Project Document

An assessment of the economic and social impacts of climate change on the water sector in the Caribbean

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Acknowledgements

The present study was prepared by Juan Llanes-Regueiro.

Notes and explanations of symbols:

A full stop (.) is used to indicate decimals

The use of a hyphen (-) between years, for example, 2010-2019, signifies an annual average for the calendar years involved, including the beginning and ending years, unless otherwise specified.

The word "dollar" refers to United States dollars, unless otherwise specified.

The term "billion" refers to a thousand million.

The boundaries and place names shown and the designations used on maps do not imply official endorsement or acceptance by the United Nations.

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Executive summary

The Caribbean is not homogenous with regard to water resources. The Caribbean climate can be characterized as tropical rainy, with two well-defined seasons, one, rainy, and another, less rainy: these characteristics have specificities according to the geographical location of each country. The rainy, tropical character of the Caribbean climate may suggest that there are enough water resources to satisfy life requirements. Notwithstanding, the availability and distribution of water depends on geological and geographical factors that—given the insular character and characteristics of each country—make water resources both vulnerable and limited.

The modelling of future climate in the Caribbean has indicated that there would be a reduction in the availability of water under the Intergovernmental Panel on Climate Change scenarios A2 and B2, a result that adds complexity to the trend already observed from the second half of the twentieth century. Although several models have estimated a reduction in precipitation for the Caribbean, this fact is not, strictly speaking, directly related to atmospheric warming in the Caribbean, but is more a consequence of changes in global and regional atmospheric circulation, especially in pressure layers at the middle and higher atmosphere that are responsible for the intensification of North Atlantic Anticyclone activity.

An increase in the influence of the north Atlantic oscillation (NAO) suggests the increase and dominance of regional eastward and vertical downward currents in the Caribbean, both of which are phenomena that may lead to precipitation decreases. There will be also changes in global-scale circulation systems like NAO, stronger in the northern-hemisphere winter months, which may reduce circulation in the Caribbean and create an increased drought influence. This whole situation is one of the main findings of the present report.

Changes in sea-level temperature would impact mainly the distribution of air temperature and humidity in lower layers over tropical oceans, generating important changes in pressure fields and atmospheric circulation.

Increased El Niño-Southern Oscillation (ENSO) influence is one of the main factors determining climate variability and the reduced likelihood of hurricane occurrence, which is one of the main sources of precipitation (10-20 per cent) in the Caribbean.

The increase in sea level will cause the expansion of saltwater intrusion which, together with the increase in temperature, may impact negatively on the quality and availability of groundwater.

This suggests a complex scenario for Caribbean countries, not only because of their dependence on precipitation, but because there needs to be a turn, from policies focused on developing, or improving, strategies for water catchment and storage and the development of water systems, towards a new policy on freshwater.

Climate variability is expected to increase, with increased frequency and intensity of extreme events, particularly droughts, which will become more intense, prolonged and extensive.

Precipitation will increase slightly in the less rainy months and will drop significantly in the wettest months.

Water availability will be higher on the larger islands than on the smaller ones, as they possess permanent rivers with huge runoff and important aquifers of amplitude and volume. The situation, nevertheless, will be more limited in Haiti, due to the environmental deterioration of that country. On the smaller islands, water availability will be severely limited:

> "Barbados, Antigua, Barbuda, and Grenada are among the driest countries per capita in the world. In some countries such as Antigua and Barbuda, Barbados, Grenada as much as 65% of the annual rainfall may occur during the wet season (June to December)."[1]

Continental countries like Suriname and Guyana will be less affected, due to strong runoff from the main rivers.

Estimated water balances have indicated that most Caribbean countries may face severe water shortages in the future, suggesting that early adaptation is an imperative. Most of the adaptation options are highly related to energy use and energy efficiency. Given the fact that about 60 per cent to 80 per cent of water use is concentrated in the agricultural sector, potential water use reduction may be found there firstly, with the introduction of innovative policies. Water use by the tourism industry represents three to four times domestic water use by inhabitants, suggesting that policy and economic instruments are needed for improved water management in the tourism sector.

Two important facts have limited a more accurate adaptation analysis: not only was there a (1) lack of accurate datasets about water: precipitation, water use, and water quality, but also (2) lack of data about water supply infrastructure, recycling, pollution control and alleviation, and the costs related to technological options. Nevertheless, the report has presented a portfolio of adaptation options by means of a combination of cost benefit analysis, a levelized costs approach to energy solutions to reduce greenhouse gas emissions, and a multi-criteria assessment.

The adaptation/mitigation options should be seen as a portfolio of credible policies that may be enhanced and modified when applied to specific countries. Desalination is a sound option under specific conditions, where water pumping over long distances would generate too high energy costs. One important lesson in decision making is that the link between energy and water has become increasingly relevant.

The multi-criteria assessment is a useful tool when different criteria cannot be expressed in monetary terms, or when the number of alternatives, including criteria from communities and specific water users, is considerably high.

All these facts suggest that a new water policy is needed for the Caribbean, one that focuses in the central role of water for the sustainability of life. This may shape new perspectives about water use, data collection, water management, technology options and community participation in decision making.

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[1] U.S. Army Corps of Engineers. 2002. Coastal Engineering Manual. Engineer Manual 1110-2-1100, U.S. Army Corps of Engineers, Washington, D.C. (in 6 volumes).

I. Introduction

The present report is organized in four main sections. One important part of the report consists in the background analysis of links between the hydrological cycle and climate change, and the central role of water. Annex 1 is devoted to extreme events and the hydrological cycle.

The report continues with an analysis of climate and the hydrological cycle in the Caribbean, including hydro-meteorological characteristics and impacts on water resources, that gives a picture of future precipitation patterns for the Caribbean and a country perspective, assessing the resource base in the past and towards 2050 and 2100. This part of the report includes hydrological scenarios, and aggregate water balances for the Caribbean and for several individual countries, including precipitation deficit estimates with respect to the baseline, in terms of water that is available as "potential". The report continues with an analysis of the possible impacts on groundwater due to sea-level rise and several aspects related to water management.

The abovementioned analysis of the resource base made it possible to construct future sectoral water use estimates, based on climate models and scenarios, and to provide brief country perspectives. Model results are given in Annex 2. This part of the report demonstrates the possibility of linking climate change scenarios and the ressource base assessment with demand and supply estimates by means of different tools. The method could be applied in greater depth for adaptation options once more accurate data become available at the country level.

The last part of the report considers different adaptation options, based on cost benefit analysis (CBA), the levelized cost approach, and a multi-criteria decision analysis assessment. Mitigation options to reduce emissions from increased use of fossil fuels were included. Finally, there are conclusions and recommendations and the references on the broad literature assessed.

A. Literature review

An extensive library of literature has been reviewed for the present report. The information from Tsuchida (1999), Naredo and Valero (1999), and various contributions from the Intergovernmental Panel on Climate Change (IPCC) report on detection and attribution (2009), together with the IPCC report on climate and water (2008), were used in the first part of the report, to give a comprehensive view of the functioning of open, stable systems, and to establish the links between the hydrological cycle and climate change. The United Nations Educational, Scientific and Cultural Organization (UNESCO) literature was especially useful with regard to scenarios and the central role of water.

Several different data sources were used for the assessment of the climate and hydrological cycle in the Caribbean in the second part of the present report, especially data obtained from the PRECIS system (Providing Regional Climates for Impacts Studies) (see methodology) and technical reports and observations from the Caribbean, including the report by the United Nations Economic Commission for Latin America and the Caribbean (ECLAC) on the *Review of the Economics of Climate Change in the Caribbean*. Information from Farrell and Trotman (2010), Falkland and Brunel (2009) and Planos and others (2011), and authors' compilations, were also very useful.

The third and fourth parts of the present report were based mainly on technical information and papers from relevant publications and authors' assumptions. The information provided by various sources within the Caribbean, including country reports and data, was considered to be useful, but would need to be systematized for future purposes to facilitate more in-depth analysis.

1. First group

- Intergovernmental Panel on Climate Change literature, including the IPCC *Special Report on Water* (2008) and *Fourth Assessment Report of the IPCC* (AR4), (2007)[2]
- IPCC *Special Report on Emission Scenarios*
- *Water Scenarios* from Global Water Future 2050, United Nations World Water Assessment Programme, UNESCO
- Global Water Futures 2050, *The Dynamics of Global Water Futures, 2011- 2050*.
- Documents and reports from World Water Council and World Water Development Report, UNESCO
- Reports from Global Water Partnership
- Food and Agriculture Organization of the United Nations (FAO) *AquaStat Online Database*
- Work Bank data base (1980-2011)
- National Oceanic and Atmospheric Administration (NOAA) database on water

2. Local and Caribbean regional literature

The local and Caribbean literature included the 2007 *Caribbean Sea Ecosystem Assessment* (CARSEA) report, and reports by Farrell and others (2009), and Falkland and Brunel (2009). This group includes regional reports from The Cuban Meteorological Institute (*Instituto de Meteorología de Cuba*, INSMET), *Caribbean Environment Outlook*, *Climate Change in the Caribbean and the Challenge of Adaptation* (United Nations Environment Programme, 2008), and other special reports and technical papers.

Other special technical reports were used to clarify technical aspects and costing, although this kind of information was rare and inaccurate.

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[2] The Report consists of three main volumes under the umbrella title *Climate Change 2007*:
(1) *Climate Change 2007 – The Physical Science Basis*. Contribution of Working Group I to the Fourth Assessment Report of the IPCC;
(2) *Climate Change 2007 – Impacts, Adaptation and Vulnerability.* Contribution of Working Group II to the Fourth Assessment Report of the IPCC;
(3) *Climate Change 2007 – Mitigation of Climate Change*. Contribution of Working Group III to the Fourth Assessment Report of the IPCC.

B. Methodology

1. Climate

Future climate will depend on the rate at which greenhouse gas emissions continue to grow. Difficulties in predicting different pathways have led to the conclusion that the best approach was to construct "emissions scenarios", a decision taken by IPCC in 2003. Each of these scenarios had a proper storyline of the way the world might evolve in terms of population, technology, energy systems, economic development, and international cooperation.[3]

These scenarios (especially on emissions) have made it possible to generate climate scenarios that were simple, plausible and physically consistent representations of future climate. Although a high variety of methods do exist, the most commonly used have been the General Circulation Models (GCM), considered the best scientific tools available.

