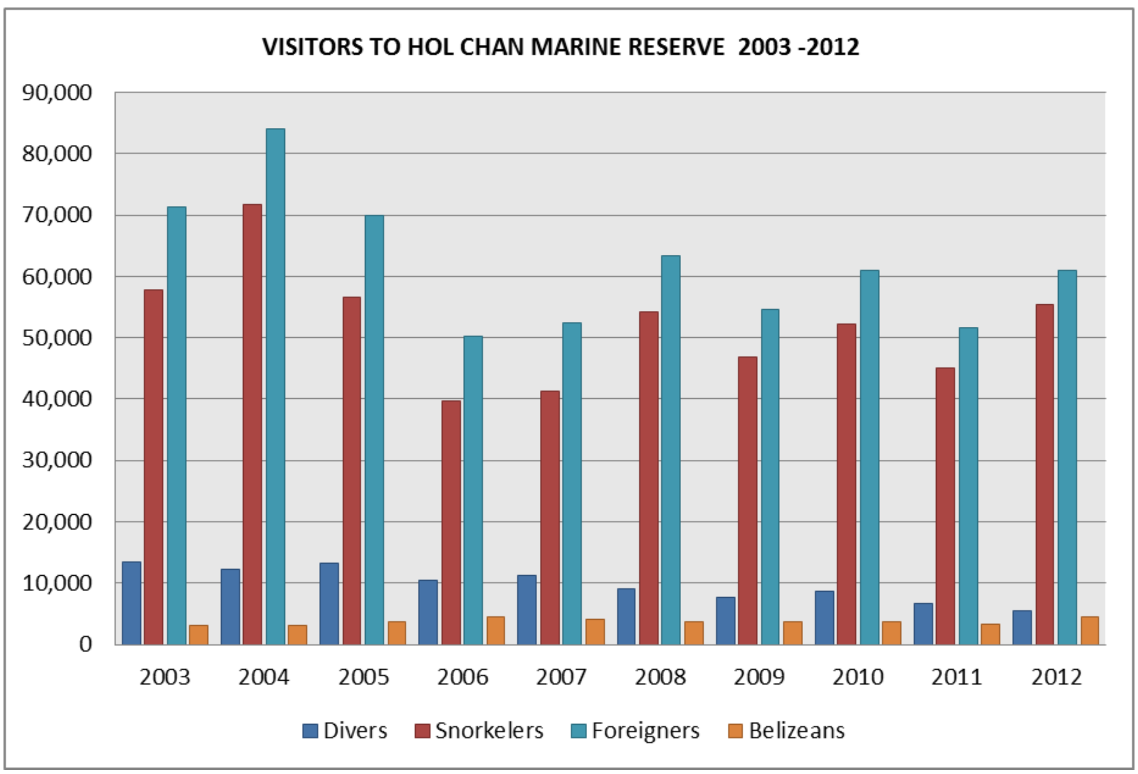


Figure 7.19: Visitors to Hol Chan Marine Reserve for snorkeling and diving – 2003-2012 (Source: Belize Tourism Board (BTZ): Travel and Tourism Statistics Digest, 2012)

Table 7.4: Visitors to Caves Branch (Source: Belize Tourism Board (BTZ): Travel and Tourism Statistics Digest, 2012)

Year	2003	2004	2005	2007	2008	2009	2010	2011	2012	%Change 2011 vs. 2012
Total	65993	94696	102359	102967	94627	47751	75535	132449	132124	0.00

Figure 7.20: Tourists visiting Caves Branch in Belize (Source: Belize Tourism Board (BTZ): Travel and Tourism Statistics Digest, 2012)

Visitations to historical Maya sites are another major tourist attraction in Belize. The Altun Ha (27.9 %), Xunantunich (27.9 %) and Lamanai (16 %) are the most frequently visited Maya sites. Again, the highest visitation rates are from November to April. Furthermore, the number of visitors declined between 2009 and 2010 on account of economic downturns in North America and Europe (Figures 7.21 and 7.22).

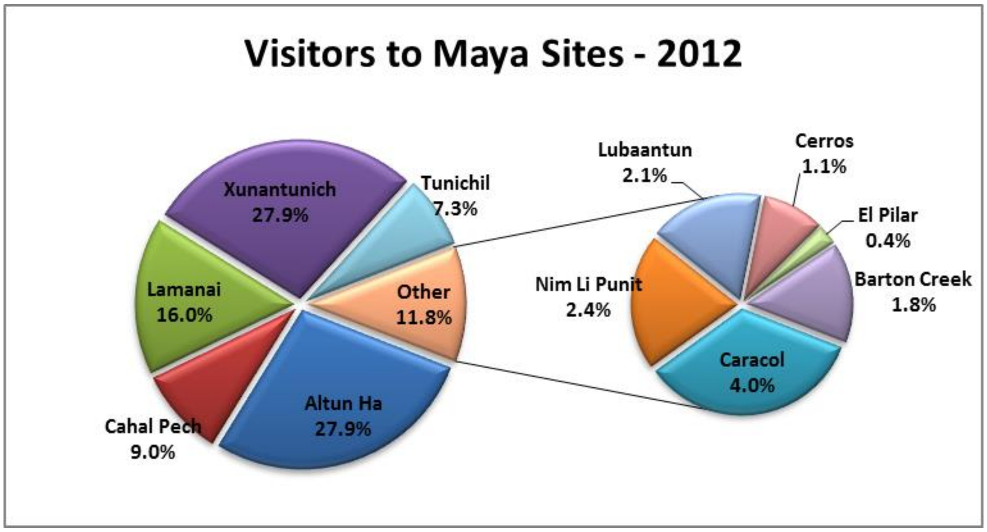


Figure 7.21: Most frequently visited Maya sites by tourists: 2012 (Source: Belize Tourism Board (BTZ): Travel and Tourism Statistics Digest, 2012)

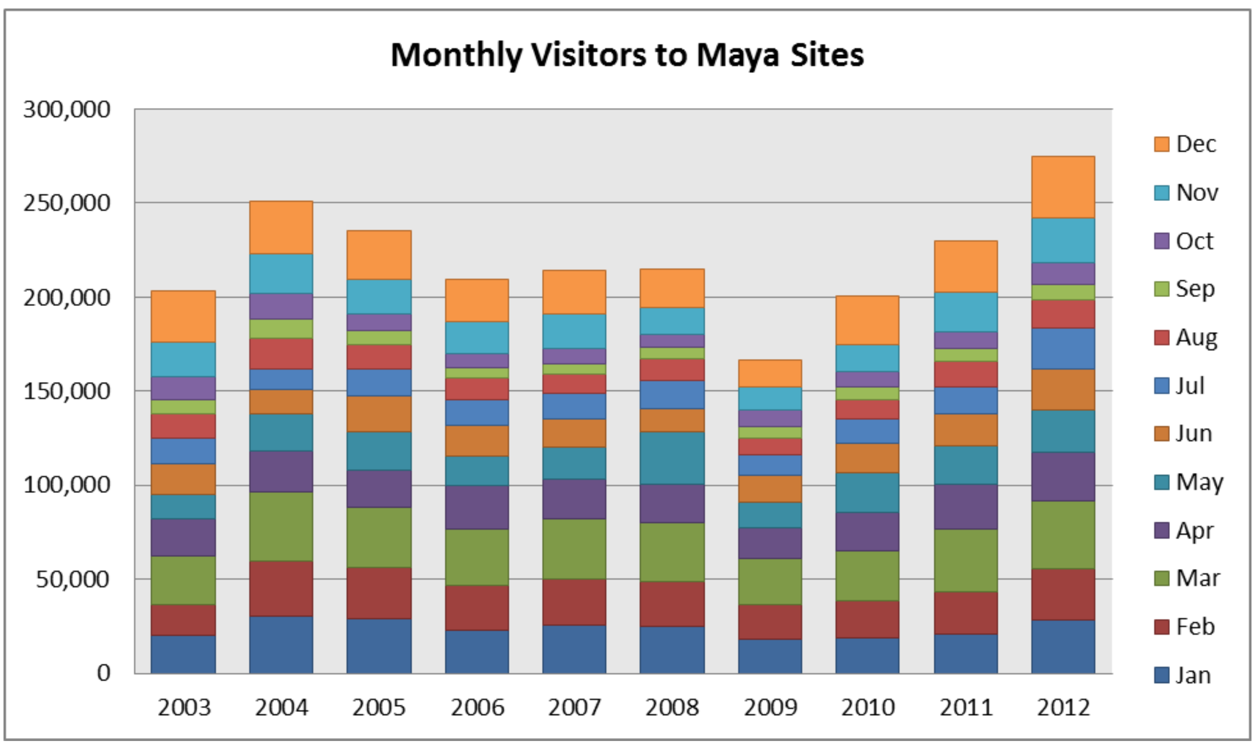


Figure 7.22: Numbers of monthly visitors to Maya sites, 2003-2012 (Source: Belize Tourism Board (BTZ): Travel and Tourism Statistics Digest, 2012)

Tourist visitations Belize Audubon Society (BAS) managed protected areas are also a major activity in Belize. The most frequently visited BAS Protected Areas are Cockscomb Basin Wildlife Sanctuary, Actun Tunichil Muknal, Half Moon Caye Natural Monument, Blue Hole National Monument and St. Hermans Blue Hole National Park (Figure 7.23).

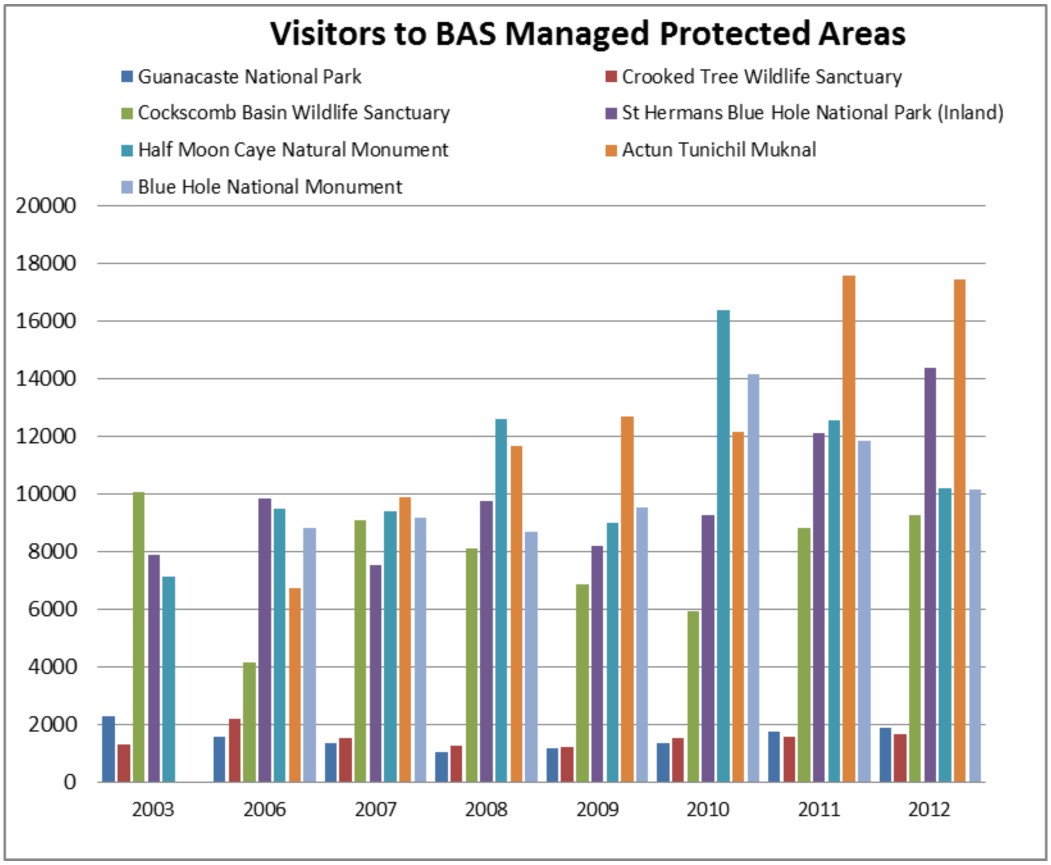


Figure 7.23: Visitors to Belize Audubon Society (BAS) managed protected Areas - 2003-2012 (Source: Belize Tourism Board (BTZ): Travel and Tourism Statistics Digest, 2012)

5.0 Tourist Accommodations: Hotels

Belize has a relatively large number of hotels to accommodate its tourists. The total number of hotels in the country grew from 466 in 2003 to 723 in 2012. By far, the highest number of hotels is found in the most popular tourist spots, namely (Ambergris Caye (153), Placencia (119) and Cayo (See Table 7.5) (Source: Belize Tourism Board (BTZ): Travel and Tourism Statistics Digest, 2012).

Table 7.5: Number of Hotels by Area (Source: Belize Tourism Board (BTZ): Travel and Tourism Statistics Digest, 2012)

	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Belize District	59	59	60	54	59	61	56	54	54	55
Ambergris	74	81	92	98	99	108	125	141	154	153
Caye Caulker	54	62	67	70	73	71	75	79	86	87
Cayo	73	79	87	89	97	95	101	101	110	114
Corozal	21	25	29	31	29	34	34	36	37	33
Orange Walk	12	18	17	18	20	19	19	19	22	21
Stann Creek	53	54	55	55	56	60	58	56	60	61
Placencia	63	67	81	81	88	99	109	104	113	119
Toledo	27	28	33	29	35	36	37	38	39	39
Other Islands	30	37	36	36	35	37	37	36	41	41
TOTAL	**466**	**510**	**557**	**561**	**591**	**620**	**651**	**664**	**716**	**723**
% Change	**6.6**	**9.4**	**9.2**	**0.7**	**5.3**	**4.9**	**5.0**	**0.5**	**1.1**	**0.0**

However, hotel occupancy rates peaks at ~ 60 % in the winter months of February and March, the tourist high season and drops to less than 20 % in the off-season months of September and October (See Figure 7.24) (Source: Belize Tourism Board (BTZ): Travel and Tourism Statistics Digest, 2012).

This tendency in hotel occupancy rates is typical of all districts and regions, especially the most popular tourist destinations such as Ambergris Caye (September: 25.8 %: October: 30.2 %), Caye Caulker (September: 19.3 %: October: 18.3 %), Placencia (September: 16.5 %: October: 20.0 %) and Cayo District (September: 20.1 %: October: 22.6 %) (See Table 7.6) (Source: Belize Tourism Board (BTZ): Travel and Tourism Statistics Digest, 2012).

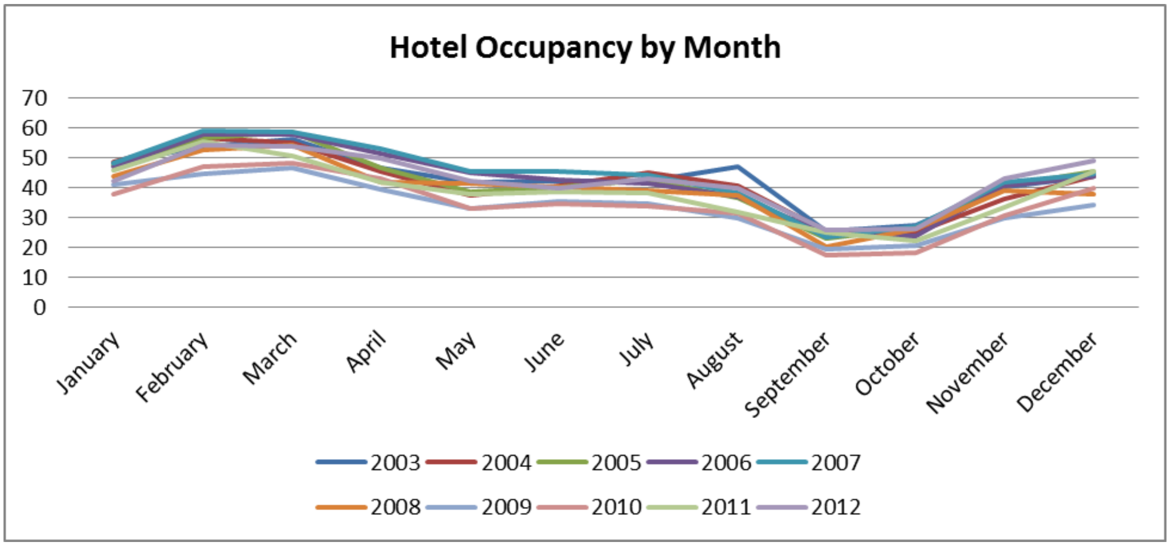


Figure 7.24: Hotel Occupancy by month (2003-2012) (Source: Belize Tourism Board (BTZ): Travel and Tourism Statistics Digest, 2012).