However, GCM models allow no possibility of studying modifications of climate variables on a regional scale. In consequence, methodologies have been developed to produce high-resolution data on a regional scale by means of (1) regional climate modelling, (2) statistical downscaling and (3) high resolution and variable resolution time slice techniques.[4]

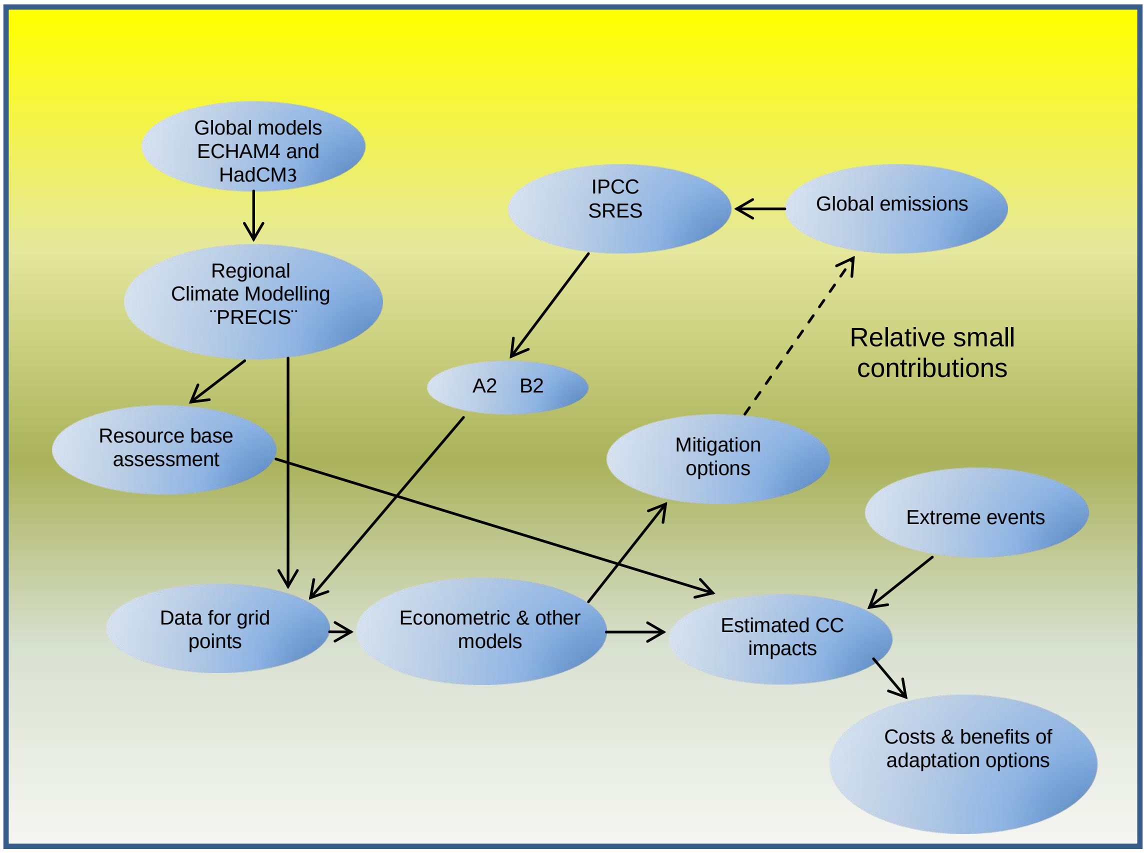
In the present study, the use of PRECIS was highly recommended, based on the experiences gained with RECCC[5] in 2009/2011 within the Caribbean (Taylor and others, 2007). PRECIS is a regional modelling system derived from a third-generation Hadley Centre regional climate model (RCM) that allowed the undertaking of a core set of 50 kilometre and 25 kilometre resolution runs using A2 and B2 SRES scenarios. Figure 1 explains the general methodology used.

3 Scenario assessments can be found in the Intergovernmental Panel on Climate Change *Special Report on Emissions Scenarios*.

4 Downscaling is a method that derives local to regional-scale (up to 100 km) information from larger-scale models or data analyses. There are two main methods that stand out: dynamic downscaling and empirical/statistical downscaling. The dynamic method uses the output of regional climate models (RCMs), global models with variable spatial resolution, or high-resolution global models. The empirical/statistical method develops statistical relationships that link the large-scale atmospheric variables with local/regional climate variables. In all cases, the quality of the downscaled product depends on the quality of the driving model.

5 The study was organized by the United Nations Economic Commission for Latin America and the Caribbean, Subregional Headquarters for the Caribbean, in collaboration with the Caribbean Community Climate Change Centre (CCCCC) with support from the United Kingdom Department for International Development (DFID), with a team of several consultants from the Caribbean and peer reviewed by a team of academics, namely, Temisan D. Agbeyegbe, Wilma Bailey, Mark Bynoe, and Juan Llanes-Regueiro.

FIGURE 1
REDUCING UNCERTAINTIES: MODELLING CLIMATE CHANGE IMPACTS IN THE CARIBBEAN



Source: Compilation of Author

PRECIS, like most RCMs, cannot be used as a predictive circulation model for oceans. Yet, although there exist no possibilities of deriving estimates from PRECIS for sea-level rise, estimates for that purpose may be obtained from IPCC sources when needed (figure 2).

2. Water availability

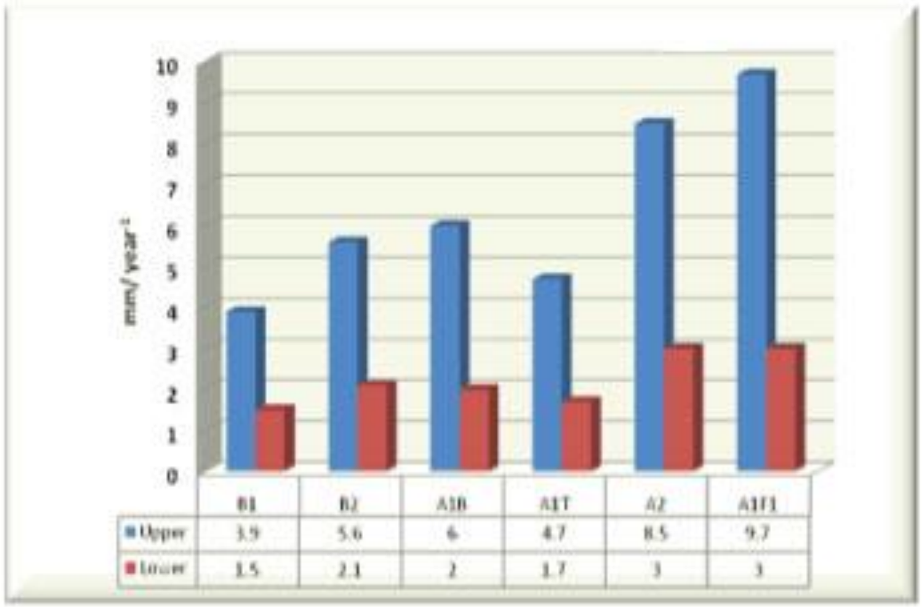
The temperature and precipitation predictions in the present report were taken from the Regional Climate Modelling system for providing regional climates for impact studies (PRECIS), driven by two models: ECHAM4 and HadCM3[6].

The 1960-1990 period averages were used as baseline references for temperature and rainfall. Sea-level rise projections were taken generally from proposals in the literature that were based on possible futures determined by mitigation and adaptation on a global scale (ECLAC, 2011). Due to lack of data, a more general formula, related to groundwater, was used to assess sea-level rise impacts. The results have referred to the A2 and B2 scenarios for the periods 2010-2070 and 2071-2100.

Several aspects of the hydrological cycle were inspected and water balances provided, including deficit projections with regard to the baseline period. Annex 1 provides a useful insight into the relationship between climate change, extreme events and water resources.

[6] Hadley Centre Coupled Model, version 3.

FIGURE 2
SEA-LEVEL RISE ESTIMATES



Source: http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-chapter10.pdf

a) Water supply and demand estimates

TEXTBOX 1
METHODS USED TO ESTIMATE TOURISM WATER DEMAND

Qualitative methods, usually based on the experience and expertise of individuals, have been in use for quite some time, the Delphi being one of the most commonly used.

Quantitative methods can be divided into three major areas which differ in the mathematical and statistical nature of the approaches taken, namely, time series, econometric (causal), and artificial intelligence methods. An examination of these models follows.

The first area, time series deals with methods which consider the variable itself (whether it is tourism arrivals or average expenditure) in its historical development only. Relying on the chronological behaviour of the variable, these methods establish the main components of the time series, such as trend, cycle or seasonality, and then forecast the future values of the variable over a defined time frame. Examples of these methods are: naive, exponential smoothing, and the ARIMA (autoregressive integrated moving average) family.

The second area, econometric modelling, comprises the most widely-used methods in economic variables forecasting, that is, those that establish causality between variables that are described through unknown functions, which regularly, in this case, are called demand functions. Thus, an econometric model of demand (or demand model) fixes a variable describing the demand, such as visitor expenditure, as a function of a number of other variables that have a direct causal relation to the first. The former is referred to as the dependent variable, while the latter are called explanatory variables, and the mathematical expression of the function, which is generally unknown, is approximated through specific methods. Examples of these methods range from simple regression to the statistically sophisticated Time Varying Parameters (TVP), Computable General Equilibrium (CGE) and panel data models, among others.

The third, and last, area, artificial intelligence methods, is populated by the comparatively more recent approaches generally classified as Artificial Intelligence (AI). These methods, based on results that model mathematically the processes in natural and human development, have been used increasingly in demand forecasting, as will be shown, with significant outcomes in comparison to the other two methods. Some of the most widely used among these methods are fuzzy logic, artificial neural networks (ANN), genetic algorithms (GA), and combinations of these.

Source: United Nations economic Commission for Latin America and the Caribbean (ECLAC), *An assessment of the economic impact of climate change on the water sector in the Turks and Caicos Islands* (LC/CAR/L.328), Port of Spain, Trinidad and Tobago, 2011.