Table 7.6: Hotel occupancy by region, 2012 (Source: Belize Tourism Board (BTZ): Travel and Tourism Statistics Digest, 2012).

AREA	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Belize District	38.0	53.6	52.0	35.0	46.9	38.4	53.2	47.6	40.8	24.8	49.9	48.6	**43.2**
Ambergris	50.6	66.9	62.6	56.8	50.1	50.8	47.2	41.6	25.8	30.2	48.1	50.1	**47.7**
Caye Caulker	51.5	71.4	43.3	58.8	39.3	39.7	48.6	36.9	19.3	18.3	35.9	57.2	**43.2**
Cayo	42.9	35.1	56.3	52.0	35.7	35.0	37.7	46.3	20.1	22.6	44.2	53.2	**40.2**
Corozal	18.1	24.5	32.3	43.1	11.9	15.8	37.4	20.2	32.2	32.6	33.3	50.9	**30.4**
Orange Walk	48.2	47.7	55.6	42.9	40.4	43.7	19.1	26.3	26.4	29.6	37.5	45.6	**38.7**
Stann Creek	36.5	23.8	47.7	53.3	40.4	53.1	52.4	63.2	28.8	45.6	50.8	61.1	**48.1**
Placencia	34.1	62.0	49.6	41.5	35.6	29.9	31.3	24.5	16.5	20.0	32.9	31.8	**33.0**
Toledo	36.6	37.3	55.3	55.8	23.9	18.0	14.9	17.5	13.7	19.5	26.2	28.9	**27.2**
Other Islands	36.7	30.5	38.9	44.6	39.1	34.2	34.6	31.0	11.4	23.9	25.6	52.9	**34.8**
Overall	**42.0**	**54.4**	**53.7**	**49.7**	**42.1**	**40.0**	**43.2**	**39.8**	**25.8**	**26.1**	**43.1**	**48.9**	**42.1**

6.0 Climate Change and Tourism

In this section an examination is made of current (2003-2012) and future (2060-2069) climate conditions, namely air temperature (Belize City only) and rainfall so as to decipher how future (2060-2069) climate conditions may impact upon the tourism industry of Belize. This is done for four typical tourist destinations in Belize, namely Belize City and Ambergris Caye in Belize District, Placencia in Stann Creek District and Belmopan in Cayo District, using the outputs from the ECHAM5/A1B climate model. However, since current (2003-2012) and future (2060-2069) air temperature conditions are similar for all regions only the changes in rainfall are considered for Ambergris Caye in Belize District, Placencia in Stann Creek District and Belmopan in Cayo District.

6.1 Belize City: Air Temperature and Rainfall

Air temperature in Belize City, as expected, does not seem to be a determining factor on the number of tourists visiting Belize under current climate conditions (2003-2010). Air temperature in Belize City fluctuates between ~ 25 ^{0} C (December and January) and ~ 28 ^{0} C (August and September). But the peak tourist season is from November to April, which is the dry hurricane-free season (See Figure 7.25).

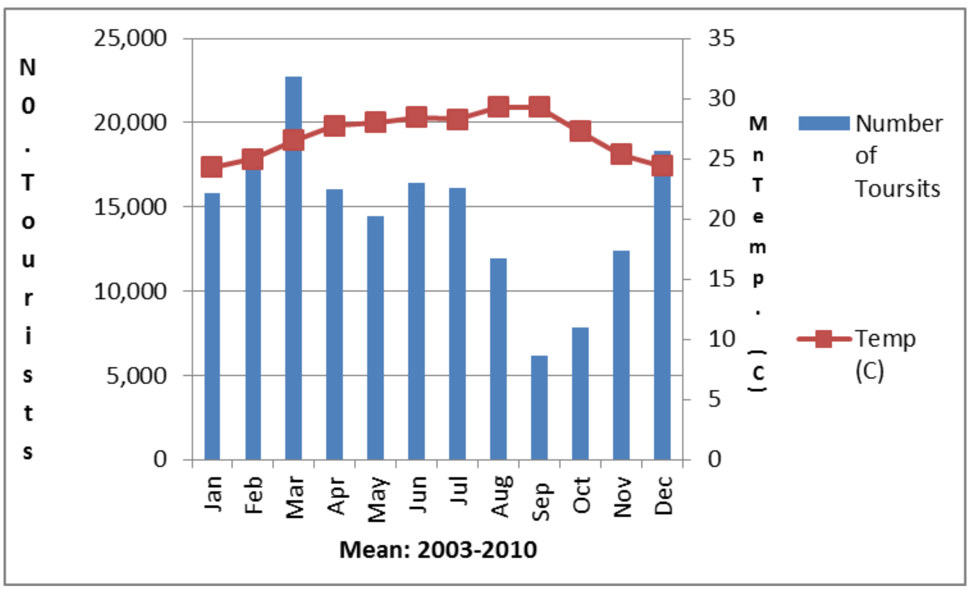


Figure 7.25: Average monthly air temperature (ºC) for the current (2003-2012) period according to ECHAM5/A1B and number of tourists arriving at Belize City

However, average monthly rainfall, as expected seem to be more influential as far as tourist arrivals at Belize City is concerned. Tourist arrivals at Belize City peak in the dry-season and hurricane-free months of November to April (See Figure 7.26). Of course the other determining factor is that these months, namely November to April correspond to winter months in the main countries of tourists origins for Belize, namely America, Canada and Europe.

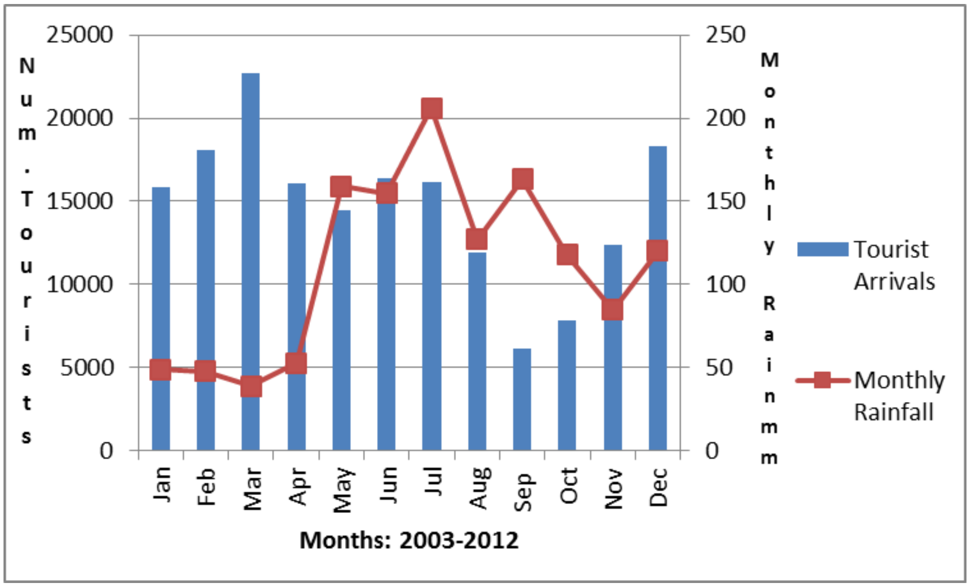


Figure 7.26: Average monthly rainfall (mm) for the current (2003-2012) period according to ECHAM5/A1B and number of tourists arriving at Belize City

When looking at future (2060-2069) temperature (^{0}C) conditions compared to current (2003-2012) conditions, according to the ECHAM5/A1B projection, air temperature (^{0}C) for the Belize City area is expected to increase by ~2 ^{0}C. This may affect comfort levels of most tourists, especially the retired elderly population, who are most sensitive to excessive heat. Hotel operating costs and pricing for tourists may also increase as a result of a greater demand for energy for cooling (See Figure 7.27).

This situation may therefore have a negative impact on the tourism industry in Belize, in terms of the numbers of tourists wanting to visit Belize, especially the interior regions such as Cayo District for such tourist activities as caving and hiking and visitations to Maya sites and BAS protected areas. The Cayes and the coastal cities such as Placencia may not be impacted to the same extent since they would benefit from the cooling and freshening sea breeze.

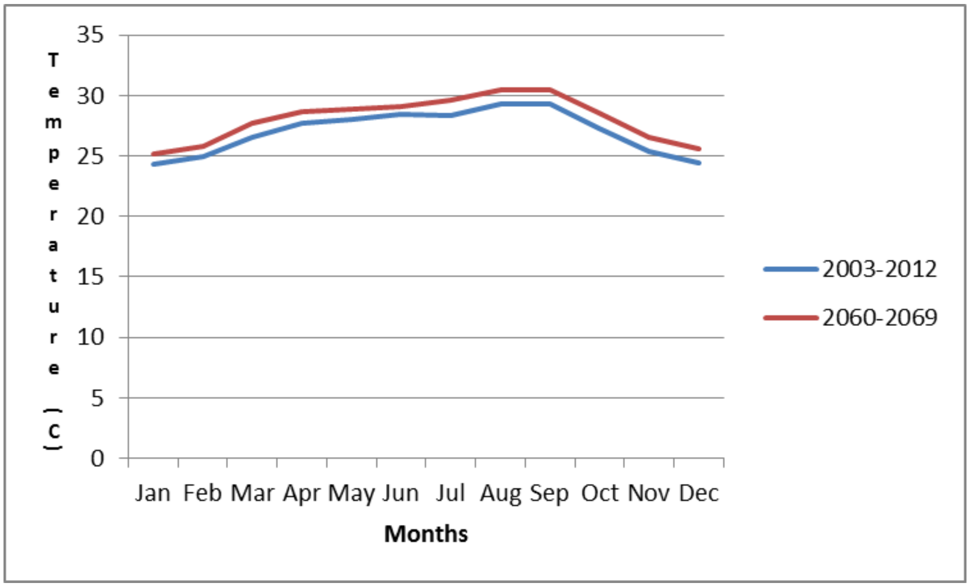


Figure 7.27: Average monthly air temperature (ºC) for the current (2003-2012) and future (2060-2069) periods according to ECHAM5/A1B model for the Belize City area

However, when looking at future (2060-2069) rainfall (mm) conditions compared to current (2003-2012) conditions, according to the ECHAM5/A1B projection, monthly rainfall (mm) for the Belize City area is expected to change in both magnitude and phase. For the future period mean monthly is expected to decrease by over 50 mm during months of May to July. But the impact on tourism in Belize may be minimal since these months fall in the off-season. But the negative impacts on tourism in Belize would be during the months of October and November, the beginning of the tourist season, when mean monthly rainfalls are expected to increase significantly (> 50 mm/month). These shifts in rainfall will, in all likelihood, be accompanied by a phase shift of the storminess season into November. This expected increase in rainfall and storminess will delay the beginning of the tourism peak season, which would have major socio-economic consequences (See Figure 7.28).

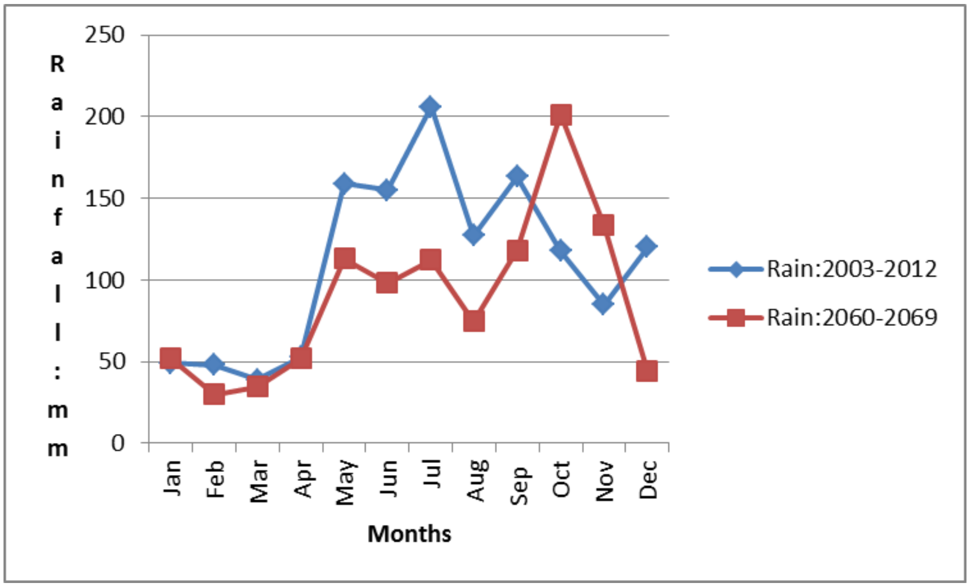


Figure 7.28: Average monthly rainfall (mm) for the current (2003-2012) and future (2060-2069) periods according to ECHAM5/A1B for the Belize City area

6.2 Ambergris Caye: Rainfall

Now, when looking at future (2060-2069) rainfall (mm) conditions compared to current (2003-2012) conditions, according to the ECHAM5/A1B projection, monthly rainfall (mm) for the Ambergris Caye area is also expected to change in both magnitude and phase. For the future period (2003-2012), compared to the current period (2003-2012), mean monthly rainfall is expected to increase in all months, except July, August, September and December, and even so the decreases are minimal. In October, future (2060-2069) mean monthly rainfall is expected to increase by over 300 mm/month, which is double its current (2003-2012) amount. Similarly, in November and January, mean monthly rainfall is expected to double their current (2003-2012) amounts of ~ 225 mm/month and ~ 150 mm/month, respectively.

These changes in both the timing and amounts of mean monthly rainfall and, in all likelihood, in the timing and intensity of stormy conditions, especially in October and November will delay and severely hamper the beginning of the tourism peak season, which would have major socio-economic consequences for the Ambergris Caye, one of the most popular tourist destinations in Belize (See Figure 7.29).

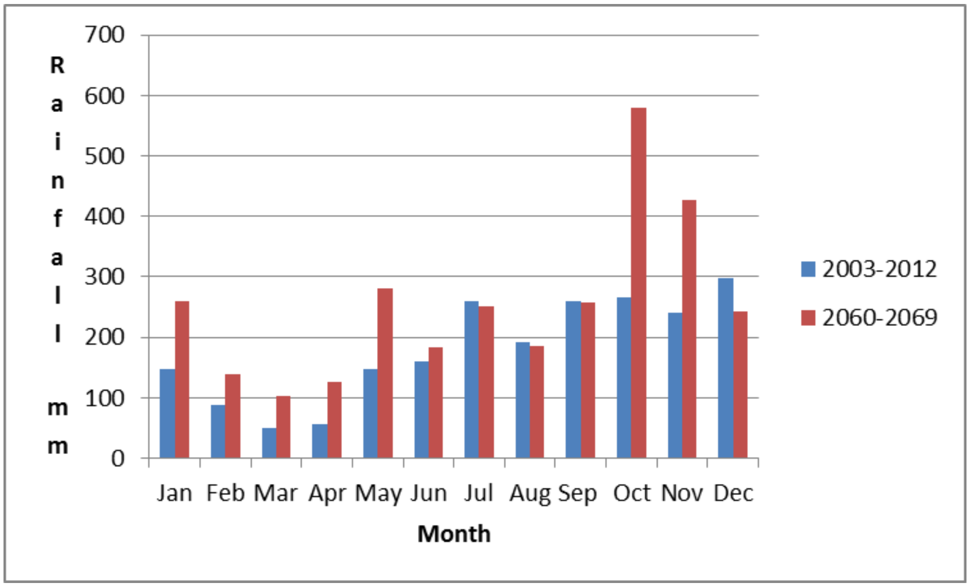


Figure 7.29: Average monthly rainfall (mm) for the current (2003-2012) and future (2060-2069) periods according to ECHAM5/A1B for the Ambergris Caye area

6.3 Placencia: Rainfall

For the Placencia area in Stann Creek District, when looking at future (2060-2069) rainfall (mm) conditions compared to current (2003-2012) conditions, according to the ECHAM5/A1B projection, mean monthly rainfall (mm) is not expected to change as much in the future. For the future period (2003-2012), compared to the current period (2003-2012), mean monthly is expected to increase significantly (by ~ 100 mm/month) only in the month of October, that is towards the end of the tourist off-season. But, in November and January, future (2060-2069) mean monthly rainfall is expected to increase slightly, compared to current (2003-2012) amounts of ~ 60 mm/month and ~ 40 mm/month, respectively.

These minimal changes in both the timing and amounts of mean monthly rainfall and intensities of stormy conditions should not hamper the peak tourism season, as was the case at the Ambergris Caye and Belize City areas, and should have minimal socio-economic consequences for the Placencia area one of the most popular tourist destinations in Belize. As a matter of fact, these conditions in the future may lead to a gravitation of tourist visits from the Ambergris Caye and Belize City areas to the Placencia area (See Figure 7.30).

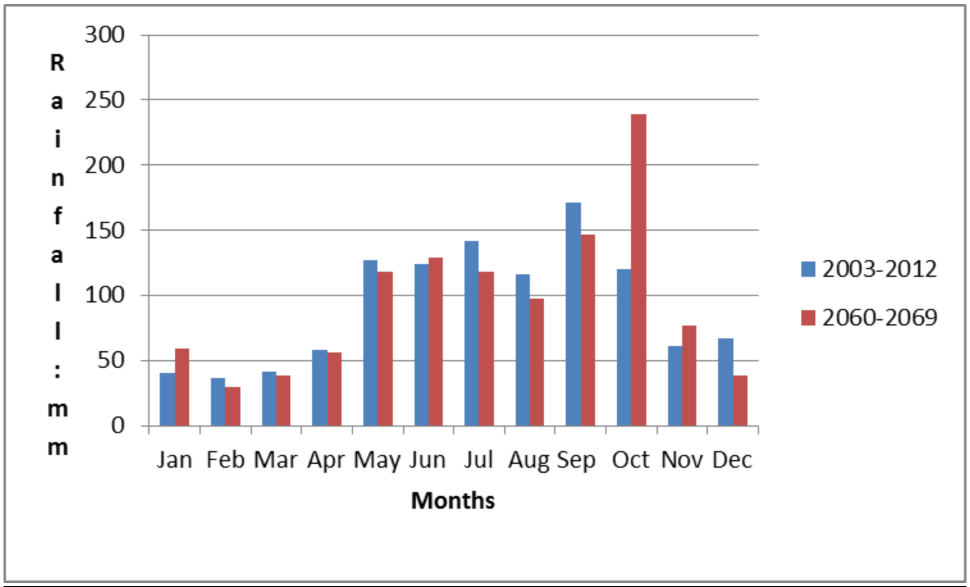


Figure 7.30: Average monthly rainfall (mm) for the current (2003-2012) and future (2060-2069) periods according to ECHAM5/A1B for the Placencia area

6.4 Belmopan: Rainfall

On the other hand, for the Belmopan area in Cayo District, when looking at future (2060-2069) rainfall (mm) conditions compared to current (2003-2012) conditions, according to the ECHAM5/A1B projection, mean monthly rainfall (mm) is expected to decrease in all months of the year in the future. For the future period (2003-2012), compared to the current period (2003-2012), mean monthly is expected to decrease significantly (by > 100 mm/month) in the months of May to December.

These major changes in the amount of mean monthly rainfall and in the future (2060-2069) in the Belmopan area, though they may lead to drier and more sunny weather, that tourists enjoy, may however have severe negative impacts. In the Belmopan area of Cayo District, the emphasis is more geared towards eco-tourism: caving, hiking and visits to Maya sites and Protected Reserves. This severe decrease in rainfall will in all likelihood lead to droughty conditions and desertification which may destroy the forest and shrub ecosystems that are vital to eco-tourism (See Figure 7.31).

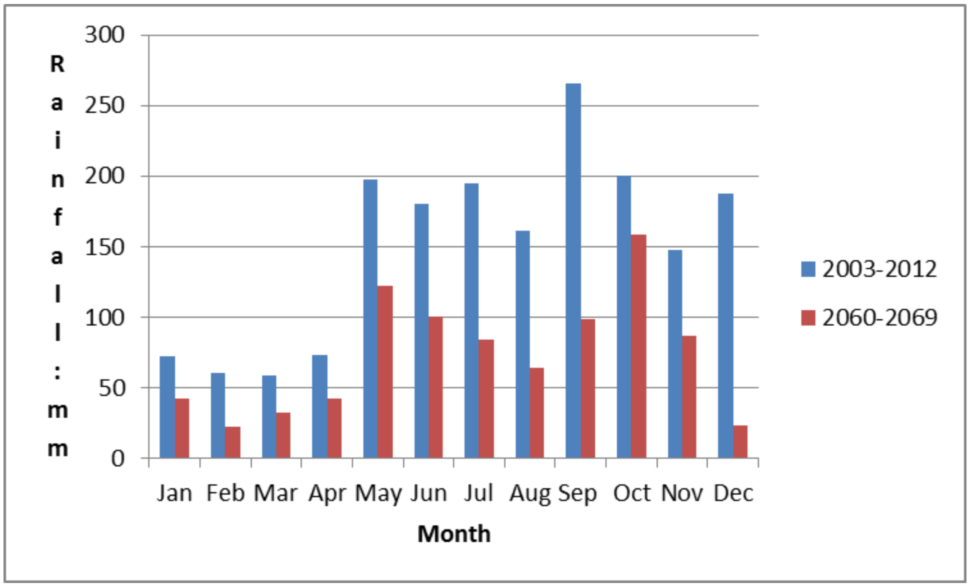


Figure 7.31: Average monthly rainfall (mm) for the current (2003-2012) and future (2060-2069) periods according to ECHAM5/A1B for the Belmopan area

7.0 Sea Level Rise and Storm Surges

As described in Section 2 sea level rise and storm surges, by-products of climate change would also negatively impact the tourism industry of Belize. Rising sea levels are expected to significantly affect coastal areas, especially the busiest tourist destinations as the Caulker and Ambergris Cayes and Placencia, which may experience a loss of land area through erosion, increased flooding, and increased threats to water supplies through salt water intrusion (See Section 3: Coastal Zone Sector).

7.1 Rise in Ocean Temperature and Acidity

Coral reefs as those of the barrier reef of Belize provide valuable ecological benefits including the provision of habitat and nutrients for numerous species and the protection of the coastline from the impact of the ocean, decreasing erosion, property damage and the effects of waves and storms. Healthy reefs also provide numerous economic benefits, generating income from both tourism and fishing and protecting the shoreline (Richardson, 2007).

However, rising near-surface ocean temperatures will very likely lead to increased coral bleaching and coral diebacks. Higher ocean temperatures impair reproductive functions and growth capacity of corals and lead to increased mortality. A conservative temperature increase of 1-2 degrees Celsius would cause tropical regions to experience sustained warming that falls within the lethal limits of most reef-building coral species. As climate change increases, the extent and severity of coral bleaching is expected to increase. Coral reefs and mangroves in some areas are already stressed by factors such as pollution, fragmentation and coastal development, and climate change is expected to exacerbate those stresses (Richardson, 2007).

Furthermore, ocean acidification, namely lower pH levels caused by the absorption of increasing levels of carbon dioxide from the atmosphere, will have devastating effects on marine life in the very near term, including additional stresses to already threatened coral reefs that apart from their ecological benefits also play a vital role in tourism in Belize. Ocean acidification and subsequent damage to coral reefs can have many negative ecological and socioeconomic effects (Richardson, 2007).

8.0 Tourism Sector Adaptation to Climate Change

It is evident from the data and discussions above that the tourism industry of Belize that is fast becoming a major contributor to the economy of Belize would face serious challenges and risks in the future on account of climate change and climate-driven sea level rise and storm surges. It is therefore incumbent on the managers of the tourism industry in Belize to begin to shape policies and integrate them into Government plans to adapt to the impacts, mostly negative, of climate change.

There are plans to promote and grow the tourism sector of Belize through promotional policies, but there is little focus on adaptation to climate change.

There are certain adaptation measures being taken, such as the construction of sea defenses to protect against beach losses and coastal erosion. For instance sea walls are being erected haphazardly around Belize City and Caye Caulker and Ambergris Caye. But their design and integrity leave much to be desired: they are generally about one meter high or less. So as seen in Section 2 they would be easily overtopped by storm surges. Furthermore, these hard structures eventually lead to the loss of beaches as seen in Ambergris Caye, Caye Caulker and around Belize City. This is because these rigid structures lead to scouring of beach sand through backwash of waves (See Figure 7.32).

Also, adaptation planning should also incorporate the expansion and diversification of tourism activities as for instance the construction of marinas in the lagoon near Placencia for sailing boats used by tourists.

But there should be comprehensive including short-term, medium-term long-term adaptation plans integrating vulnerabilities of the tourism industry of Belize to climate change and sea level rise.

Figure 7.32: Loss of beach area for swimming due to the construction of hard structures (sea walls) in San Pedro, Ambergris Caye

Other efforts include the installation of soft defenses such as the planting of mangroves. But one of the most effective sea defenses is the use of the limbs of Pimento trees that allow for some dissipation of wave energy while at the same time retaining most of the sand during back wash and thereby maintains the integrity of the beach, was done at Placencia and Monkey River (see Figure 7.33).

Figure 7.33: Use of the limbs of Pimento trees to arrest beach erosion and promote sand accretion at Placencia and Monkey River

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Section 8: Health Sector

1.0 Introduction

The health of millions of people worldwide is impacted upon each year by the acute and long-term effects of climate. Climate change has wide ranging consequences for human health. Public health depends on sufficient food, safe drinking water, secure shelter, good social conditions and a suitable environment for controlling infectious diseases. All of these factors can be affected by climate. Climate change is expected to exacerbate this condition. The basic requirements for good health are clean air and water, sufficient food and adequate shelter and each of these conditions are very likely to be affected by future climate changes (Haines et al. 2000; Heslop-Thomas et al. 2009; Leary et al (2008); Martens, 1996).

On a global scale, each year, about 800 000 people die from causes attributable to urban air pollution, 2.2 million from diarrhoea, (largely resulting from lack of access to clean water supply, sanitation and poor hygiene), 3.5 million from malnutrition and approximately 60 000 from climate-related disasters, mostly in low resource countries such as Belize (WHO, 2012). Climate change will lead to higher levels of some air pollutants, will lead to an increasing number of extreme weather events and increased outbreaks and transmission of diseases through unclean water and through contaminated food, will threaten agricultural production in some of the poorest countries such as Belize. Furthermore, climate change will also bring new challenges to the control of infectious diseases. Many of the major killer diseases are highly sensitive to temperature and rainfall, including cholera and diarrhoeal diseases, as well as vector borne diseases including malaria, dengue and schistosomiasis (WHO, 2012).

Malaria and dengue fever, two diseases linked to climate change, have become major public health problems in Belize in the recent past, although malaria seems now to be controlled.

2.0 Climate and Health

Globally, the number of reported weather-related natural disasters is increasing. Reports of natural catastrophes have more than tripled since the 1960s (IPCC, 2007). Reports of climate disasters are partly due to population growth in high-risk areas, such as the coastal zone and Cayes of Belize, where the majority of the population is to be found. It is very likely that climate change is also a contributing factor and more people are placed in the path of weather-related disasters. At the same time, climate change has driven extreme high temperatures and has probably contributed to more frequent and extreme precipitation events and more intense tropical cyclone activity. Together, these trends will increase weather-related hazards to human health.

2.1 Extreme heat

Studies have shown that daily temperatures above a locally specific threshold result in higher mortality rates (Lindsay and Birley, 1996; Martens, 1996). For instance, the hot summer of 2003 in Europe produced sustained record high temperatures which resulted in markedly higher death rates, particularly among the elderly population. In total, it has been estimated that 70 000 more deaths occurred in Western Europe during that extreme summer than expected. Continuing global warming and possible increases in temperature variability will make such events more frequent and more severe. Mean annual temperature in Belize is expected to increase by between 2 and 4 ^{0} C by the end of the century (See climate change sector) and this may place more and more people at risk of heat-related mortalities. Heat stress and cardio and cerebro-vascular conditions resulting from extreme temperature are therefore likely to increase in the future (Sookdeo, 2008).

Acute Respiratory Infections (ARI) continues to be one of the leading causes of mortality and morbidity in the general population of Belize. Information from the Ministry of Health showed that deaths attributable to ARI in the 1-4 age group were 9.4% in 2001, 8.8% in 2004 and there was no reported death in this age group in 2005 (Ministry of Health, Belize, 2009).

Heat waves, flooding, storms and drought can cause deaths and injuries, famine, the displacement of populations, disease outbreaks and psychological disorders. Higher temperatures also alter the geographical distribution of species that transmit disease. For example, outbreaks of dengue and yellow fever, transmitted by mosquitoes, increase in warmer temperatures.

2.2 Floods and droughts

Although total annual and seasonal rainfalls are not projected to change significantly, extremes of rainfall events that cause either flooding or drought, both of which can impact upon human health either directly or indirectly, are expected to increase in occurrence (See climate change sector).

For instance, floods can cause drowning and physical injuries; heighten the risk of diseases transmitted through water, insect vectors and rodents; damage homes and infrastructure and disrupt the supply of essential medical and health services. On the other hand, droughts can increase the risk of water and food shortages and malnutrition, necessitate greater reliance on contaminated water, and lead to diminished health among vulnerable members of the population. Droughts and floods also increase the risk of diseases spread by contaminated food and water and foodborne diseases such as Salmonella, Shigella, Campylobacter and Escherichia Coli (Epidemiology Unit, Ministry of Health, Belize, 2009).The combination of extreme heat and drought are also important risk factors for causing wildfires, resulting in direct health and economic losses, and increased risk of respiratory illnesses due to smoke pollution.

2.3 Tropical storms

Extreme winds, particularly in the tropical regions, bring death, illness, injury, psychosocial impacts, and destruction of health facilities and health services. There is evidence of a marked increase in the numbers of the most extreme hurricanes in recent decades, and this trend is likely to continue. Studies suggest that a doubling of CO_2e in the atmosphere would result in a minimal increase in average hurricane windspeed but in a significant increase in the frequency of the strongest (category 5) storms (IPCC, 2007).

2.4 Vector-borne diseases: Changing patterns of infection

The two main vector borne diseases affecting the country are malaria and dengue. The principal specie causing malaria in Belize is the *Plasmodium vivax* parasite although *P. falciparum* remains an important and dangerous threat in parts of the country. Malaria cases fluctuated from 1,441 cases in 2000, 1,066 in 2004 and 1,549 in 2005, of which 653 cases (42%) were from the Stann Creek District. Malaria cases will continue to represent an important public health concern in Belize, especially in rural areas of the Southern Districts since there is an active migrant population that works in the citrus and banana industries and the constant population movement resulted in substandard housing, among other factors (Ministry of Health, Belize, 2009).

Dengue is also endemic in Belize. While the number of cases had been relatively low (under 5 cases), outbreaks were experienced in 2002 (42 cases) and 2005 (652 cases). Of the 652 cases reported in 2005, 614 cases (94%) were from the Cayo District. The first officially confirmed case of dengue hemorrhagic fever in Belize occurred in 2005. Belize has had serotypes 2, 3, and 4, and, as such, the population remains vulnerable to an outbreak of dengue hemorrhagic fever (Ministry of Health, Belize, 2009).

Recently a few chronic cases of Chagas disease have been reported, and recent studies reveal the presence of the vector in western (Cayo) and southern districts (Stann Creek and Toledo) (Ministry of Health, Belize (2009).

Infections caused by pathogens that are transmitted by insect vectors are strongly affected by climatic conditions such as temperature, rainfall and humidity. These diseases include some of the most important current killer diseases in Belize: malaria, dengue and other infections carried by insect vectors, and diarrhoea, transmitted mainly through contaminated water.