Although econometric models have been used to estimate the relationship between water use and population income, the use of climate scenarios complements such studies, especially because, to some extent, water demand is inelastic with respect to income. In some countries, 100 litres was considered to be the minimal water use per person per day. Countries with less than 1 000 cubic metres per year (m^3/year) of potential water supply per capita were considered to be "water stressed". The climate scenario used was the Q&Q (quality over quantity) scenario from the CARSEA report.

The literature on estimating water demand however, has focused on three main users: domestic (10 per cent), agricultural (82 per cent) and industrial (8 per cent). While other uses were important, comprehensive data were unavailable in general.

In the present report, an econometric model of panel data has been used to estimate the availably of renewable water resources as a function of temperature and rainfall, with the addition of gross domestic product (GDP) per capita to measure the impacts of levels of global activity on water resources. The model offered results for 15 Caribbean countries (although, in some estimates, the results were for fewer countries, due to the lack of data and/or resolution), and its specifications responded to a panel of fixed effects (annex 2).

b) Adaptation

Several adaptation options with direct links to mitigation were explored. The most important savings were related to water and energy, due to the link between them. One important issue with adaptation for small island developing States (SIDS) was economies of scale, which was explored together with desalination as a main adaptation policy towards improved water supply, since this was a technique that could be used when considering technological investment. Water saving in supply grids was considered to be an important option to reduce water supply and demand. Finally, a multi-criteria assessment was conducted to give a more comprehensive picture of adaptation policies.

C. Results

1. Water, sustainability and open, stable systems

Sustainability is synonymous to the continuous functioning of a system, in this case, the functioning of semi-open, stable systems, like the earth. The first condition for continuous operation of the earth system is the input of low-entropy energy, while the second condition for continuous activity is discarding entropy outside the system. The present report explores the first two of the five conditions of sustainability that are associated to the earth's atmospheric and hydrological cycles.

The thermally-radiated, low-entropy, infrared radiation provides the earth with the greenhouse effect which determines the temperature of 150° Celsius (C) for the earth's surface. Around 25 per cent of the energy warms the atmosphere at this temperature, creating updraughts with decreasing temperature due to adiabatic expansion. In the higher layers, these updraughts radiate heat into space at −230° C. By this operation, the air cooled becomes heavy and forms a downward current that is known as the atmospheric circulation. This dry air evaporates water from the earth and ocean surfaces, absorbing heat depending on the surface temperature. At high altitudes, the water vapour cools and reaches the dew point, condensing or freezing and falling back to earth as rain or snow. This is the hydrological cycle that complements atmospheric circulation: both cycles are extremely closely interdependent.

The main function of the atmospheric and hydrological cycles is to discard surplus thermal entropy into outer space, which makes activity on Earth possible. The hydrological cycle, which contributes to about 75 per cent of entropy disposal into space and is dependent on atmospheric circulation, is also related to configurational (entropy of mixed gases and materials) and gravitational entropy.[7] Thus, global warming impacts the two main cycles that allow continuous activity on Earth. Moreover, the water cycle is the most important for discarding entropy outside the earth system.

The presence of water in Earth is the condition for the existence of life. Considering the total amount of water on our planet, 97 per cent is salt water and the cryosphere contains around 80 per cent of the remaining 3 per cent. Solar energy and atmospheric circulation act as stimulators of the hydrological cycle in a process of evapo-transpiration into the higher layers of the atmosphere, and as precipitation in different forms. Considering the earth's available freshwater, 68.7 per cent, is part of glaciers and ice surfaces, and 30 per cent is groundwater. The remaining 1.3 per cent consists of 0.3 per cent surface water and 0.9 per cent freshwater in other states. Total surface water (0.3 per cent) consists of 87 per cent concentrated in lakes and smaller water bodies, 11 per cent in swamps, and 2 per cent in river runoff. (Gallopin, 2012).

The hydrological cycle moves around 111,000 cubic metres ($m^{3)}$ of water annually. Two thirds of this amount are circulated as water vapour or as water (humidity) in soils. The remaining one third (40 000 m^3) is the runoff to seas, lakes and groundwater. Human intervention into the water cycle has produced infrastructure that allows our societies to obtain access (withdrawal) to around 12 000 m^3. The biological water need of humans is two to four litres per day. Water use has been steadily increasing since 1950 (Naredo and Valero, 1999) (table 1).

The complexity of the hydrological cycle is expressed by the fact that planetary water stock is renewed continuously but in different time frames: water in polar glaciers takes 10 000 years to renew, water stocks in mountains and certain aquifers need around 1 000 years, while water vapour in the atmosphere needs only a week. More attention has been made to investments to expand water use and withdrawal at zero resource cost, and less to conservation, reuse, recycling and pollution control.

TABLE 1
WORLDWIDE WATER USE ESTIMATES, 1950-2000
(Thousands of cubic metres)

1950	1 360
1960	1 982
1970	2 594
1980	3 316
1990	4 138
2000	5 189

Source: Gallopin. G. (2012)

Note: Total water available: 40 700 cubic metres. Annual water withdrawal increase since 1950: 2.7 per cent

[7] There is no material input into the Earth system, with only very few exceptions, like meteorites, and thus materials and nutrients that fall into the deep ocean layers need to move upwards by means of temperature differentials and other physical phenomena, to maintain recycling.

II. The hydrological cycle and climate change

Now that the connection between the hydrological and atmospheric cycles has been well established, the relationship between the hydrological cycle and climate change needs to be inspected by means of theoretical understanding and observed facts.

Theoretical understanding of the response of the hydrological cycle to anthropogenic warming has been consistent with the predictions of climate models and theoretical expectations. Although global precipitation will continue to be constrained by the energy budget, specific humidity should increase with temperature (IPCC, 2009).

Anthropogenic influence has been detected in surface humidity and lower tropospheric moisture content: anthropogenic forcing has an important influence in precipitation change. Nevertheless, the literature on detection and attribution has considered changes in precipitation to be more ambiguous than changes in temperature, since precipitation data were more uncertain than temperature datasets, and because no reliable, long-term precipitation data over oceans were available.

Experts have suggested that climate variability and natural forcing could not explain those changes, providing the certitude that human footprints have been causing those effects. Moreover, the magnitude of the observed changes has been much larger than the results of simulations, implying the possibility that the effects of human-induced global warming could have been underestimated.[8]

Other studies have demonstrated that human-induced changes in greenhouse gas emissions are the main source of observed changes in sea-level temperature during the twentieth century.

The following cases of detection and attribution[9] of changes in systems due to climate change illustrate the procedures for reducing uncertainty in the detection of human footprints:

- Demonstration of anthropogenic contribution to area burnt by forest fires in Canada, using Single-Step Attribution

[8] P. Stott and S. Sullivan (eds.), *Political Ecology: Science, Myth and Power,* London and New York: Arnold, pp. 117-131.

[9] Detection is defined as *the process of demonstrating that climate has changed in some defined statistical sense, without providing a reason for that change*. Attribution of causes of climate change is *the process of establishing the most likely causes for the detected change with some defined level of confidence*.

- Measuring the impact of rising atmospheric CO2 on reef-building corals, by Multi-Step Attribution
- Studying the link between rising atmospheric carbon dioxide and the reduced calcifying abilities of coral reefs
- Studying the anthropogenic influence on physical and biological systems using Associative Pattern Attribution
- Detection and attribution of anthropogenic climate change and ocean acidification and the impacts on marine ecosystems from a global perspective
- Detection and attribution related to anthropogenic climate change in the Cryosphere from a global perspective
- Detection and attribution of tropical cyclones from a global perspective
- Investigating the ways human-modified temperature could induce species changes.

The IPCC Working Group I Fourth Assessment Report (WGI 4AR), *Climate Change 2007: The Physical Science Basis*, came to the confident conclusion that the cause of global temperature increases since the mid-twentieth century was very likely to be human-induced greenhouse gas concentrations. The significance of that conclusion—one that raised important concerns—was that a discernible human footprint now has extended to other aspects of climate.

After that, warming over Antarctica was also attributed to human influence. IPCC 4AR presented strong evidence that the changes observed was very unlikely to have been caused by natural variability. Claims about the fact that both years 2007 and 2008 have broken the trend of increased temperatures and that global warming has stopped were rebutted by later contributions in 2009[10] that demonstrated that "decade-long trends with little warming or cooling are to be expected under a sustained, long-term warming trend, as a result of multi-decadal-scale internal variability."[11]

These results have underscored the importance of understanding the effects of variability, in addition to the external drivers of climate. An important conclusion is that changes are broadly consistent with theoretical understanding and simulations.

The following have been important conclusions drawn from the available scientific literature:

- Reducing snow cover and widespread melting of ice
- Changes in soil moisture and runoff with controversial signs
- Precipitation changes with substantial spatial and inter-decadal variability, with difficulties in obtaining certitude about the long-term direction of changes.
- Precipitation has mostly increased over land in high northern latitudes over the twentieth century, while decreases have dominated from 10° S to 30° N since the 1970s.
- The frequency of heavy precipitation events has increased over most areas, increasing runoff and impacting water quality due to increased erosion.
- The area of land globally classified as very dry has more than doubled since the 1970s (Bates and others, 2008).

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10 More information is available from D.R. Easterling and M.F. Wehner, "Is the climate warming or cooling?", *Geophysical Research Letters*., No. 36, 2009 as well as J. Knight and others, "Do global trends over the last decade falsify climate predictions?", *BAMS State of the Climate*, 2009.

11 T. Stocker and others (eds.), "IPCC Expert Meeting on Detection and Attribution Related to Anthropogenic Climate Change: meeting report", Intergovernmental Panel on Climate Change, Geneva, Switzerland, September, https://www.ipcc-wg1.unibe.ch/publications/supportingmaterial/EM_D&A _MeetingReport_Final.pdf, 2009.

The main projections for the twenty-first century are related to the following:

- The climate model simulations for the twenty-first century are consistent in projecting precipitation increases in high latitudes and parts of the tropics, and decreases in some subtropical and lower mid-latitude regions.
- Outside these areas where high resolution exists, the direction and magnitude of projected changes varies between models, leading to substantial uncertainty.
- By the middle of the twenty-first century, average annual river runoff and water availability have been projected to increase at high latitudes and in some wet tropical areas, and decrease over some dry regions at mid-latitudes and in the dry tropics as a result of climate change.
- Increased precipitation intensity and variability projected to augment the human footprint have been detected in the climate system.
- Detection and attribution has been well established as a process to deal with climate change impacts.
- Links between the atmospheric and hydrological cycles have been consistent.
- Changes have been consistent with model predictions and simulations but possibly have been underestimated.