Malaria transmission is strongly affected by climate and is transmitted by *Anopheles* mosquitoes. The number of mosquito vectors depends on the availability of freshwater breeding sites. Warmer temperatures, higher humidity and more places where water can collect also favour malaria transmission. However, the incidence of Malaria in Belize is declining mostly to improved health services.

Dengue prevalence is increasing rapidly. Transmitted by *Aedes* mosquitoes, dengue is a fast growing health challenge, particularly in tropical cities and towns in developing countries such as Belize. Cases have risen dramatically in the last 40 or so years, as unplanned urbanization with standing water in waste and other receptacles have created mosquito breeding sites, and movement of people and goods has spread both mosquito vectors and infections. Future climate trends are also expected to play a role, since the distribution of dengue is also highly dependent on climate.

2.5 Chronic stresses: water shortages, malnutrition and psychosocial stress

In the long run, the greatest health impacts may not be from acute shocks such as disasters or epidemics, but from the gradual increases in pressure on the natural, economic and social systems that sustain health which are already under stress. These gradual stresses include reductions and seasonal changes in the availability of fresh water, regional drops in food production, and rising sea levels, all of which apply to Belize.

Mounting water stress fosters a range of long-term public health challenges. Lack of access to clean water supply and sanitation, along with poor hygiene, is already the main contributor to the burden of diarrhoeal disease. Climate change in Belize is projected to bring changing rainfall patterns, increased temperatures and evaporation, and salinization of coastal water sources through rising sea levels.
Pressures on agriculture threaten to increase the burden of malnutrition. Undernutrition and related diseases is currently the greatest contributor to the global burden of disease, killing millions of people every year, mostly children in developing countries. It is projected that climate change will cause decreases in agricultural production in many tropical developing regions as Belize.

Increased frequency of El Niño events and future changes to the ocean ecology also have the potential to substantially alter fish breeding habitats and food supply for fish, and ultimately the abundance of fish populations and the risk of food insecurity and the health consequences of malnutrition.

2.6 Vulnerable regions: exposed populations

All regions of the world will be affected by a changing climate, but the resulting health risks to human populations vary greatly, depending on where and how people live. People living in coastal regions, as in Belize, are particularly vulnerable in different ways. Populations in these regions are vulnerable to death and injury and destruction of not only their public health infrastructure from increasingly severe tropical storms, but also salinization of water resources and agricultural land from sea level rise. Many of these countries, like Belize, struggle to supply adequate fresh water for basic sanitation and hygiene to the population, particularly to outlying isolated areas where populations suffer elevated rates of diarrhoea and nutritional deficiencies during droughts, floods and high temperatures.

2.7 Solutions: health governance and the climate change agenda

Climate change will affect the health and well-being of all populations, with impacts escalating into the foreseeable future in many different ways. The extent to which these risks translate into increased numbers of deaths and burdens of injury and disease will depend on the effectiveness of mitigation and adaptation policies. Strengthening public health systems and health emergency management systems in Belize is necessary, particularly to safeguard the health of the most vulnerable population groups and respond effectively to emergencies when they arise.

3.0 Health Impacts of Climate Change

In view of that fact that climate has a significant influence on human health and well-being climate change may very well further strengthen this relationship. Certain diseases such as vector- borne diseases as dengue and malaria, respiratory diseases such as asthma and water borne diseases such as cholera and dysentery may become more acute and prevalent in the future with climate change.

Important determinants of vector-borne disease transmission include: vector survival and reproduction; the vector's biting rate and the pathogen's incubation rate within the vector organism. Vectors, pathogens and hosts each survive and reproduce within a range of optimal climatic conditions: temperature and precipitation are the most important, while sea level elevation, wind, and daylight duration are also important (Lindsay and Birley, 1996; Martens, 1996).

However, we focus attention on the two most common vector-borne diseases, namely dengue and malaria. Based on available data (2004-2012) for all districts of Belize, it appears that in the case of malaria, the trend for all of Belize is downward so much so that the disease is under control or eliminated in all districts except Stann Creek 2012 (Table 8.2 and Figure 8.1). On the other hand the incidence of dengue has been increasing overall in Belize in all districts, except Orange Walk (Table 8.1 and Figure 8.1).

Table 8.1: Number of Reported Cases of Dengue Fever by District in Belize, 2004 – 2012 (Source: Ministry of Health, Belize, 2013: Health Statistics of Belize 2004 – 2012)

District	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
Corozal	1	8	0	72	2	175	127	22	104
Orange Walk	6	3	1	14	0	2	23	8	7
Belize	13	18	8	38	34	423	1,308	593	1365
Cayo	8	614	2	4	3	795	323	255	663
Stann Creek	0	5	0	7	0	23	46	53	60
Toledo	13	1	0	0	0	39	35	115	351
Total	**41**	**652**	**11**	**137**	**39**	**1,457**	**1,862**	**1,046**	**2,550**

Table 8.2: Number of Reported Cases of Malaria by District in Belize (2004-2012 (Source: Ministry of Health, Belize, 2013: Health Statistics of Belize 2004 – 2012)

District	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
Belize	25	31	8	13	3	0	3	3	0
Orange Walk	11	16	5	12	17	4	5	1	1
Cayo	357	479	150	104	110	27	22	08	0
Stann Creek	306	653	405	263	143	77	97	47	29
Toledo	302	358	273	436	256	147	23	20	5
Total	**1066**	**1549**	**844**	**845**	**540**	**256**	**150**	**79**	**37**

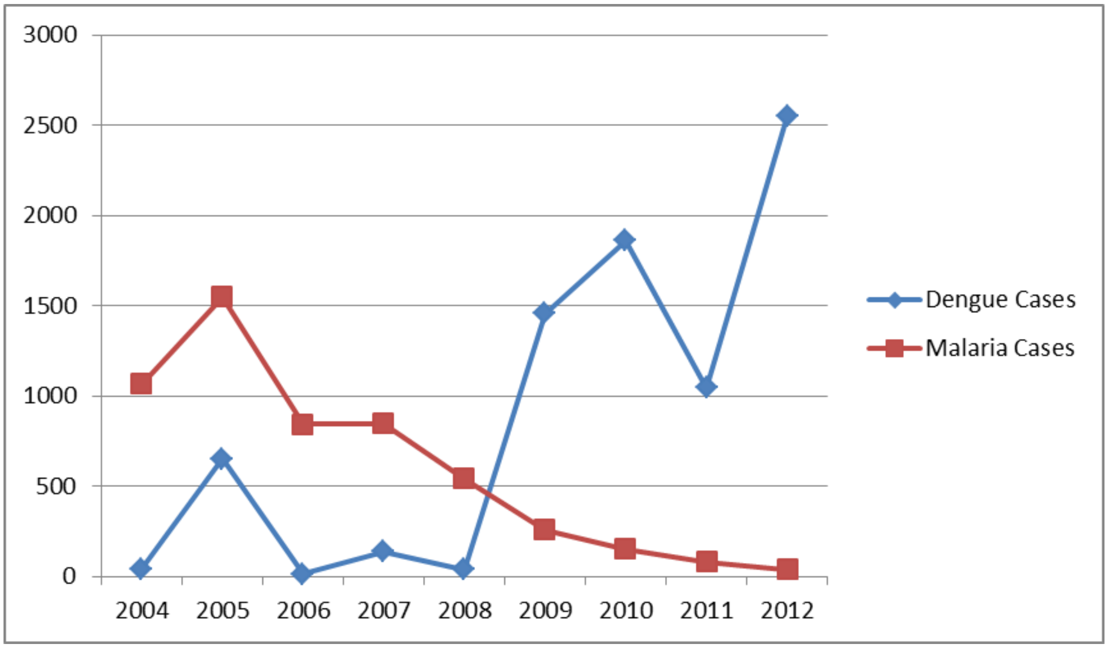

Figure 8.1: Trends in the number of reported cases of Dengue Fever and Malaria by District, 2004 – 2012 (Source: Ministry of Health, Belize, 2013: Health Statistics of Belize 2004 – 2012)

3.1 Dengue Fever

In this section we examine the relationship between dengue fever and changing climate conditions. There has been a recent increase in the incidence of Dengue Fever (DF) in the Caribbean and the temperature increases expected from climate change may exacerbate this condition. Studies have revealed that the occurrence of DF is sensitive to factors such as temperature increases and rainfall (Amarakoon et al. 2003; Chadee et al. 2007; Taylor et al. 2008).

The primary vector responsible for DF transmission is the *Aedes aegypti* mosquito. Although DF outbreaks are multifactorial - involving social, biological and environmental factors, such as poor sanitation or water retaining receptacles such as discarded water containers and tyres, climatic factors also play a significant role in their occurrence (Amarakoon et al. 2003; Chadee et al. 2007; Taylor et al. 2008).

When focusing on the monthly incidence of dengue cases over the last three years (2010, 2011 and 2012) for which data is available, it is evident the total number of dengue cases has been decreasing for the Districts of Belize: from a total of 483 in 2010 to 182 cases in 2011 to 139 cases in 2012. Also the monthly incidence of dengue cases is highest in the Belize and Cayo Districts (Figures 8.3, 8.4 and 8.5: Source - Ministry of Health –Vector Control, Belize)

Table 8.3: Relationship between monthly rainfall and the monthly incidence of dengue (rapid test-positive) for Districts of Belize, 2010 (Source: Ministry of Health –Vector Control, Belize)

Month	District of Residence							
	Corozal	Orange Walk	Belize	Cayo	Stann Creek	Toledo	Unknown	Total
1	0	0	3	2	2	0	0	7
2	0	3	3	6	1	4	0	17
3	0	5	2	7	4	2	0	20
4	0	0	1	4	1	0	0	6
5	0	2	0	3	1	0	0	6
6	0	1	2	49	1	0	0	53
7	0	4	26	25	5	0	0	60
8	1	2	55	13	0	0	0	71
9	0	3	134	11	2	1	3	154
10	2	1	49	8	2	1	1	64
11	0	0	10	2	1	1	0	14
12	0	0	9	2	0	0	0	11
Total	3	21	294	132	20	9	4	483

Table 8.4: Relationship between monthly rainfall and the monthly incidence of dengue (rapid test-positive) for Districts of Belize, 2011 (Source: Ministry of Health –Vector Control, Belize)

Month	District of Residence							
	Corozal	Orange Walk	Belize	Cayo	Stann Creek	Toledo	Unknown	Total
Jan	0	0	2	0	0	0	0	2
Feb	0	0	0	4	1	0	0	5
Mar	1	0	0	1	0	0	0	2
Apr	0	0	0	0	0	0	0	0
May	0	0	3	0	0	3	0	6
Jun	0	0	1	3	0	1	0	5
Jul	0	0	6	5	0	1	0	12
Aug	0	0	8	12	1	2	0	23
Sep	0	0	5	6	1	5	0	17
Oct	0	2	14	18	1	4	1	40
Nov	1	2	21	10	0	5	0	39
Dec	1	0	21	8	0	1	0	31
Total	3	4	81	67	4	22	1	182

Table 8.5: Relationship between monthly rainfall and the monthly incidence of dengue (rapid test-positive) for Districts of Belize, 2012 (Source: Ministry of Health –Vector Control, Belize)

Month	**District of Residence**							
	Corozal	**Orange Walk**	**Belize**	**Cayo**	**Stann Creek**	**Toledo**	**Unknown**	**Total**
Jan	**0**	**0**	**8**	**9**	**1**	**14**	**0**	**32**
Feb	**0**	**0**	**17**	**28**	**1**	**1**	**0**	**47**
Mar	**0**	**0**	**3**	**25**	**1**	**1**	**0**	**30**
Apr	**1**	**0**	**1**	**20**	**0**	**0**	**0**	**22**
May	**0**	**0**	**0**	**0**	**0**	**2**	**0**	**2**
Jun	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Jul	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Aug	**0**	**0**	**2**	**0**	**0**	**0**	**0**	**2**
Sep	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Oct	**0**	**0**	**2**	**0**	**0**	**0**	**0**	**2**
Nov	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Dec	**0**	**0**	**2**	**0**	**0**	**0**	**0**	**2**
Total	**1**	**0**	**35**	**82**	**3**	**18**	**0**	**139**

Furthermore, it is evident, using the year 2011 as an example for Belize and Cayo Districts, that there is a close relationship between monthly rainfall and the monthly incidence of dengue (Figures 8.2 and 8.3: Source - Ministry of Health –Vector Control, Belize). Air temperature also plays a role since an increase in air temperature may lead to a shortening of the incubation period of the mosquito larvae an earlier presence of mosquitoes in the environment.

This correlation between rainfall and the incidence of Dengue diseases in Belize as seen in Figures 8.2 and 8.3 , show that the highest incidence of Dengue cases are in the rainy season, namely July to November. However, there is normally a lag of about one month between peak rainfall (June to October) and peak incidence of dengue (July to November). This is very likely due to the fact that about one month is needed for the larvae of the Aedes aegypti to morph into adult mosquitoes when they can act as vectors for the transmission of the disease (Figures 8.2 and 8.3: Source - Ministry of Health –Vector Control, Belize).

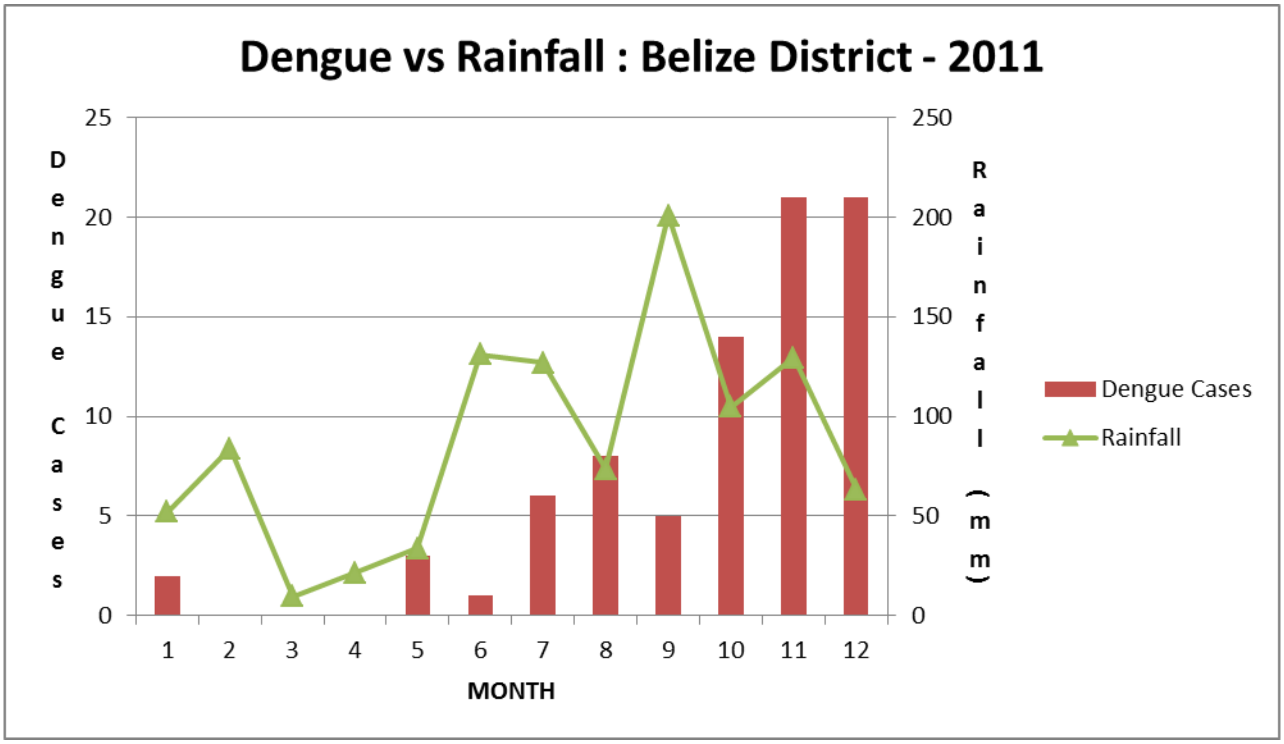

Figure 8.2: Relationship between monthly rainfall and the monthly incidence of dengue (rapid test-positive) for Belize District, 2011 (Source: Ministry of Health –Vector Control, Belize)

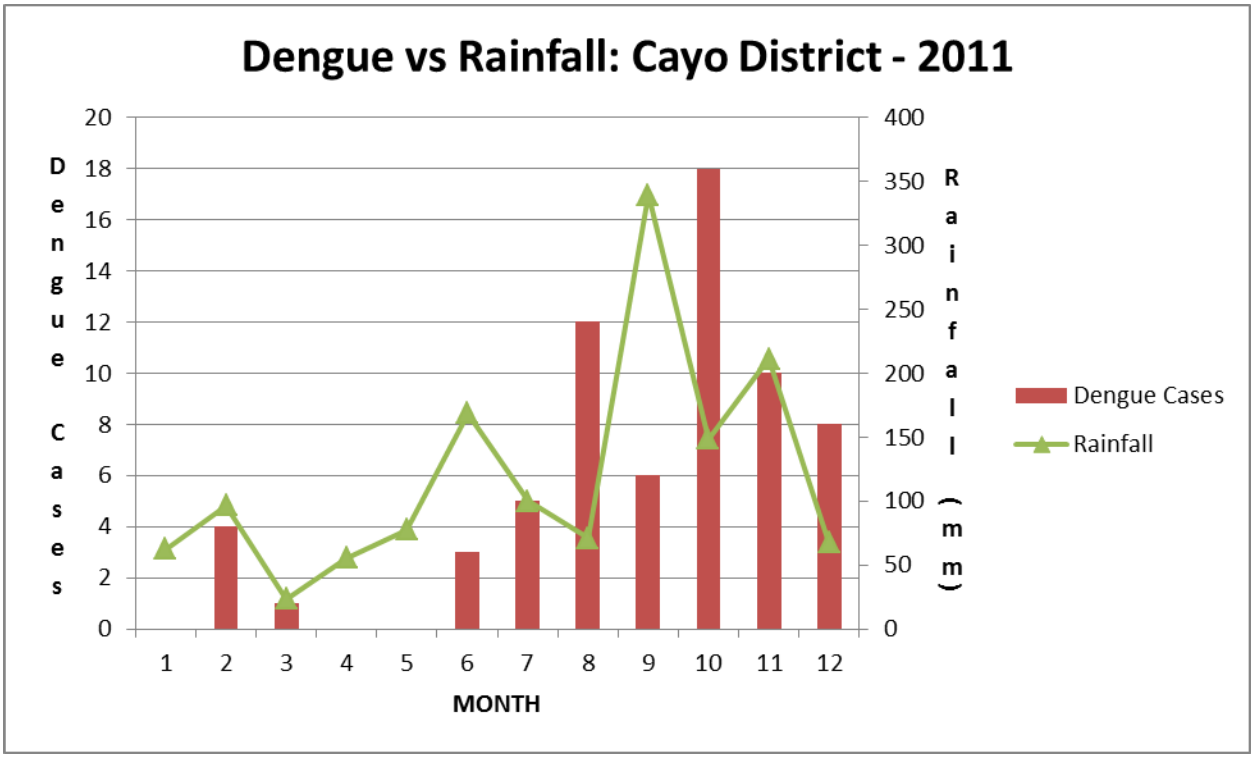

Figure 8.3: Relationship between monthly rainfall and the monthly incidence of dengue (rapid test-positive) for Cayo District, 2011 (Source: Ministry of Health –Vector Control, Belize)

In a recent study on dengue fever (DF) and dengue haemorrhagic fever (DHF) in Trinidad, no significant correlations were observed between temperature and DF or DHF incidence but rainfall was found to be significantly correlated with DF incidence, with a clearly defined 'dengue season', between June and November, the rainy season (Figure 8.4: Chadee et al., 2007).

The Breteau Index, namely the number of positive containers (i.e. containing *Aedes aegypti* larvae) per 100 premises or households, is also correlated with the incidence of DF and DHF. When the Breteau index is 50 or more then the risk of transmission is high and when it is 5 and less the risk of transmission is low (Chadee et al., 2007; WHO, 2012). According to a recent study on entomological indices according to District and Village, Belize, 2008, the Breteau Index was zero in Valley Community in Stann Creek District and Fire Bum Village in Orange Walk District. The highest values were 22 % in Ontario Village in Cayo District and 24 % in South Stann Creek Village in Stann Creek District (See Table 8.6).

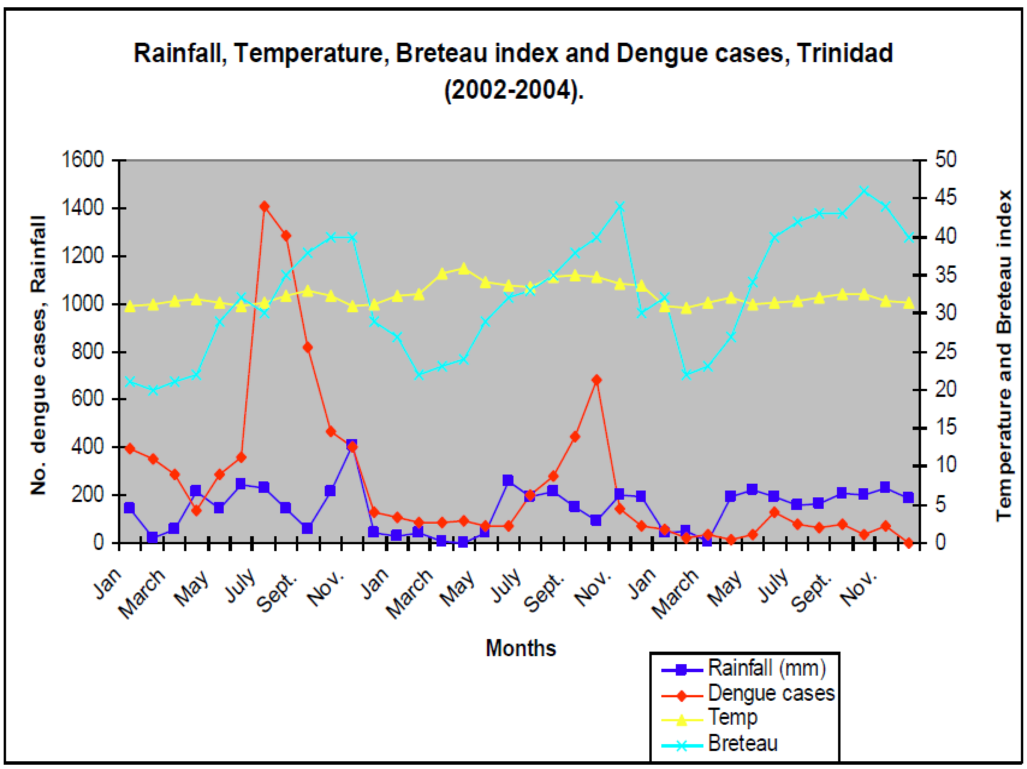

Figure 8.4: Rainfall, temperature, Breteau index, and dengue cases, Trinidad (2002-2004). Source: Chadee *et al.* (2007)

Table 8.6: Entomological indices according to District and Village, Belize, 2008 (Source: Vanzie et al (2008)

District	Village	House Index	Cont Index	Breteau Index
Corozal	Ranchito	4%	2%	4%
	Paraiso	3%	2%	3%
	Little Belize	9%	2%	9%
Orange Walk	Douglas	2%	1.4%	0.2%
	Fire Burn	0%	0%	0%
	Trial Farm	3.8%	1.3%	4.7%
Belize	Double Head Cabbage	3.9%	1.1%	3.9%
	Barrel Boom	4.2%	3.1%	4.2%
	Crooked Tree	7%	2.4%	9%
Cayo	Santa Familia	9%	6.32%	16%
	Ontario	16%	7.28%	22%
	Cristo Rey	9%	5.21%	17.14%
Stann Creek	Valley Community	0%	0%	0%
	South Stann Creek	14%	13.6%	24%
	Hope Creek	7%	3.8%	9%
Toledo	Blue Creek	4.9%	2%	4.9%
	Forest Home	4%	.9%	4%
	San Antonio	8.7%	3%	12%

Source: entomological Survey, Vanzie et al, 2008.

3.2 Climate Change and incidence of Dengue

In view of the fact that the incidence of the dengue disease seems to be strongly correlated with lagged (one month) rainfall, based on available data, we examined how changes in climate, namely rainfall, would affect the incidence of dengue. We compared available data on the annual incidence of dengue (Table 8.7) with total annual rainfall (mm) for a current decadal period (2003-2012) and the total annual rainfall for a future decadal period (2060-2069) from the ECHAM5 model for all Districts of Belize, but with the climate data point selected being close to the largest population centers in each District, namely, Belize City in Belize District, Orange Walk Town in Orange Walk-Corozal Districts, Belmopan in Cayo District, Dangriga in Stann Creek District and Punta Gorda in Toledo District.

Table 8.7: Dengue cases by District in Belize (2005-2007 (Source: Ministry of Health, Belize, 2013: Health Statistics of Belize 2008 – 2012)

District	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Belize City	0	13	18	8	38	34	423	1308	593	1365
Orange Walk	0	6	3	1	14	0	2	23	8	7
Cayo	1	8	614	2	4	3	795	323	255	663
Stann Creek	0	0	5	0	7	0	23	46	53	60
Toledo	0	13	1	0	0	0	39	35	115	351

At first, examining Belize District there is little or no relationship in the trends between current (2003-2012) total annual rainfall (mm) and number of dengue cases. However the number of dengue cases generally increases steadily from 2005-2010. Furthermore, total annual rainfall (2060-2069) is projected to decrease in all years. But the number of dengue cases increased significantly starting in 2009 (Year 6: Figure 8.4). Based on the presumption that the incidence of dengue is related to rainfall amounts, then one would expect the number of cases of dengue to decrease in the future (2060-2069) in Belize District (See Table 8.7 and Figure 8.5).

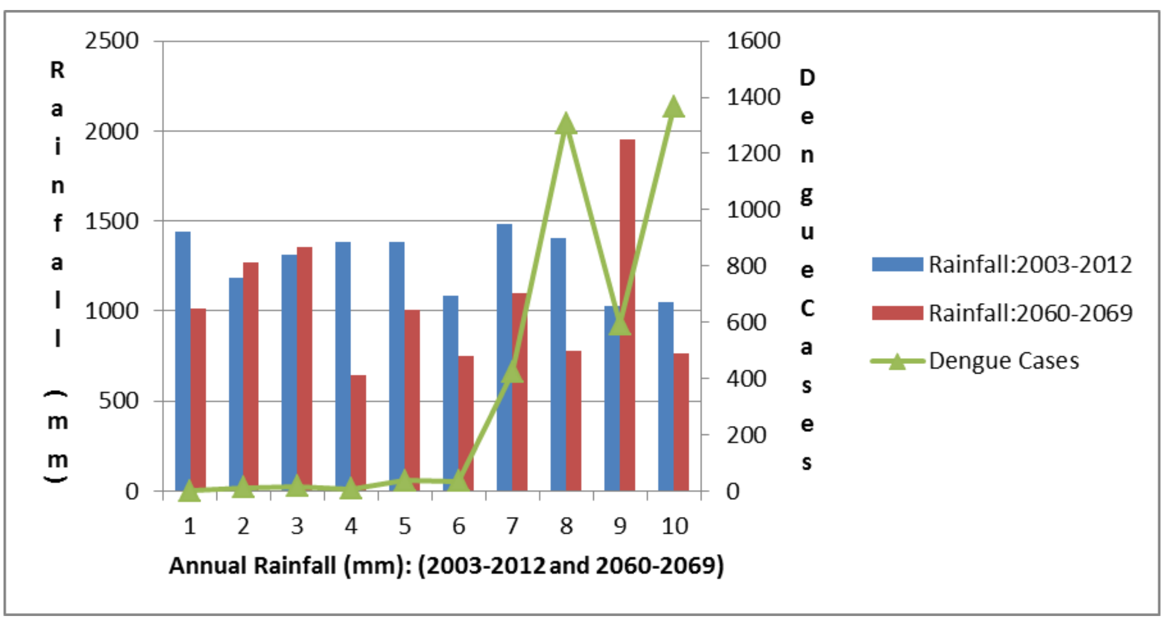

Figure 8.5: Number of dengue cases and total annual rainfall (mm) for the current (2003-2012) and future (2060-2069) for Belize District

Next, when examining Orange Walk District, again there is little or no relationship in the trends when comparing current (2003-2012) total annual rainfall (mm) and number of dengue cases. However the number of dengue cases peaked in 2007 and again in 2010. Furthermore, total annual rainfall (2060-2069) is projected to increase in all years. Again, based on the presumption that the incidence of dengue is related to rainfall amounts, then one would expect the number of cases of dengue to increase in the future (2060-2069) in Orange Walk-Corozal Districts (See Table 8.7 and Figure 8.6).

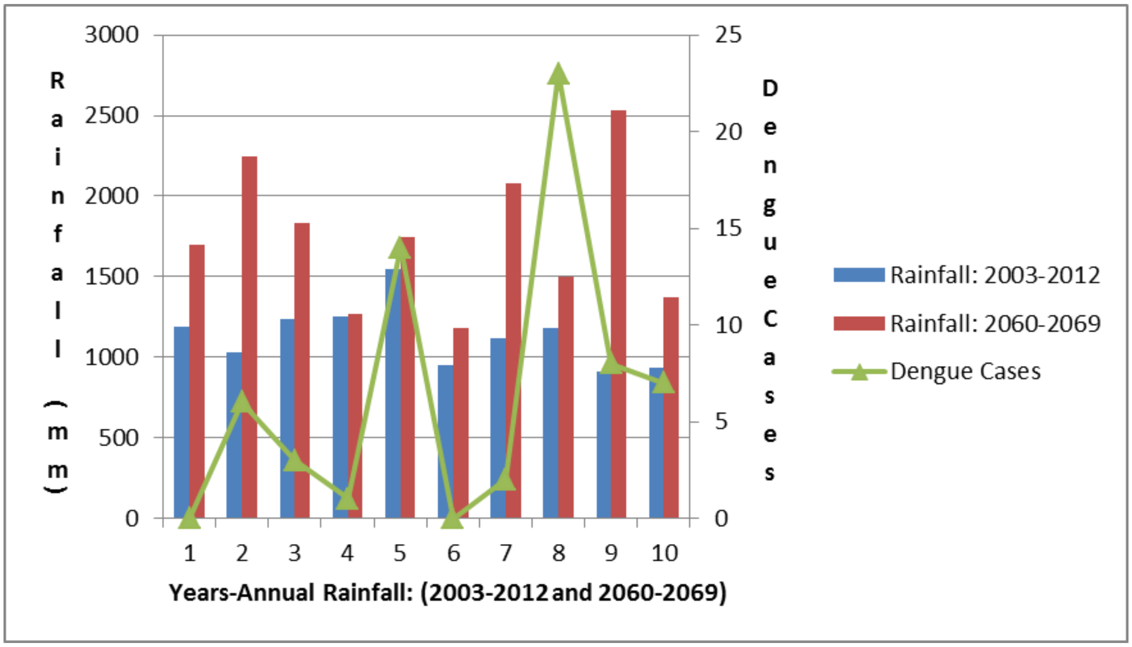

Figure 8.6: Number of dengue Cases and total annual rainfall (mm) for the current (2003-2012) and future (2060-2069) for Orange Walk District

But when examining Cayo District, again there is little or no relationship between current (2003-2012) total annual rainfall (mm) and number of dengue cases. Also, the number of dengue cases generally is generally low but for some reason peaked at > 600 cases in 2005 and 2012 and even > 700 cases in 2009. Furthermore, total annual rainfall (2060-2069) is projected to decrease in all years. Based on the presumption then that the incidence of dengue is related to rainfall amounts, one would expect the number of cases of dengue to decrease in the future (2060-2069) in Cayo District (See Table 8.7 and Figure 8.7).