Understanding climate variability and extremes has a high priority for forecasting changes in the hydrological cycle

A. Observed changes and evidence in the hydrological cycle

The following main changes have been observed in the large-scale hydrological cycle:

- Increasing atmospheric water vapour content
- Changing precipitation patterns, intensity and extremes
- Risks of flooding and drought in many areas. The frequency of heavy precipitation events will increase over most areas during the twenty-first century
- Higher water temperatures and changes in extremes, including floods and droughts, are projected to affect water quality and exacerbate many forms of water pollution

As a consequence of these results, it is expected that, globally, negative impacts on freshwater systems would outweigh the benefits, and that the land area under increased water stress may double. This would probably affect the conditions, functioning and operation of existing water infrastructure, including hydropower, flood defences, drainage and irrigation systems and water management practices and policies in use. For example:

- Current water-management practices may not be robust enough to cope with the impacts of climate change on water supply reliability, flood risk, health, agriculture, energy and aquatic ecosystems. In many locations, water management might not cope satisfactorily even with current climate variability.
- Climate change challenges the traditional assumption that past hydrological experiences provide a good guide to future conditions.
- Adaptation options designed to ensure water supply during average and drought conditions require integrated demand-side as well as supply-side strategies.

- The demand-side strategies improve water-use efficiency, e.g. recycling water, expanding the use of economic incentives, including metering and pricing, to encourage water conservation, and the development of well-studied water markets and the implementation of virtual water trade, when possible.
- Water-resource management clearly impacts on many other policy areas, e.g. energy, health, food security and nature conservation.

Therefore, future water demand and supply scenarios may be quite different from the present experience.

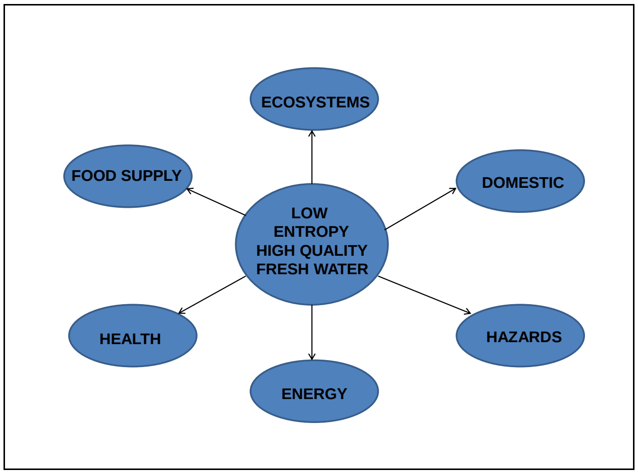
B. The central role of water

Water has been seen as a 'sector' because many experts have considered water to be constrained to precipitation and groundwater surveillance and monitoring, while water supply grids have been considered more as 'infrastructure' like other supply grids. Water policies from a sectoral perspective have been developed more to match supply, and infrastructural water policy to matching growing demand and less to providing assessments of water conservation, management and sustainable use. Delivering adequate water for social, economic and environmental needs is more, however, than the preservation and management of the 'water sector', which is expected merely to provide the appropriate infrastructure and channel water in the right direction. Water cuts across all social, economic and environmental activities.

In the main, water policies have been disconnected from a holistic perspective. Many decisions have been taken from a fragmented viewpoint, focused on meeting sector-specific demands and objectives, principally from an anthropogenic point of view, neglecting those needs that are—yet—poorly understood, such as the combined services provided by water, forests and coastal zones in preserving the coastal watershed from saltwater intrusion.

This perspective has increased the vulnerability of the resource base. More than a problem of optimizing water use, it has become a problem of understanding and management. While the economics of water, water pricing and payment of environmental services are important, more important still is an understanding and learning of water management, as monetary indicators may not always be available for the whole hydrological cycle. 'Water consumption' has remained more a concept derived from common language, than the concept of water withdrawal from the hydrological cycle, that would illustrate that water was a resource that humans and biota used for a certain time, returning the same amount to the water cycle.

FIGURE 3
THE CENTRAL ROLE OF WATER



Source: Compiled by Author

TEXTBOX 2
METHODS USED TO ESTIMATE TOURISM WATER DEMAND

Agriculture and food supply

Water for irrigation and food production constitutes one of the greatest pressures on freshwater resources. Agriculture accounts for around 70 per cent of global water use.

Energy

The relationship between water and energy is reciprocal. Energy is required for humans to make use of water – to lift, move, and process and treat it at every phase of its extraction, distribution and use. Out of all energy produced globally, 7-8 per cent is used to lift groundwater and pump it through pipes, and to treat both groundwater and wastewater, a figure that rises to around 40 per cent in developed countries. Desalination, the process by which seawater is converted to freshwater, is especially energy-intensive. The treatment of wastewater also requires significant amounts of energy, and demand for energy to do this is expected to increase globally by 44 per cent between 2006 and 2030, especially in non-OECD countries where wastewater currently receives little or no treatment.

Population and domestic use

Beyond physiological hydration (roughly 60 per cent of human body weight is water), water is necessary for meeting most of our basic physiological needs, and provides us with myriad additional benefits. Access to drinking water supply and sanitation services is key to meeting many of these needs. The importance of safe drinking water and sanitation for human health, well-being and socioeconomic development has been well established.

Ecosystems

Ecosystems provide a multitude of benefits and services to humans; for example, products such as food, timber, medicines and fibre, and services such as regulating climate and supporting nutrient cycling, soil formation and deposition. Providing water, as a resource for direct use is also an ecosystem service, in terms of both its quality and quantity. Ecosystems, in turn, depend on water in order to function; when they are stressed, the benefits are reduced, or eliminated.

The water cycle is a biophysical process. Without life on Earth, the water cycle would still exist, but be quite different. Ecosystems underpin the sustainable quantity and quality of water available: for example, the life in soils regulates water storage there and nutrient cycling, supporting all terrestrial life (including food production); forests (through plant transpiration) regulate local and regional humidity and precipitation; wetlands (and soils) regulate the extremes of drought and flood.

The role of ecosystems in the water cycle has two interrelated implications for water management. The first is that water must be allocated so as to allow ecosystems to continue to deliver the level of benefits needed (e.g. through maintaining environmental flows). The second is that ecosystems can be proactively managed (other than by allocating water to them), through, for example, conservation or rehabilitation, in order to deliver what is needed to meet water-related objectives. For example, forests are very good at delivering clean water, and wetlands at regulating floods and restoring soil functionality, a key mechanism to combat desertification.

Water-related hazards

Many of the impacts of natural hazards on socioeconomic development have occurred through water. Between 1990 and 2000, natural disasters in several developing countries caused damage representing between 2 per cent and 15 per cent of their annual GDP. Water-related hazards account for 90 per cent of all natural hazards, and their frequency and intensity has been rising generally. Some 373 natural disasters killed over 296,800 people in 2010, affecting nearly 208 million others, and costing nearly US$ 110 billion.

Source: W. Cosgrove and F.R. Rijsberman, *World Water Vision*, Earthscan Publications, London, 2000.

C. Climate and the hydrological cycle in the Caribbean

1. Climate and hydrometoreological characteristics

During the decade of the 1970s, significant changes in climate behaviour have been observed in the tropical American Region. These changes have been reflected clearly in the hydrological cycle, and were preceded by an important increase in inter-annual variability (Planos and others, 2011; Gutiérrez and others, 1999; Planos, 2001).

Atmospheric circulation in the decade of the 2000s has been dominated by complex manifestations in natural climate variability, with cycles from two to ten years; including variations in the structure and intensity of the Anticyclone influence on the Caribbean basin, the Gulf of Mexico and the south of the United States of America. The most relevant regulator of regional climate for the American Region has been the El Niño-Southern Oscillation (ENSO).

Although these observations have some level of uncertainty, Caribbean atmospheric circulation has responded to changes observed recently in global circulation, and it is very likely that a narrow link exists in the American Tropics between the variations of the North Atlantic Anticyclone, the thickness of the low layer atmosphere, and observed fluctuations in precipitation. It is also possible that changes in the frequency and intensity of droughts could be linked to these processes. Dharmaratne Amarakoon and others (2004), according with Peterson and others (2002), Chen and Taylor, (2002), indicated that the climate in the Caribbean was exhibiting a changing trend. These studies predicted a warming trend in the Caribbean, drier-than-normal conditions with warmer temperatures in the latter half of El Niño years, and an increase in precipitation in the early part of the following year.

Among the changes in meteorological variables observed during the 1970s were a significant intensification in precipitation in the winter months, and a decrease in the duration of the rainy season. In addition, a significant increase in moderate and severe drought processes had been detected for the period 1961-2011 relative to the period 1931-1960.

The unquestionable influence of the North Atlantic Anticyclone (NAA) on regional atmospheric characteristics was confirmed by the finding that

> "… the influence of the growing lineal tendency observed in the atmospheric pressure at mean and high levels during the last decades on precipitation is an indication of an intensification of the North Atlantic Anticyclone."[12]

Fonseca (2001) reported that the relationship between the position and the intensity of the North Atlantic Anticyclone was expected to result in significant periods of rainfall deficit.

The following were some meteorological facts that corroborated the atmospheric anomalies:

- Throughout the period 1948-2000, a sustained modification of the atmospheric circulation characteristics was observed in all tropospheric levels of the Caribbean, producing an increase in vertical downward movements.
- The variation in the North Atlantic Oscillation (NAO) Index during winter was inversely related to average annual precipitation. Conversely, wet periods matched times of low NAO.
- The strong presence of ENSO events was associated with dry, warm northern-hemisphere summers in the Caribbean as well as periods of no tropical storm formation. Strong ENSO periods were shown to reduce the number and intensity of hurricanes in the Atlantic.
- Over the past 30 years, maximum sea surface temperature has increased by 0.7° C during the Northern-hemisphere summer.
- Reduction in annual precipitation, increase in drought and air temperature.
- Since the 1970s, a change in the anomalies of sea surface temperature has been observed.

a) Temperature

The Caribbean is a warm region. The annual average temperature of the air is 26.8° C.