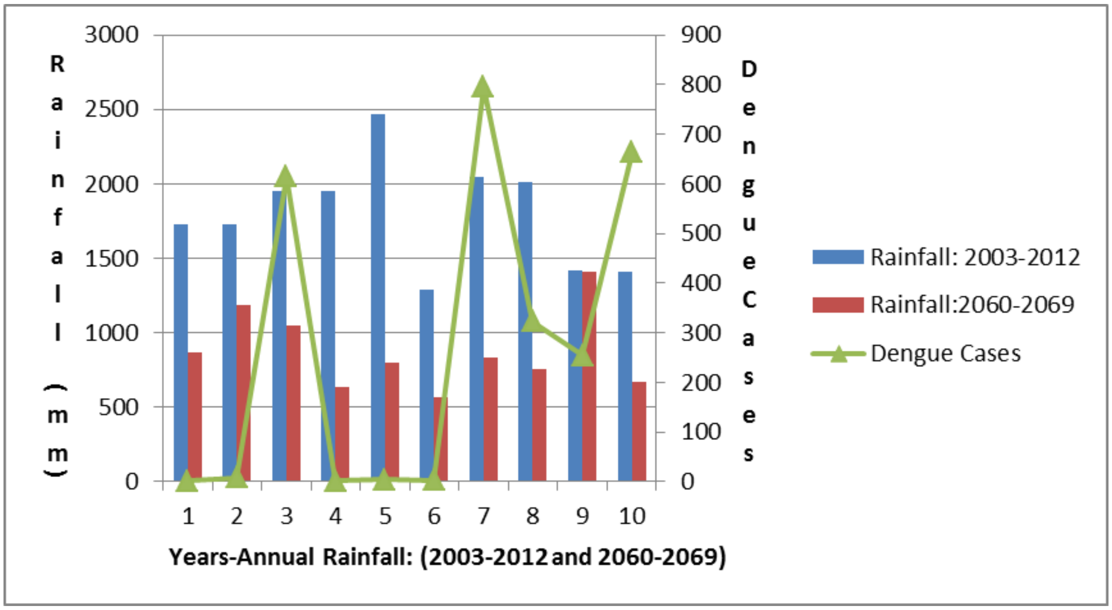

Figure 8.7: Number of dengue cases and total annual rainfall (mm) for the current (2003-2012) and future (2060-2069) for Cayo District

Next, by examining Stann Creek District there is again little or no relationship between current (2003-2012) total annual rainfall (mm) and number of dengue cases. However the number of dengue cases generally fluctuates from year to year but shows an upward and increasing trend from 2009-2012. Furthermore, total annual rainfall (2060-2069) is projected to increase in all years in the future, except 2063, 2065 and 2066. Based on the presumption then that the incidence of dengue is related to rainfall amounts, then one would expect the number of cases of dengue to generally increase in the future (2060-2069) in Stann Creek District (Table 8.7 and Figure 8.8).

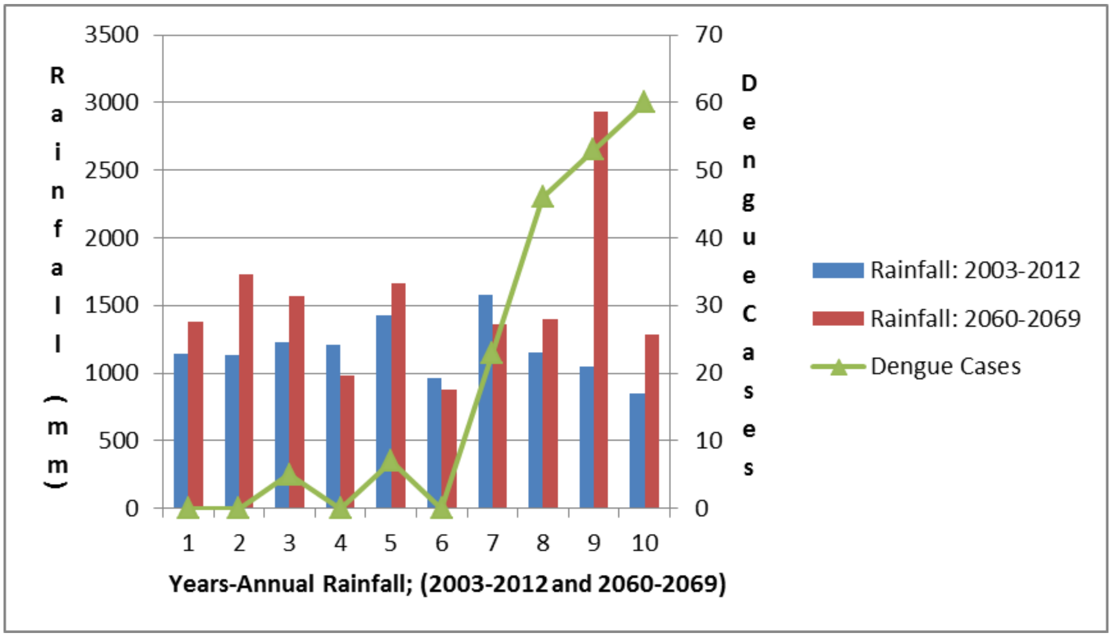

Figure 8.8: Number of dengue cases and total annual rainfall (mm) for the current (2003-2012) and future (2060-2069) for Stann Creek District

Finally, when examining Toledo District, again there is little or no relationship between current (2003-2012) total annual rainfall (mm) and number of dengue cases. However the number of dengue cases generally increases steadily from 2008-2010. Furthermore, total annual rainfall (2060-2069) is projected to generally decrease in all years, except 2061 and 2064. Again, based on the presumption that the incidence of dengue is related to rainfall amounts, then one would expect the number of cases of dengue to generally decrease in the future (2060-2069) in Toledo District (Table 8.7 and Figure 8.9).

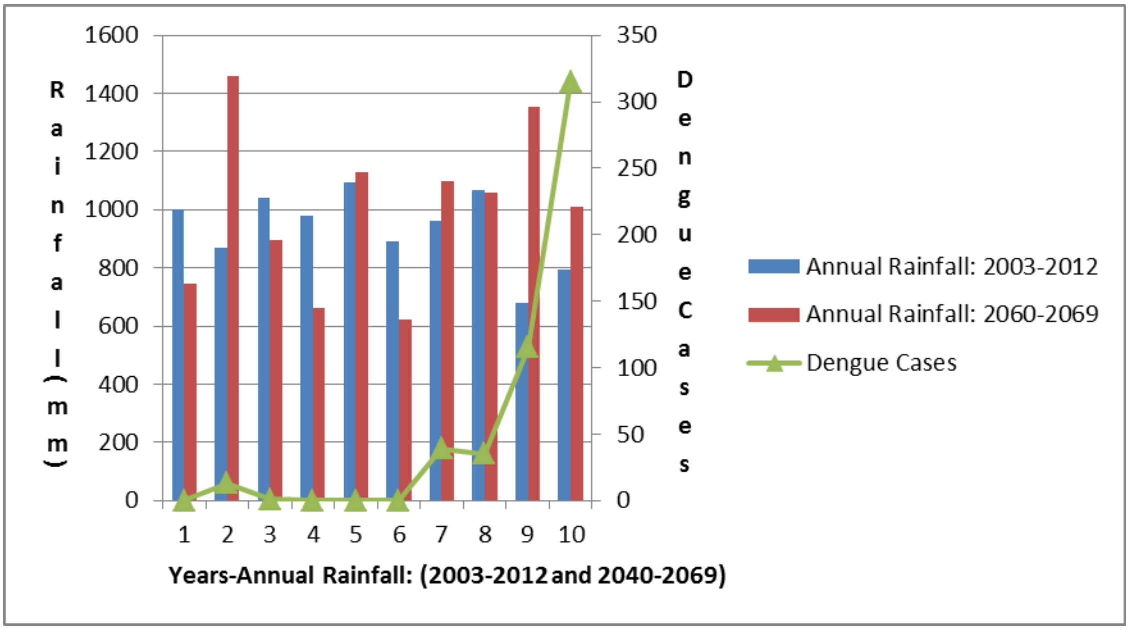

Figure 8.9: Number of dengue cases and total annual rainfall (mm) for the current (2003-2012) and future (2060-2069) for Toledo District

3.3 Climate Change and incidence of Malaria

Malaria is a life-threatening parasitic disease transmitted by mosquitoes. The principal specie causing malaria in Belize is the *Plasmodium Vivax* parasite although *P. Falciparum* remains an important and dangerous threat in parts of the country. These parasites are transmitted from person to person through the bite of a female *Anopheles* mosquito.

For the years for which data is available, it is evident that the incidence of malaria is declining rapidly in all districts of Belize, so much so to be almost non-existent by 2012, except in Stann Creek District (See Figure 8.10 and Table 8.8 and also Figure 8.1).

The number of malaria cases in Belize has declined steadily from 9,513 cases in 1995 to 79 cases in 2011. The most drastic reduction in the number of cases of malaria occurred between 1995 (9,513 cases) and 1998(1,436 cases) (Figure 8.10).

Belize has therefore made great strides in the control of malaria and according to the Ministry of Health is poised to enter the pre-elimination stage (< 1case/ 100000) (Belize Millennium Development Goals and Post 2015 Report).

Table 8.8: Malaria cases by District in Belize (2005-2007 (Source: Ministry of Health, Belize, 2013: Health Statistics of Belize 2004 – 2012)

District	2004	2005	2006	2007	2008	2009	2010	2011	2012
Belize	25	31	8	13	3	0	3	3	0
Orange Walk	11	16	5	12	17	4	5	1	1
Cayo	357	479	150	104	110	27	22	08	0
Stann Creek	306	653	405	263	143	77	97	47	29
Toledo	302	358	273	436	256	147	23	20	5
Total	**1066**	**1549**	**844**	**845**	**540**	**256**	**150**	**79**	**37**

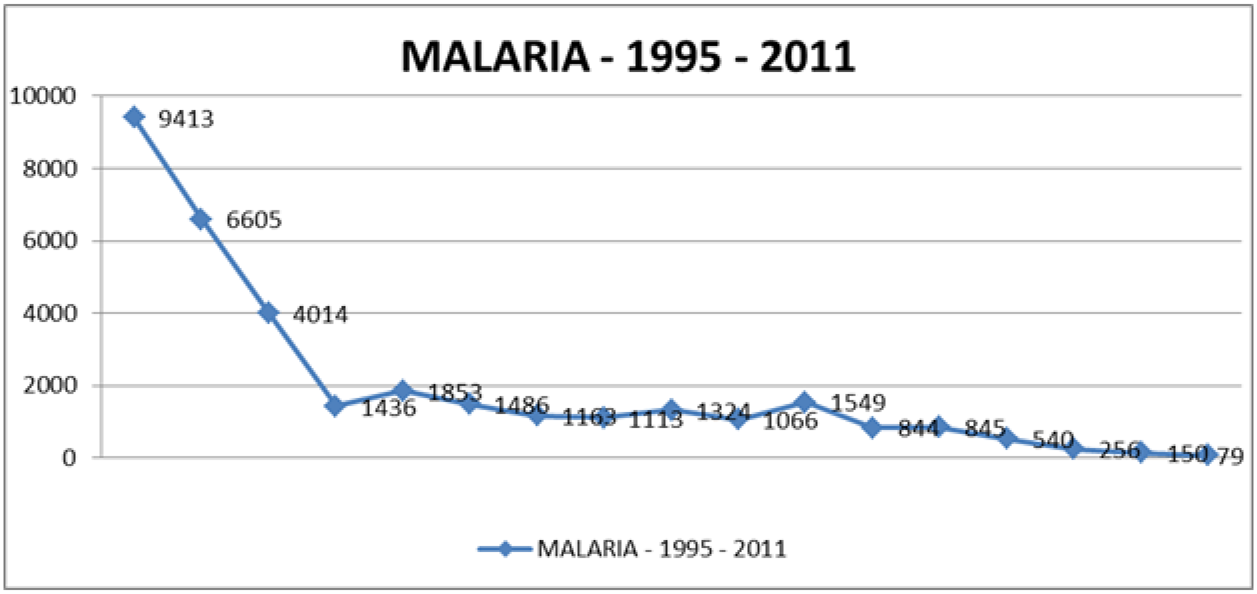

Figure 8.10: Malaria cases in Belize (1995-2011 (Source: Ministry of Health, Belize, 2013: Health Statistics of Belize 2004 – 2012)

3.4 Climate Change and incidence of Other Diseases

Other climate-sensitive diseases that may increase in proliferation rates in the future with climate change include cholera, diarrhoeal diseases such as dysentery, acute respiratory diseases such as asthma, schistosomiasis and tuberculosis and chagas.

Of these, acute respiratory infections and tuberculosis seem to be the most prevalent in Belize. However, tuberculosis infection is commonly linked with HIV infections so the link with climate and climate change is obscured. On the other hand, the incidence of respiratory infections may very likely increase in the future from climate change and changes in other triggers such as air pollution of increased pollen levels in the air (Martens, 1996; Haines, 2000; Leary et al. 2008).

Moreover, Diarrhea, Gastroenteritis and Hepatitis continue to be the three main water borne diseases affecting Belize, especially young children. Between 2005 and 2010, the number of reported cases of Diarrhea showed an increase of almost three fold with increases reported in all districts, with two deaths occurring. In addition, Gastroenteritis also doubled in the amount of cases reported between 2009 and 2010, while Hepatitis had a small increase from 107 to 113 reported cases. Cayo District reported the highest number of cases, while Corozal district had a sharp decline for the same period (Environmental Statistics for Belize, 2012).

Human exposure to waterborne infections occurs by contact with contaminated drinking water, recreational water, or food. This may result from human actions, such as improper disposal of sewage wastes, or be due to weather events. Rainfall can influence the transport and dissemination of infectious agents, while temperature affects their growth and survival (Gatrell and Elliot, 2009).

Many of life-threatening diseases are highly sensitive to temperature and rainfall, including cholera and diarrhoeal diseases such as dysentery (WHO, 2012).

Diarrhoea, cholera and gastroenteritis are amongst the main intestinal infectious diseases and remain one of the biggest killers of children, especially in Belize. Viruses and bacteria transmitted through water and contaminated food can cause severe diarrhoea in children, often locking them into a vicious cycle of undernourishment, susceptibility to other infectious diseases, and eventually death. Higher temperatures and too much or too little water can each facilitate transmission of this disease. In tropical countries like Belize with inadequate water and sanitation services, diarrhoea is much more common when temperatures are high. For example, studies have shown that the rates of diarrhoeal disease increase by about 8% for every 1 °C increase in temperature (Lindsay and Birley, 1996; Martens, 1996).

In Belize, access to safe drinking water (97.2% of the population) contributed significantly to the reduction of cases of gastroenteritis and the control of cholera. There have been no cases of cholera since 1999. On the other hand, gastroenteritis between the period 2001-2005 accounted for 703, 293, 371, 3,006, and 3,737, respectively. The number of cases of food-borne illnesses rose from 13 in 2001 to 76 in 2003 and dramatically increased to 224 cases in 2005, the latter increase can be partially attributed to improved surveillance (Ministry of Health, Belize, 2009).

In Belize, a warming of 2 to 4°C is projected by the end of the century, which could lead to a significant increase in the incidence of diarrhoeal disease. Both flooding and unusually low levels of water, as in the coastal zone and Cayes of Belize, can also lead to water contamination and trigger higher rates of illness and death from diarrhoea. Global warming and greater variability in precipitation threaten to increase the burden of diarrhoeal diseases.

Climate change may also increase the incidence of fog and this can lead to an increase in the number of deaths due to road accidents.

4.0 Climate Change Adaptation in the Health Sector

It is apparent from the foregoing that adaptation options for the health sector in Belize include both climate and non-climatic factors. These adaptation measures are likely to include:

- Current and future incidence of diseases;
- Control of vectors (mosquitoes) for diseases (malaria, dengue);
- Stagnant water control measures and sanitation improvements in areas where houses are built in swampy locations;

- Looking after the most vulnerable population at risk such as the elderly, infants and young children and the economically disadvantaged groups;
- Lifestyle changes such as eating healthier foods to maintain good health;
- Improved health care and access, such as health alerts, more ambulances with more rapid response times and more health care centers and hospitals and professional staff.

The global public health community has a wealth of experience in protecting people from climate sensitive hazards. Many of the necessary preventive actions to deal with the additional risks of climate change are already clear (IPCC, 2007; Gatrell et al., 2009: Leary et al, 2008; Martens, 1996; Lindsay and Birley, 1996). Widening the coverage of proven, effective health interventions will be critical to the efforts of Belize to adapt to climate change in the health sector.