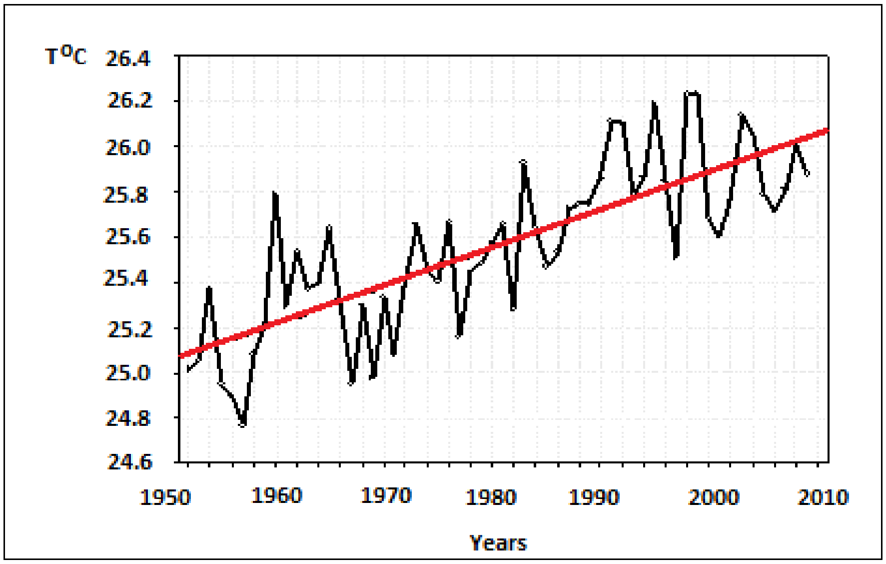
> "An analysis of data from the late 1950s to 2000 has shown that the number of very warm days and nights in the Caribbean is increasing dramatically and very cool days and nights are decreasing, while the extreme inter-annual temperature range is also decreasing. (United Nations Environment Programme"[13] (UNEP), 2008).

This warming trend was evident in data collected from Barbados, Cuba and the Dominican Republic during the period 1960-2000; and in the gridded data of the Climatic Research Unit (New and others, 2002). Data from different studies showed that both daytime and night-time temperatures have increased (Farrell and others, 2009; Perez and others, 2010; and Planos, 2005). Figures 4 to 14 show the temperature trends estimated with the Climatic Research Unit Gridded Data (New and others, 2002).

[12] B. Lapinel and B., *Visión de la sequía en Meso América y el Caribe: diagnóstico, impactos y mitigación*, United Nations Educational, Scientific and Cultural Organization International Hydrological Programme (IHP-UNESCO) Flow Regimes International Experimental Network Data (FRIEND) project, 2002.

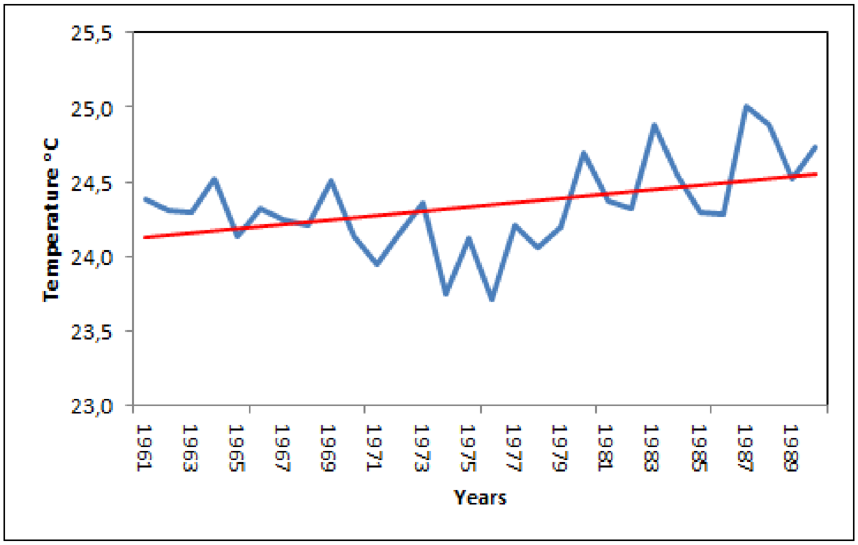
[13] United Nations Environment Programme Regional Office for Latin America and the Caribbean, *Climate change in the Caribbean and the challenge of adaptation*, UNEP, Panama, http://www.pnuma.org/deat1/pdf/Climate_Change_in_the_Caribbean_Final_LOW20oct.pdf, 2008.