As a matter of fact health impacts of climate change will be determined by both climate change and non-climatic factors such as, the quality of the environment, health care and the health condition of the population (Figure 8.11). In fact environmental risk factors play a role in more than 89 % of diseases reported (WHO, 2012).

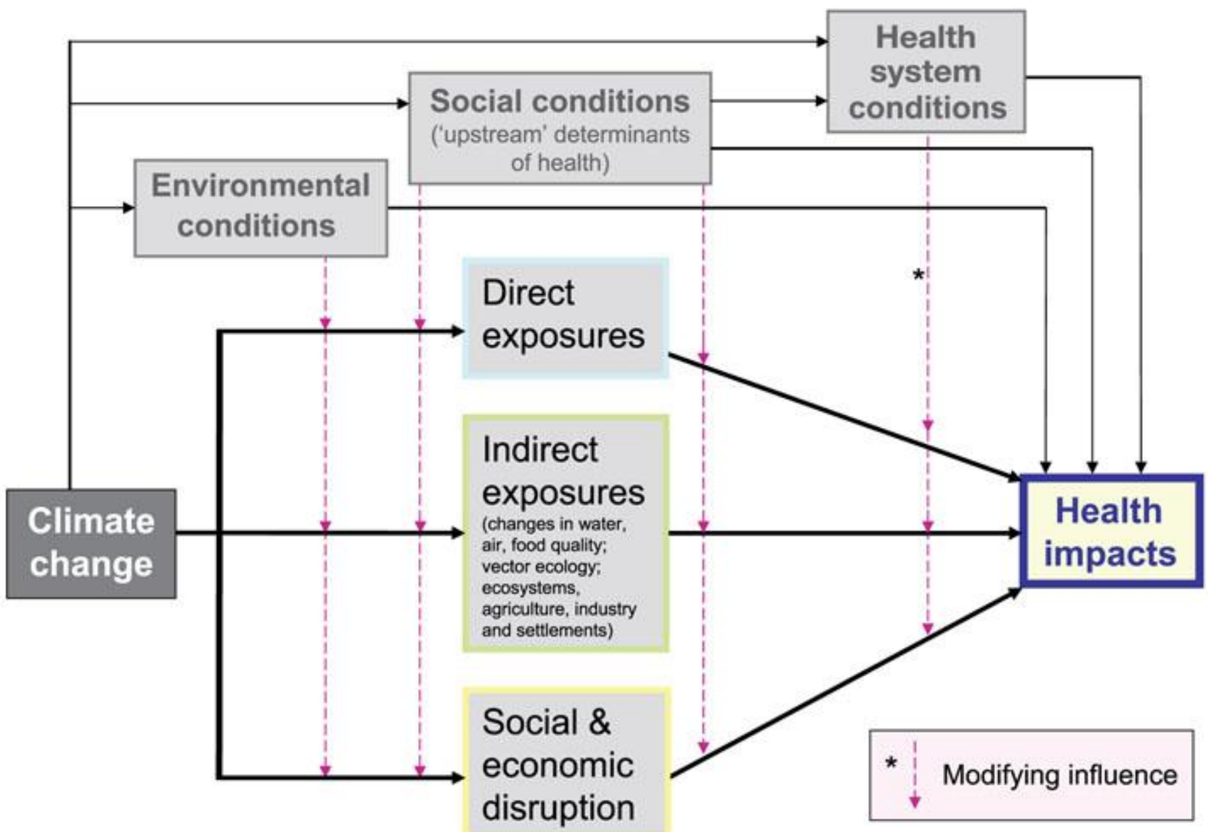

Figure 8.11: Direct and Indirect impacts of Climate Change on Human Health (Source: IPCC, 2007)

It is evident from the above sections then that adaptation has to follow a holistic path by integrating adaptation measures across sectors.

There is a need for additional investment to strengthen key health functions and for forward planning to address the new challenges posed by climate change. This additional investment should include an increase in the capacity of the health system to extend services and continuity of care to both mobile and remote populations. Further reinforcing health vulnerability and risk assessment, multi-sectoral disaster risk reduction, health emergency preparedness, early warning, and health action in emergencies can help to ensure that people are better protected from the increasing hazards of extreme weather and help communities recover faster following a disaster. This approach will need to strengthen the health coordination, health emergency management systems, early warning systems related to the health consequences of climate change, and interventions to control tropical diseases. The investment in hospitals, health facilities and other infrastructure should be protected from the long-term effects of climate change. Renewed emphasis should be placed on primary health care, and improving the environmental and social determinants of health, from provision of clean water and sanitation, to enhancing the welfare of women, especially in emergency situations (WHO, 2012).

Strengthening of public health systems is necessary with or without climate change; climate change makes this need even more critical and urgent. There is a need for additional investment to strengthen key health functions and for forward planning to address the new challenges posed by climate change. This additional investment should include increase in capacity of the health system to extend services and continuity of care to both mobile and remote populations.

Enhanced capacity to address public health emergencies saves lives and protects communities. Acute shocks such as extreme weather events and disease epidemics can overload the capacities of health systems especially in developing countries such as Belize. Complex emergencies, resulting in humanitarian crises, result in enormous health burdens for the affected population, and often require wide-scale international assistance.

Further reinforcing health vulnerability and risk assessment, multi-sectoral disaster risk reduction, health emergency preparedness, early warning, and health action in emergencies can help to ensure that people are better protected from the increasing hazards of extreme weather such as intense rainfalls during tropical storms and hurricanes, storm surges, flooding and landslides, and help communities recover faster following a disaster.

Strengthened surveillance and control of infectious disease can protect health from local to global scales. Effective disease surveillance and control become even more important under conditions of rapid environmental change and movement of people, disease vectors and infections. Rapid and accurate disease notification, in compliance with the International Health

Regulations, is the essential basis for planning disease control. Approaches such as Integrated Vector Management, which make the best use of proven interventions, such as bed nets, insecticide spraying and environmental management, to control malaria, dengue and other vector-borne tropical diseases, are required to protect against the effects of climate change (WHO, 2012).

There is great potential for using meteorological information to enhance early warning and effective response over a range of time scales, from hours or days (for example for flood warnings), to weeks (for seasonal epidemics of vector-borne disease), to months (seasonal forecasts of precipitation anomalies allowing planning for flooding or drought) or years (for drought and associated food insecurity).

Also, there is a need for improved institutional arrangements to ensure that the roles of meteorological, humanitarian, health and other agencies are well-defined, that climate information products are demand driven, user friendly and relevant for operational decision making in health and other sectors, and that there is sufficient capacity for operational response.

Local public health interventions to build community resilience are also crucial. Action on environmental and social determinants of health is critical to protecting populations from climate change in both emergency and non-emergency situations. For example, scaling up water and sanitation services and disinfection at the household level would immediately reduce diarrhoea and, at the same time, lessen the health impacts of decreasing and more variable water supplies before and during emergencies.

Implementing community-based participatory approaches to empower local communities to manage disease vectors in an integrated manner and thus increase their capacity to protect their health will increase climate resilience. The use of Larvicide and ULV-Melathaion for controlling of Aedes Mosquito and Dengue and insecticides such as deltamethrin in repeated cycles for controlling the Anopheles mosquito is already producing very positive results in Belize, especially in the case of Malaria, which is now almost completely eradicated (Ministry of Health, Belize, 2013: Health Statistics of Belize 2004 – 2012).

The benefits of such interventions are already several times greater than the costs, and the threat of climate change makes these preventive health measures an even more judicious investment. Improving social welfare in emergency situations, particularly educating and empowering women in developing countries such as Belize, is a fundamental requirement for improving health. It is also essential to strengthening community resilience to disasters and to climate change (WHO, 2012).

Furthermore, adaptation policies and forward planning, both short-term and long-term, including an enabling environment will be required to assess and cope with the threats posed by climate change and enhance capacity to deal with public health emergencies. This approach will need to strengthen the health coordination, health emergency management systems, early warning systems related to the health consequences of climate change, and interventions to control tropical diseases. The investment in hospitals, health facilities and other infrastructure should be protected from the long-term effects of climate change. Renewed emphasis should be placed on primary health care, and improving the environmental and social determinants of health, from provision of clean water and sanitation, to enhancing the welfare of women, especially in emergency situations (WHO,2012).

All adaptation measures are designed to build the resilience of nations and communities to disasters and negative health impacts attributable to climate change through awareness raising, capacity building on interventions and relevant research (WHO, 2012).

However, these adaptation measures would need to be implemented by examining policies to facilitate the transformation process and need to be supported by policy, institutional and legal frameworks.

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9.0. Cross-cutting Sector

1.0 Introduction

This Section deals with the Cross-cutting sector of V&A assessment component of the Third National Communication (SNC) of Belize and puts the focus on integrated impacts and adaptation assessments for the most vulnerable sectors of concern, namely, temperature and rainfall changes, sea level rise and extreme events such as storm surges, the coastal zone, water resources, agriculture, fisheries, tourism and human health.

The most recent IPCC V&A Assessment Reports on Climate Change (IPCC, 2007; 2013) indicated that countries that contain extensive low-lying coastal zones, as Belize where a significant percentage of the population is located, are likely to be among those most vulnerable to the adverse impacts of climate change. In fact parts the low-lying coastal zone of Belize, especially around Belize City, is already protected from sea inundation by a system of sea walls other defenses. However, the entire coastal zone is not protected by sea defenses and some of the infrastructures do not meet strict engineering standards and are not high enough to protect against storm surges. The IPCC Assessment Reports (2007; 2013) and other similar reports point to a number of vulnerabilities that low-lying coastal zones in Small Island Developing Countries (SIDS) face in regards to climate change and variability, including vulnerability due to their size and limited resource base, vulnerability to existing weather events such as heavy rainfall, dry-season drought, tropical storms and storm surges, and restricted economic opportunities that are being exacerbated by globalization and trade barriers. Though there is more than ample space in the interior of Belize, economic resources and poor soils for agriculture make displacement to the interior difficult.

It is now widely recognized that climate change/global warming due to anthropogenic greenhouse gas (GHG) emissions is one of the most pressing environmental concerns today. Low-lying coastlands, such as those of Belize, are highly vulnerable to climate change because of their limited size and low elevation, which increase their sensitivity to climate change and limit their ability to adapt. In fact, the various IPCC (2007; 2013) reports claim that adaptive capacity of human systems is generally limited in low-lying coastlands of developing countries, such as those of Belize, and vulnerability to climate change and sea level rise is high. Developing countries with extensive low-lying coastal zones, as in the case of Belize, where the narrow coastal plain that is already precariously located with respect to high-tide sea levels, that is to say below sea level, and where the bulk of the population and economic activities are centred, are therefore likely to be among those most seriously affected by climate change and variability and their impacts. Furthermore, one of the most important consequences of climate change, especially for coastal zones, is climate-driven sea level rise, which in turn can severely impact upon coastal waters and coastal ecosystems and infrastructure well into the future.

The preceding sections on Climate Scenarios (Section 2), the Coastal Zone (Section 3), Water Resources (Section 4), Agriculture (Section 5), Fisheries (Section 6), Tourism (Section 7), and Human Health all focused on how future (2060-2069) climate change affect:

- Vulnerabilities of these sectors and human livelihoods that are likely to be most critically impacted upon to current climate variability and future climate change;
- Difficulties or barriers to adaptation in critical areas or sectors;
- Opportunities, positive and adverse impacts, and priorities for adaptation.

2.0 Methodology: Cross Linkages

Given the availability of data and resources, the methodologies used in the Cross-cutting sector of the study made use of Matrix Tables, based on qualitative relationships criteria to indicate synergies between sectors study so as to assess cumulative or reduced impacts and vulnerabilities.

The essential components of this integrated approach incorporate:

- Interactions and feedback between multiple drivers and impacts;
- policy options and some indication of costs, when available;
- Cross-sectoral interactions;
- Integration of climate with other non-climatic drivers and stakeholder discussions.

3.0 Integration of Sectors/Cross-cutting Issues

For the coastal zone of Belize, for instance where all the sectors are to be found and are inter-linked, climate change impacts and vulnerabilities are not expected to occur in isolation. Non-climate factors such as population centers, linkages between sectors, as for instance the link between sea level rise and excessive rainfall and flooding in the low-lying coastal zone and the subsequent impacts on agriculture, tourism and human health and settlements should also be taken into consideration.

For instance, it is evident from the separate sectors reports that climate change and sea level rise would affect all sectors considered, namely the coastal zone, water resources, agriculture, fisheries, tourism and human health. The potential threats of climate change and sea level rise and storm surges along the coastal zone will be particularly acute due to the fact that over a significant percentage of Belize's population resides within the coastal zone, and this is the area where soils are most suitable for cultivation of crops (Table 9.1).

Table 9.1: Cross-linkages between the targeted sectors

SECTORS	Climate - Sea Level	Coastal Zone	Water	Agriculture	Fisheries	Tourism	Health
Climate - Sea Level		XX	XX	XX	XX		X
Coastal Zone	XX		XX	XX	XX		X
Water	XX	XX		XX	X		XX
Agriculture	XX	XX	XX		X		XX
Fisheries	XX	XX	X	X			XX
Tourism	XX	XX	XX	XX	XX		XX
Health	X	X	XX	XX	XX	X	

X: Significant Impact **XX: Very Significant Impact**

As an illustration of the interrelationships between sectors, the following Figure (9.1) describes the chain of impacts caused by sea level rise and how these may increase the vulnerabilities of coastal communities (Figure 9.1)

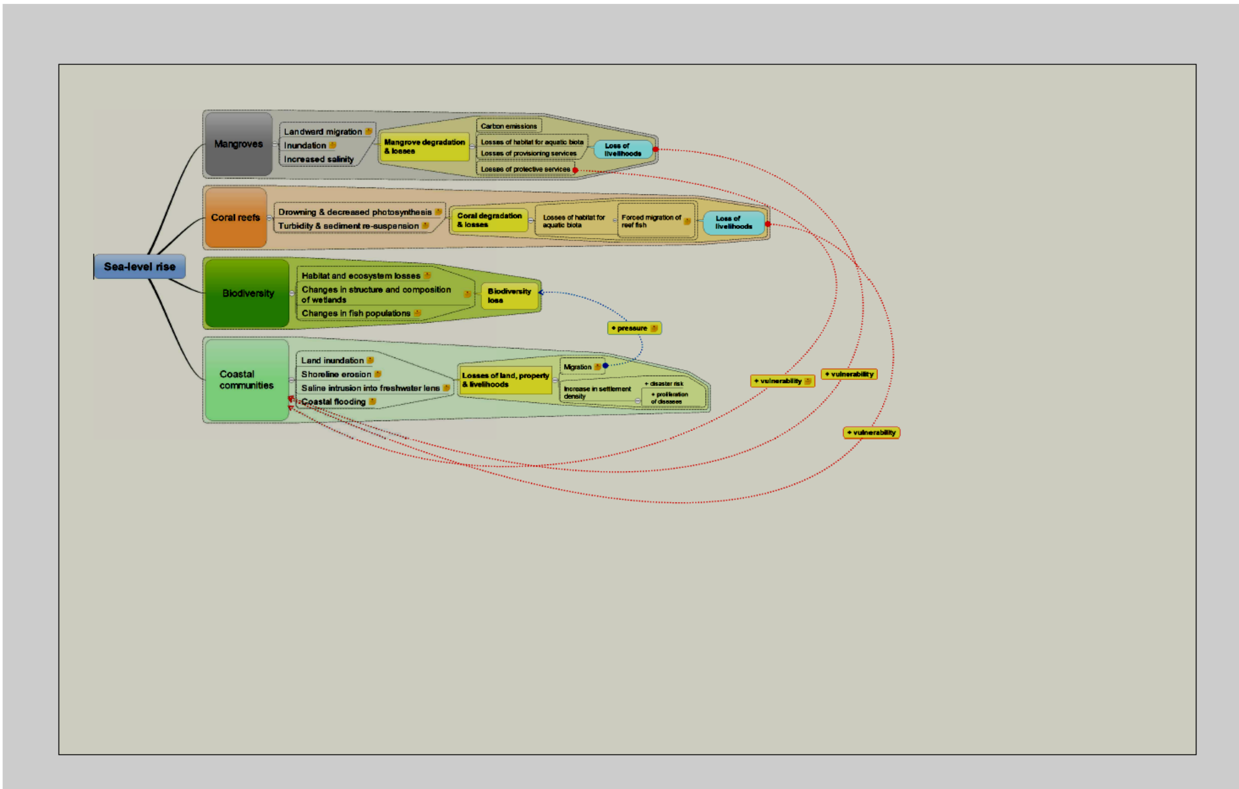

Figure 9.1: Chain of impacts caused by sea level rise and increase in vulnerabilities of coastal communities (Source: Chazarin et al. 2013)

4.0 Adaptation

It is evident from the above sections that adaptation has to follow a holistic path by integrating adaptation measures across sectors.