FIGURE 4
ANNUAL AVERAGE AIR TEMPERATURE, CUBA, 1950-2010



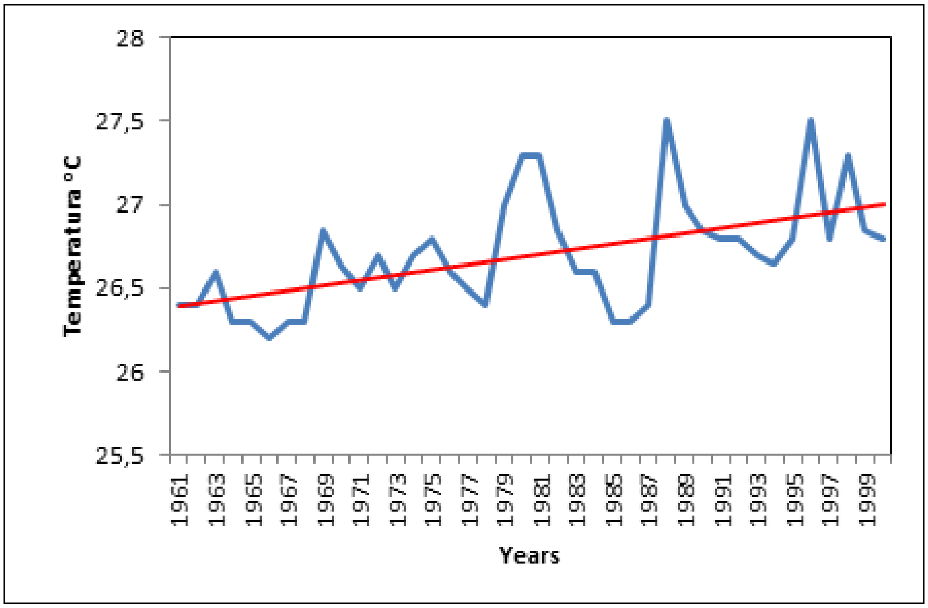
Source: Compiled by Author

FIGURE 5
ANNUAL AVERAGE AIR TEMPERATURE, THE DOMINICAN REPUBLIC, 1961-1990



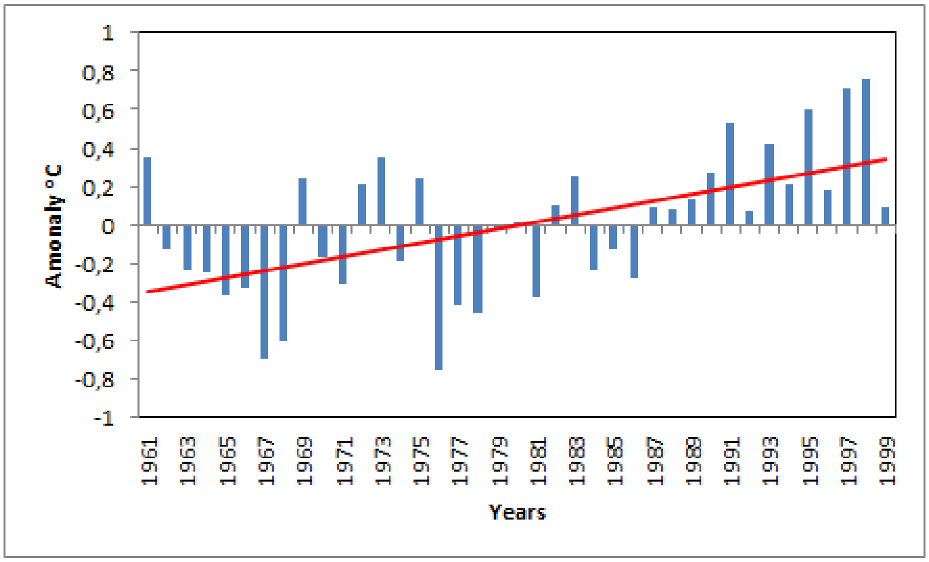
Source: Compiled by Author

FIGURE 6
ANNUAL AVERAGE AIR TEMPERATURE, BARBADOS, 1961-2000



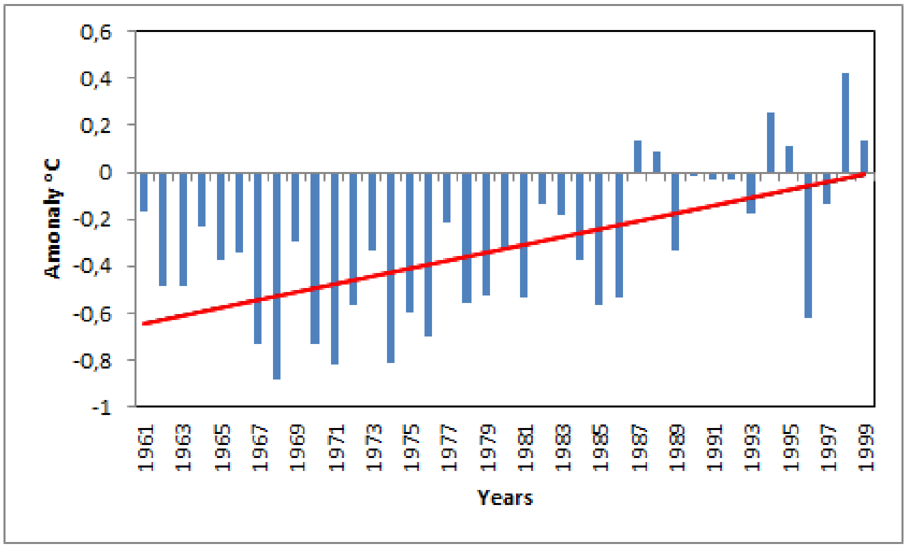
Source: Compiled by Author

FIGURE 7
ANNUAL AVERAGE AIR TEMPERATURE, BELIZE, 1961-2000



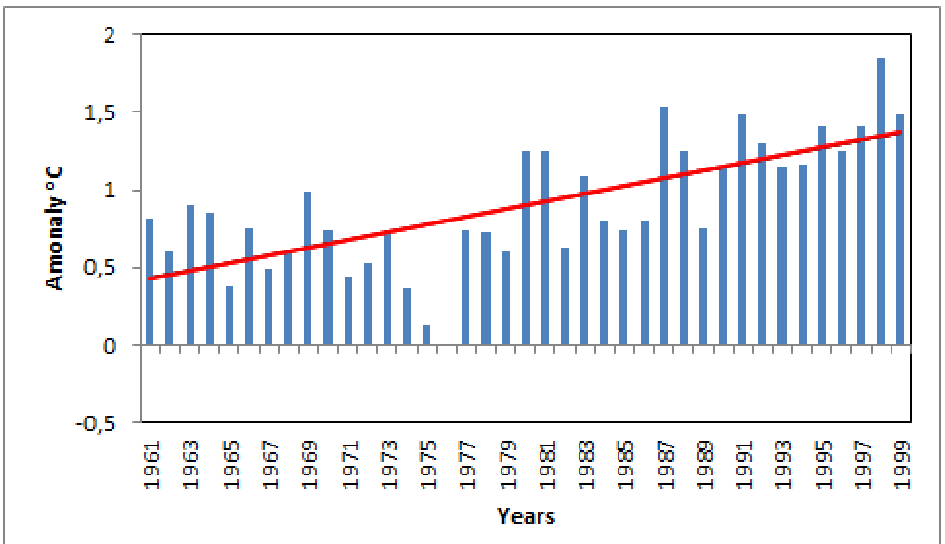
Source: M. New and others, "A high-resolution data set of surface climate over global land areas." *Climate Research*, No. 21, 2002

FIGURE 8
ANNUAL AVERAGE AIR TEMPERATURE, JAMAICA, 1961-2000



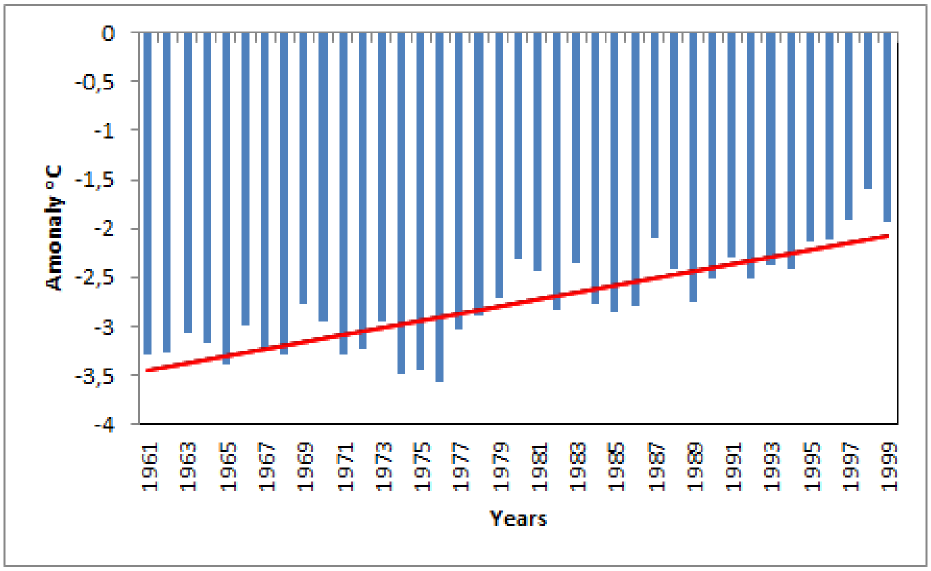
Source: M. New and others, "A high-resolution data set of surface climate over global land areas." *Climate Research*, No. 21, 2002

FIGURE 9
ANNUAL AVERAGE AIR TEMPERATURE, ANTIGUA AND BARBUDA, 1961-2000



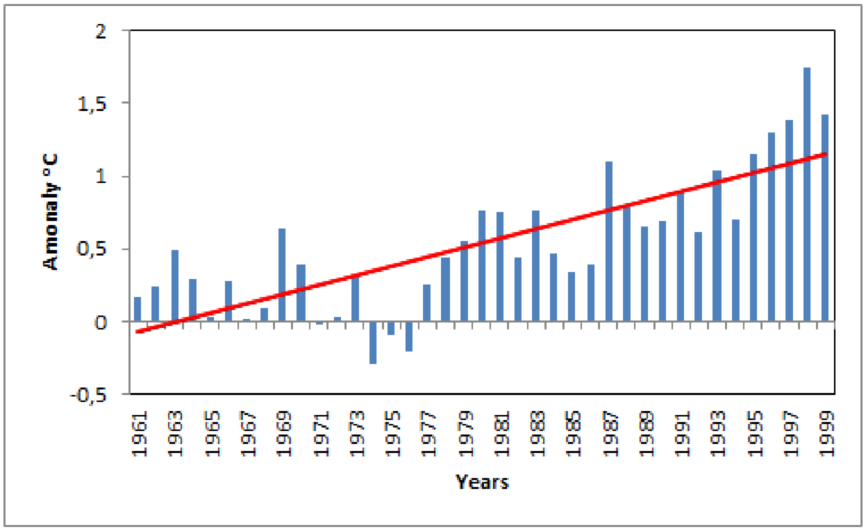
Source: M. New and others, "A high-resolution data set of surface climate over global land areas." *Climate Research*, No. 21, 2002

FIGURE 10
ANNUAL AVERAGE AIR TEMPERATURE, DOMINICA, 1961-2000



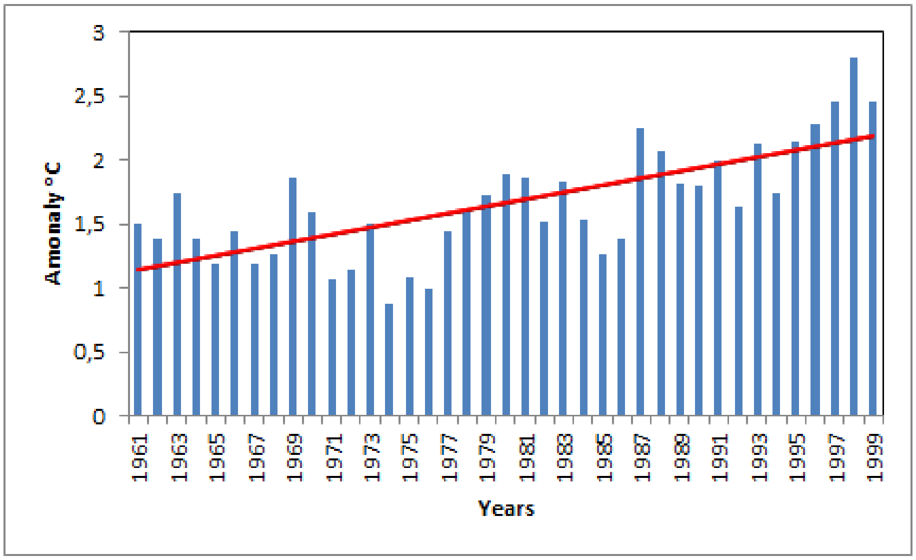
Source: M. New and others, "A high-resolution data set of surface climate over global land areas." *Climate Research*, No. 21, 2002

FIGURE 11
ANNUAL AVERAGE AIR TEMPERATURE, SAINT LUCIA, 1961-2000



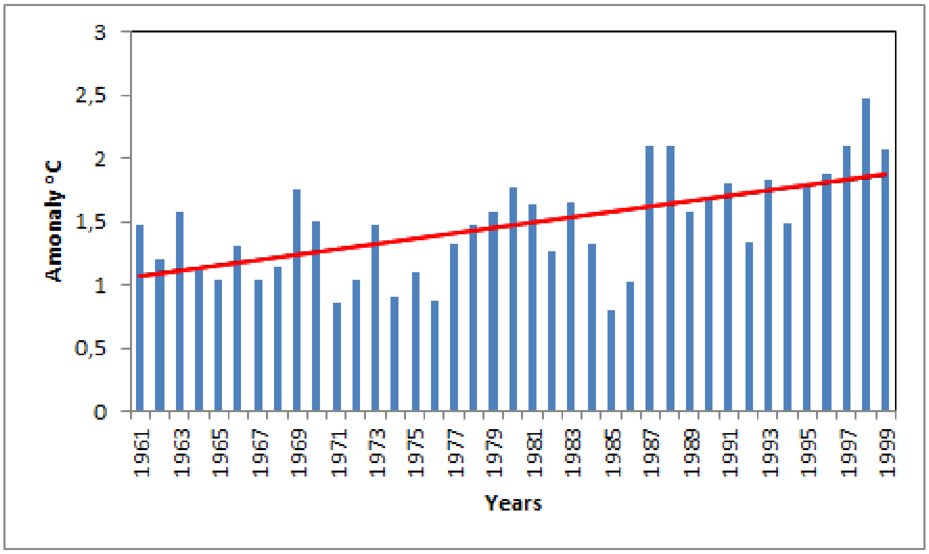
Source: Compiled by Author

FIGURE 12
ANNUAL AVERAGE AIR TEMPERATURE, SAINT VINCENT AND THE GRENADINES, 1961-2000



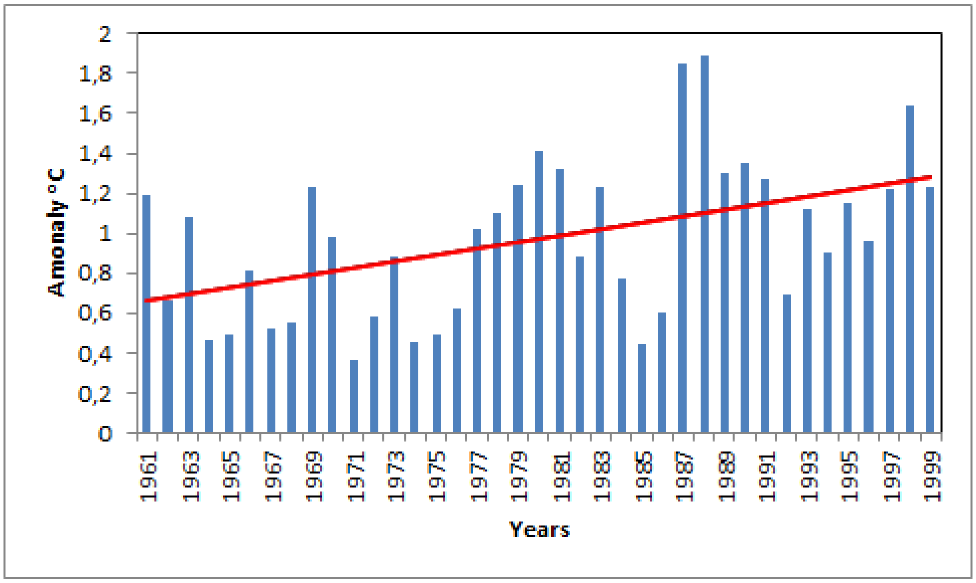
Source: Compiled by Author

FIGURE 13
ANNUAL AVERAGE AIR TEMPERATURE, GRENADA, 1961-2000



Source: Compiled by Author

FIGURE 14
ANNUAL AVERAGE AIR TEMPERATURE, TRINIDAD AND TOBAGO, 1961-2000



Source: Compiled by Author

b) Precipitation

The main natural source of water in most of the Caribbean is precipitation. The average annual precipitation obtained for the period 1961-1990 was 1,880 millimetres, distributed monthly as shown in table 2.

The trend observed in precipitation during the period 1961-1990 was, in general, a decreasing one. That trend was associated with the meteorological causes described previously, particularly to the influence of the North Atlantic Anticyclone. In the eastern region of Cuba, precipitation had a significant, negative trend since the nineteen seventies and, in some cases, prior to that; a negative trend was also observed in Jamaica and in the northern area of the island of Hispaniola (Haiti and the Dominican Republic) and Puerto Rico. This behaviour was linked mainly to the dominant influence of the North Atlantic Anticyclone over those areas. In the central and western parts of Cuba, and in the south of Hispaniola and Puerto Rico, where the influence of the North Atlantic Anticyclone was combined with other important meteorological phenomena, a different trend in the annual rain series was observed. In the area around the Lesser Antilles, the precipitation trend was variable, due to the north-to-south orientation of the Antilles Arc. Closer to the tropical belt, the precipitation trend was a decreasing one, while, in the islands nearer to South America, there was no consistent trend. Figures 15 to 37 show the geographical distribution of the annual precipitation anomalies between 1931 and 2000, and figure 38 shows that the trend of the annual precipitation was negative in the whole Caribbean basin.

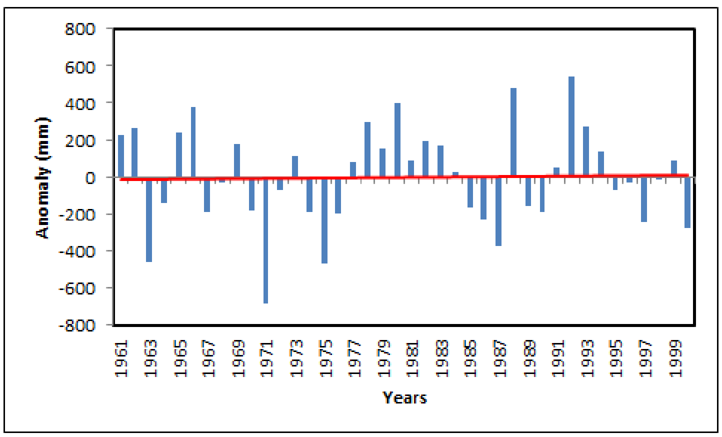
Taking into account the longitudinal orientation of the Lesser Antilles, Lapinel (2000) analysed three subregions, according the volume and monthly distribution of annual precipitation: North Antilles Arc (the Virgin Islands to Antigua and Barbuda); Central Antilles Arc (Montserrat to Martinique) and South Antilles Arc (Saint Lucia, Saint Vincent and the Grenadines, Barbados and Grenada). The author demonstrated the negative precipitation trend for those areas (figure 38)

TABLE 2
CARIBBEAN MONTHLY DISTRIBUTION OF PRECIPITATION, 1961-1990
(Millimetres and percentage)

Month	Precipitation (mm)	Percentage
January	103.5	5.5
February	76.9	4.1
March	70.6	3.8
April	101.4	5.4
May	190.3	10.1
June	199.3	10.6
July	184.6	9.8
August	199.6	10.6
September	222.1	11.8
October	230.2	12.2
November	175.7	9.3
December	125.9	6.7
Total	1880	100