It is clear the climate change and sea level rise will critically impact on the coastal zone, where most of the population and infrastructure are located, where the most fertile soils and agricultural lands and crops are located and where the bulk of fisheries and tourist activities take place.

Adaptation policies should as a consequence be designed to link the various sectors of concern. It is evident that by addressing adaptation measures in regards to coastal protection works, that adaptation of the agriculture and water and tourism sectors, in particular, will be greatly facilitated.

The Government of Belize should therefore urgently pursue finances from the UNFCCC Adaptation Fund to revitalize and upgrade its coastal protection, including drainage and irrigation, since these measures will go a long way to promote adaptation of other key sectors such as agriculture, water resources and tourism, and even peoples, settlements and human health and well-being.

Another social component of adaptation to climate change and other stressors is the question of alternative livelihoods for vulnerable peoples such as fishermen. A good example of such an initiative is the Sustainable Natural Resources Based Livelihoods (SNRL) project in Belize funded by the Japan Social Development Fund (JSDF)/World Bank (WB). The project provides methodologies, instruments, procedures and responsibilities for environmental management to be applied by the Belize Enterprise for Sustainable Technology (BEST), the implementing agency, in order to ensure that potential environmental impacts are prevented or mitigated. It is developed in the context of the existing national legislative framework, World Bank safeguard policies and existing best practices for the sectors involved (BEST, 2013).

The Sustainable Natural Resources-based Livelihoods Project will address the issues of natural resource degradation that results from overexploitation and misuse. The objective of the project is to promote viable and sustainable natural resource-based livelihoods for poor communities in Belize, thereby reducing anthropogenic pressures, such as climate change, on the key natural resources through (1) support for social mobilization, facilitation, and community co-management, (2) development of community-based sustainable livelihoods of non-timber forest products in and around the selected protected areas, (3) support for innovative models of green livelihoods of fishing communities through mariculture development, and (4) community-led natural resources vigilance and knowledge dissemination (BEST, 2013).

5.0 Summary and Conclusions

From the previous sector reports, it is clearly evident that Belize, on the whole, will be very susceptible to climate change and sea level rise and extreme storm surges.

Furthermore, the coastal zone of Belize, where a significant percentage of the population is located and where the bulk of agricultural production takes place, is for the most part below the high tide level. This places the coastal zone in a very precarious position with regards to climate-driven sea level rise, especially when augmented by storm surges. The cross-linkages between the coastal zone and agriculture and fisheries and by extension tourism and human health are thus very strong and evident and adaptation measures designed to protect the coast will also address these inter-linked sectors.

Also, as described in the agriculture sector report, agricultural production, especially of sugarcane, would also be negatively affected, mainly due to decreasing yields on account of more frequent and prolonged drought, mainly. This emphasizes the cross-linkages between climate change, water resources and agriculture.

The water resources sector would also be affected by extreme and variable rainfalls leading to flooding on the one hand and droughts on the other, thereby affecting agriculture, limiting industrial activity, including tourism, and commercial and domestic activities. Adaptation measures then in the water sector will go a long way in addressing concerns in the agriculture, tourism and health sectors.

Finally, the health sector will also be at risk as the incidence of diseases (such as dengue fever and malaria) can be expected to increase on account of warmer temperatures and variable and excessive rainfalls causing flooding and promoting the proliferation of disease vectors such as mosquitoes. Inundation due to sea level rise and storm surges or to excessive rainfall and flooding may also lead to injury and even loss of life. Also, if agriculture would be at risk, food security and nutrition may be threatened.

The next steps should include, amongst others: cumulative impacts of climate change and sea level rise and how certain vulnerable groups may be affected in the short and medium term and the development and implementation of policy instruments such as NAPs (National Adaptation Plans) to move this process forward.

References: Cross-cutting Sector

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Annex 1

An In-Depth Draft Report on 'Enhancing Belize's Resilience to Adapt to the Effects of Climate Change: Project Number 00083646 - Contract Number: GCCA/PS/2013/01was submitted to the Ministry of Forestry, Fisheries and Sustainable Development and UNDP, Belize Climate Change Solutions International/Bhawan Singh on December 27, 2013.

Thereafter, following reviews by various stakeholders in Belize, an INTEGRATED VULNERABILITY AND ADAPTATION ASSESSMENT VALIDATION WORKSHOP was held at the Best Western Belize Biltmore Plaza Hotel, BELIZE CITY, BELIZE on February 5 - 6, 2014

The AGENDA of the VALIDATION WORKSHOP was as follows:

DAY 1 (FEBRUARY 5, 2013)

1. REGISTRATION: 8.30 – 9:00 AM

2. PRAYER AND NATIONAL ANTHEM: 9.15 AM

3. WELCOME AND OPENING REMARKS: MRS. ANN GORDON - MINISTRY OF FORESTRY, FISHERIES AND SUSTAINABLE DEVELOPMENT

4. OFFICIAL OPENING OF THE V&A VALAIDATION WORKSHOP BY THE HONORABLE LISEL ALAMILLA, MINISTER OF FORESTRY, FISHERIES AND SUSTAINABLE DEVELOPMENT, GOVERNMENT OF BELIZE

5. SESSION I: VALIDATION OF REPORT: 9.45 – 12.00 AM

5. 1. **METHODOLOGIES AND RESULTS FOR CLIMATE CHANGE AND SEA LEVEL RISE**: DR. BHAWAN SINGH – CLIMATOLOGIST-CONSULTANT, HONORARY PROFESSOR, UNIVERSITY OF MONTREAL – followed by questions and discussions;

5. 2. **METHODOLOGIES AND RESULTS FOR THE COASTAL ZONE SECTOR**: DR. BHAWAN SINGH – CLIMATOLOGIST-CONSULTANT, HONORARY PROFESSOR, UNIVERSITY OF MONTREAL– followed by questions and discussions;

6. SESSION 2: VALIDATION OF REPORT: 1.00 – 04.30 PM

6. 1. **METHODOLOGIES AND RESULTS FOR THE WATER SECTOR**: DR. BHAWAN SINGH – CLIMATOLOGIST-CONSULTANT, HONORARY PROFESSOR, UNIVERSITY OF MONTREAL– followed by questions and discussions;

6.2. **METHODOLOGIES AND RESULTS FOR THE AGRICULTURE SECTOR**: DR. BHAWAN SINGH – CLIMATOLOGIST-CONSULTANT, HONORARY PROFESSOR, UNIVERSITY OF MONTREAL– followed by questions and discussions;

6.3 **METHODOLOGIES AND RESULTS FOR THE TOURISM SECTOR**: DR. BHAWAN SINGH – CLIMATOLOGIST-CONSULTANT, HONORARY PROFESSOR, UNIVERSITY OF MONTREAL– followed by questions and discussions;

6.4 **SUMMARY OF THE DAY'S PROCEEDINGS**

7. SESSION 3: VALIDATION OF REPORT - Continued: 9:00 AM – 12:00 PM

7.1. **METHODOLOGIES AND RESULTS FOR THE FISHERIES SECTOR:** DR. BHAWAN SINGH – CLIMATOLOGIST-CONSULTANT, HONORARY PROFESSOR, UNIVERSITY OF MONTREAL– followed by questions and discussions;

7. 2. **METHODOLOGIES AND RESULTS FOR THE HUMAN HEALTH SECTOR:** DR. BHAWAN SINGH – CLIMATOLOGIST-CONSULTANT, HONORARY PROFESSOR, UNIVERSITY OF MONTREAL– followed by questions and discussions;

7. 3. **METHODOLOGIES AND RESULTS FOR THE CROSS-CUTTING SECTOR:** DR. BHAWAN SINGH – CLIMATOLOGIST-CONSULTANT, HONORARY PROFESSOR, UNIVERSITY OF MONTREAL– followed by questions and discussions;

7. 4. **WRAP UP AND DISCUSSIONS ON THE CONTENT AND FORMAT OF THE FORMAL REPORT:** DR. BHAWAN SINGH – CLIMATOLOGIST-CONSULTANT, HONORARY PROFESSOR, UNIVERSITY OF MONTREAL– followed by questions and discussions;

As per the TOR, this Annex-1 provides a log of corrections and adjustments made to the In-Depth Draft Report of December 27, 2013 and reflects inputs derived from the National Consultations held in Belize City on February 5 - 6, 2014.

Log of Changes made to Draft Report of December 27th, 2013

1. Acknowledgements: added – See page 2;
2. Table of Contents: added – See pages 3-10;
3. List of Acronyms: added – See pages 11-12;
4. List of Tables: added – See pages 13-20;
5. List of Figures: added – See pages 21-33;
6. Executive Summary: added - See pages 34-41;

7. **1.0 Introduction Section** (See pages:42-52);

   - Corrected minor editorial and typographical errors;
   - Added - reference: IPCC, 2013: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp.
   - Clarification on the fact Ambergris Caye was chosen to represent Zone 1 based on the fact that it is the closest weather station to zone 1 (See page 47).

8. **2.0 Climate Sector**

   - Corrected minor editorial and typographical errors;
   - Replaced Figures 2.27, 2.28, 2.29 and 2.30 (ECHAM5) and 2.35, 2.36, 2.37 and 2.38 (HadCM3Q11): at the suggestion of a stakeholder (5 Cs) rainfall changes are changed from mm/day to mm/season accompanied by changes to the textual descriptions. The justification is that values in mm/season are easier to understand for the climate section (See pages 88-92 (ECHAM5 and pages 96-100 (HadCM3Q11)).

9. **3.0 Coastal Zone Sector**

   - Addition of causes and discussions on the severe erosion problems in the Monkey River coastal zone (See page 141).

10. **4.0 Water Sector**
    - The drying up Five Blues Lake addressed and Day and Reynolds (2011) added to list of references (See page 150);
    - Karstic conditions that promote the leaching of solutes and salinization especially in northern Belize is addressed (See page 150):

- Explanation that Mollejon is a dam hydro power station, and that Chalillo and Hydro Maya are run of the river power stations provided (See page 178);

11. 5.0 Agriculture Sector

- Flooding of sugarcane fields in Orange Walk District caused by the Riohond River on the Mexican border: Figure 5.3 and information provided Dr Anil K. Sinha; Caribbean Agricultural Research and Development Institute, Central Farm, Cayo District, February, 2014 – added (See page 1950, and subsequent changes to the Figure numbers in the Agriculture Sector (See pages196-207);
- Little Belize in Corozal District added as another rice-producing area: (See page 196);
- Correction suggested by Dr Anil K. Sinha: Caribbean Agricultural Research and Development Institute, Central Farm, Cayo District, February, 2014: there is normally only one production cycle of RK beans in Belize, namely planting in November-December and harvest in February-March (Personal Communication - as a result the ECHAM5 and HadCM3Q11 yield simulations of RK Beans have been changed together with the textual descriptions (Tables 5.13, 5.14 and 5.15 and Figure 5.6 (See pages 204-208);

12. 6.0 Fisheries Sector

With new data provided by the Fisheries Department (Mrs. Vivian Ramnarace) and other stakeholders from the Department of Fisheries, the information in the Fisheries Sector was updated as follows:

- Tilapia on the industrial scale (i.e. Fresh Catch Ltd) has been dormant; Fish farm has been in receivership. Cobia farming also has been dormant since the ending of 2010 due to Hurricane Richard destroying the marine cages: corrections made to reflect these comments (See pages 240-243);
- First and Second paragraph has repeated sentences (describing the fishing fleet): corrected (See page 244);
- Table 6.1- updated (up to 2012) - Fishing Licences granted, together with the accompanying editorial changes (See page 244);
- Lobster production in 2008 decreased because of Hurricane Dean (August 2007)…Fishermen in Northern and Central Belize lost a lot of their traps and shades: observation noted and inserted and discussed (See page 245);
- There are 2 main cooperatives out of five (5): corrected (See page 246);
- Increase in conch production- this is based on annual quotas…Quotas are determined through a national survey. The quota is usually 75% of the maximum sustainable yield: comment noted and discussed (See page 248);

- In formation on fish production and exports were updated to 2013, where data was available, and replaced Figures 6.2; 6.5; 6.7; 76.9; 6.12;and 6.13 together with the accompanying editorial changes (See pages 245-258);
- There is no more marine shrimp fishery on the industrial scale due to the ban of trawling in Belizean waters. The small amount of marine shrimp captured from 2011 to present has been on the artisanal level: fact taken into consideration and appropriate corrections/insertions made (See pages 250-251);
- First and Third paragraph has repeated sentences (describing aquarium fishes, etc.): corrected (See pages 256-257);
- Inserted information on Sea Cucumber (Figure 6.15) and Seaweed and Red Drum Fish (See pages 259-261);
- Expansion of section on coral reefs and coral bleaching events beyond 1995 and up to 2012 and insertion of Figure 6.17: inserted in document (See pages 253-265);
- Also although we do not have a National Fisheries Management Plan, the Fisheries Department will be developing species specific management plans for Lobster and Conch starting in 2014: clarification noted and inserted (See page 264);
- For the graphs, the areas need to be clarified. The fishing zones are different than the areas identified. Example Ambergris Caye is not Zone 1; Zone 1 is actually Turneffe Atoll: this observation was clarified by stating that Ambergris Caye is not in Zone 1, but it is the closest weather station to Zone 1 (See pages 265-266);
- Attached to this is a summary of the regulations on closed seasons, size limit, etc. This is because you mentioned the protection of parrotfish and grouper. The Nassau Grouper has been regulated with a close season and size limit. Parrotfish and other grazers have been fully protected from 2009; Necessary corrections made and Inserted Figure 6.22 (new) – Fishing Regulations, together with accompanying editorial changes (See pages 268-275);
- Insertion of discussions of Managed Access and alternative livelihoods for fishermen from Glovers Reef Marine Reserve and Port Honduras Marine Reserve fishermen (See pages 272-274);
- Discussion of Managed Access and alternative livelihoods for fishermen from Sarteneja (See pages 274-275);
- Integration of the Report on short-term impacts and adaptation measures in the Fisheries and Aquaculture Sector using Report sent by Mrs. Ann (McConney et al., 2013) (See page 275).

13. 7.0 Tourism Sector

- Mention of adaptation planning and the expansion and diversification of tourism activities as for instance the construction of marinas in the lagoon near Placencia for sailing boats used by tourists (See page 309).

- Recommendation for comprehensive including short-term, medium-term long-term adaptation plans integrating vulnerabilities of the tourism industry of Belize to climate change and sea level rise (See page 309).

14. 8.0 Health Sector

- Insertion of monthly data for the years 2010, 2011 and 2012 : Tables 8.3, 8.4 and 8.5 accompanied by discussions (See pages 320-324);
- Insertion of monthly data and graphics correlating the incidence of dengue with rainfall for the year 2011 for the Belize and Cayo Districts : Figures 8.2 and 8.3 accompanied by discussions (See pages 322-324);
- Elaboration of adaptation measures and discussions: lifestyle changes, short-term and long-term policies and enabling environment - policy, institutional and legal framework (See pages 336-338).

15. 9.0 Cross-cutting Sector

- Insertion of discussions on the social component of adaptation to climate change and other stressors: the question of alternative livelihoods for vulnerable peoples such as fishermen (See page 345);
- Mention of the need to undertake cumulative impacts of climate change and sea level rise and how certain vulnerable groups may be affected in the short and medium term and the development and implementation of policy instruments such as NAPs (National Adaptation Plans) to move this process forward (See page 346).