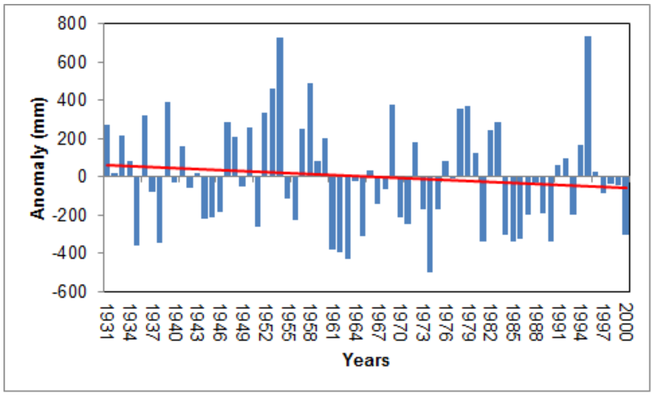
Source: Data compiled by Author

FIGURE 15
ANOMALY OF ANNUAL PRECIPITATION, BELIZE, 1961-2000



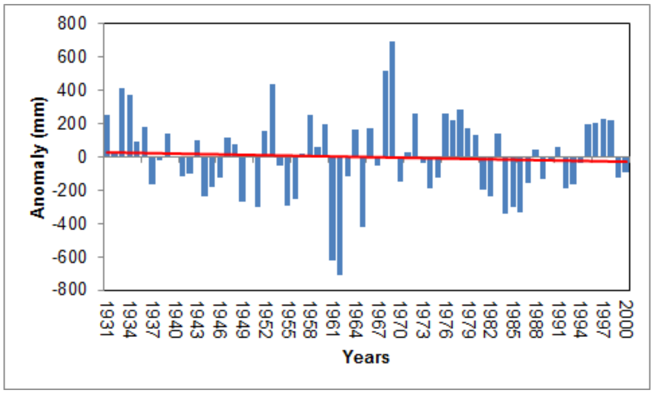
Source: Compiled by the Author

FIGURE 16
ANOMALY OF ANNUAL PRECIPITATION, PINAR DEL RIO, CUBA, 1931-2000



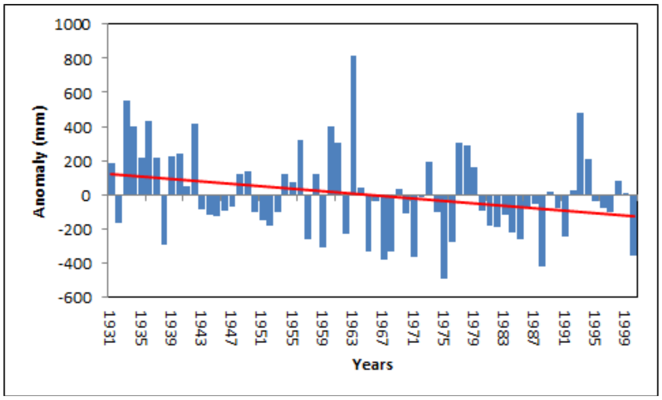
Source: Compiled by the Author

FIGURE 17
ANOMALY OF ANNUAL PRECIPITATION, VILLA CLARA, CUBA, CENTRAL NORTH REGION, 1931-2000



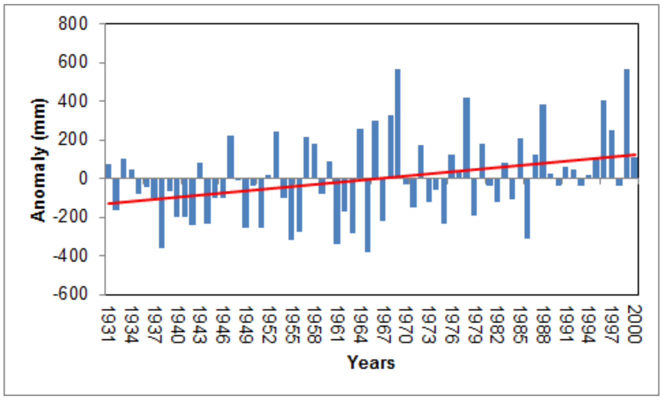
Source: Compiled by Author

FIGURE 18
ANOMALY OF ANNUAL PRECIPITATION, HOLGUIN, NORTH EAST AREA, CUBA, EASTERN REGION, 1931-2000



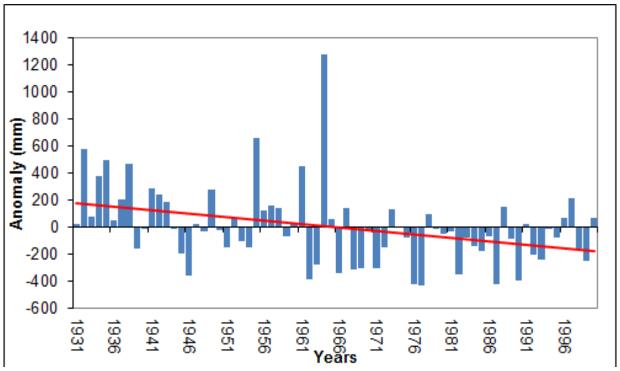
Source: Compiled by the Author

FIGURE 19
ANOMALY OF ANNUAL PRECIPITATION, CIENFUEGOS, CUBA, SOUTH REGION, 1931-2000



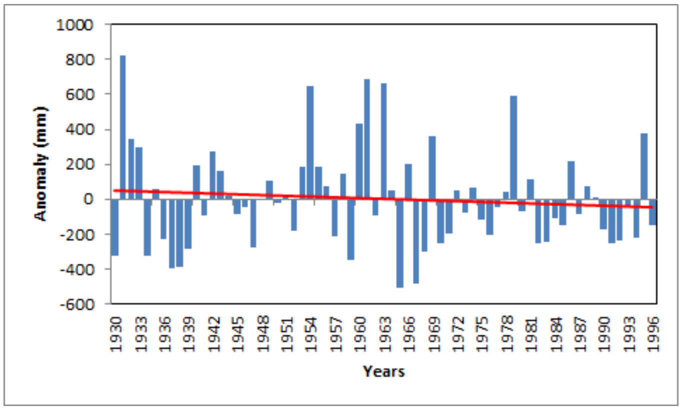
Source: Compiled by Author

FIGURE 20
ANOMALY OF ANNUAL PRECIPITATION, VALLEY OF GUANTANAMO, CUBA, SOUTH-EASTERN REGION, 1931-2000



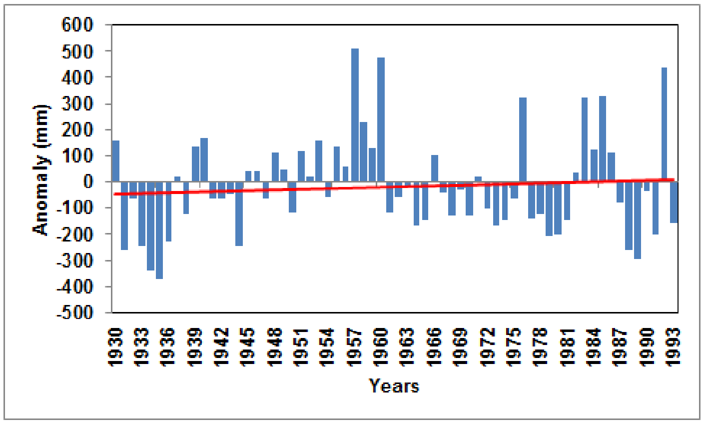
Source: Compiled by Author

FIGURE 21
ANOMALY OF ANNUAL PRECIPITATION, GRAND ANSE REGION, HAITI, 1931-1996



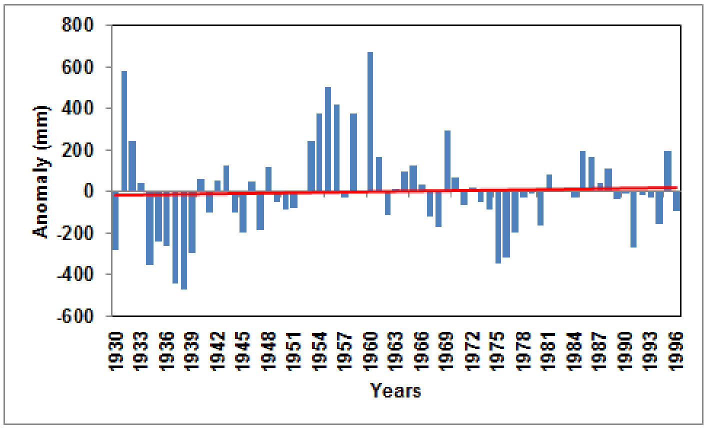
Source: Compiled by Author

FIGURE 22
ANOMALY OF ANNUAL PRECIPITATION, GRAND SUD-EST REGION, HAITI, 1931-1996



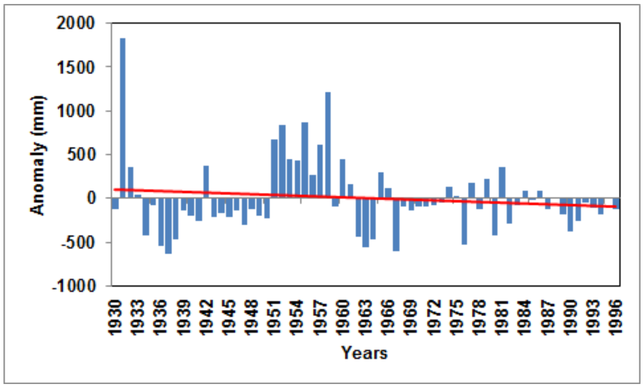
Source: Compiled by Author

FIGURE 23
ANOMALY OF ANNUAL PRECIPITATION, GRAND NORD-EST REGION, HAITI, 1931-1996



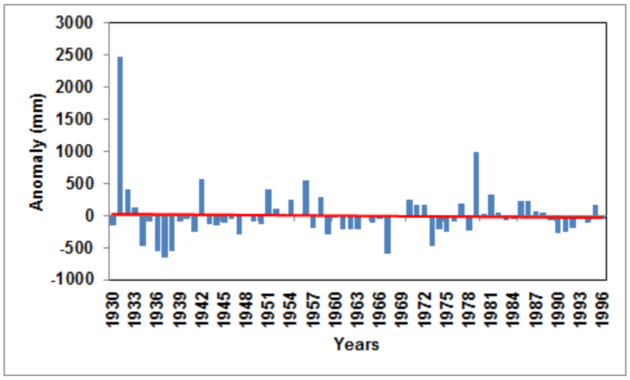
Source: Compiled by Author

FIGURE 24
ANOMALY OF ANNUAL PRECIPITATION, NORTH-EAST REGION, THE DOMINICAN REPUBLIC, 1931-1996



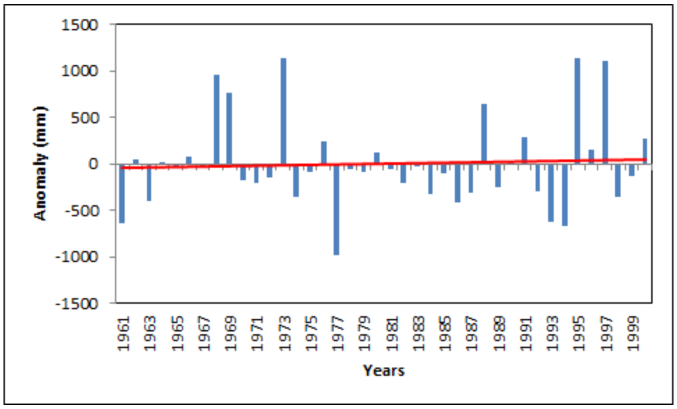
Source: Compiled by Author

FIGURE 25
ANOMALY OF ANNUAL PRECIPITATION, CENTRAL REGION, THE DOMINICAN REPUBLIC, 1931-1996



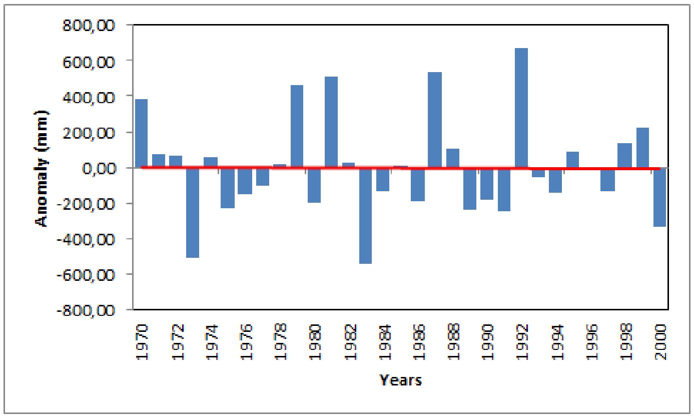
Source: Compiled by Author

FIGURE 26
ANOMALY OF ANNUAL PRECIPITATION, THE BAHAMAS, 1961-2000



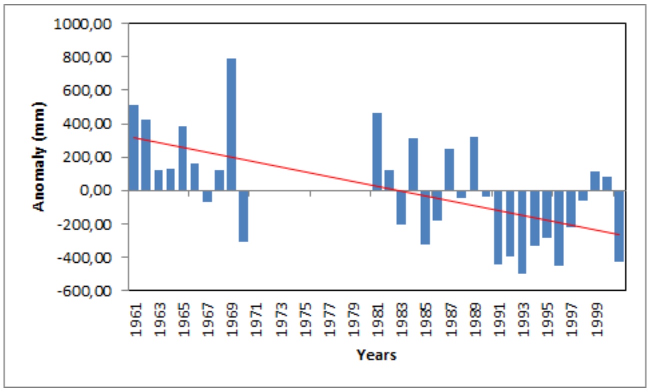
Source: Economic Commission for Latin America and the Caribbean (ECLAC), based on country data

FIGURE 27
ANOMALY OF ANNUAL PRECIPITATION, ANTIGUA AND BARBUDA, 1970-2000



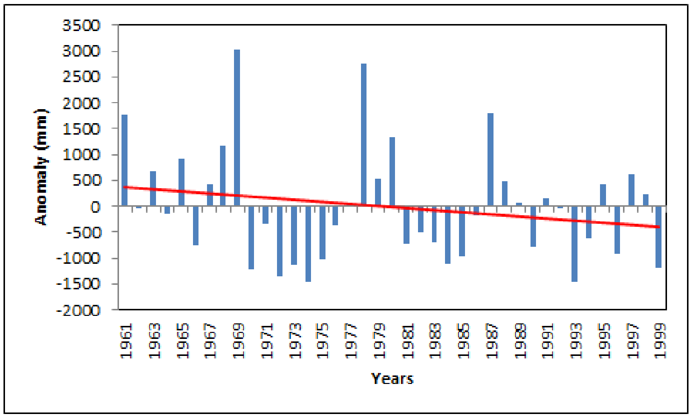
Source: Economic Commission for Latin America and the Caribbean (ECLAC), based on country data

FIGURE 28
ANOMALY OF ANNUAL PRECIPITATION, SAINT KITTS AND NEVIS, 1961-2000



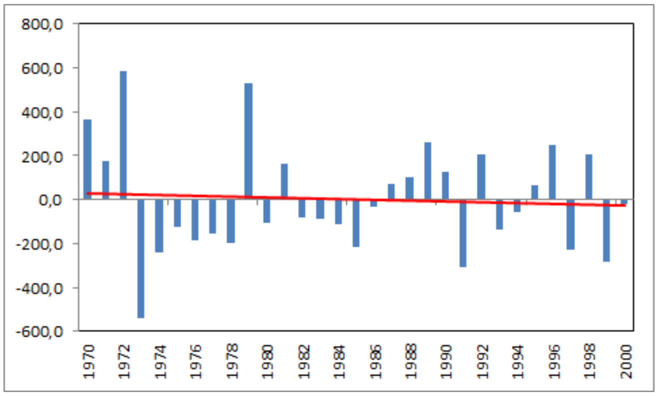
Source: Economic Commission for Latin America and the Caribbean (ECLAC), based on country data

FIGURE 29
ANOMALY OF ANNUAL PRECIPITATION, DOMINICA, 1961-2000



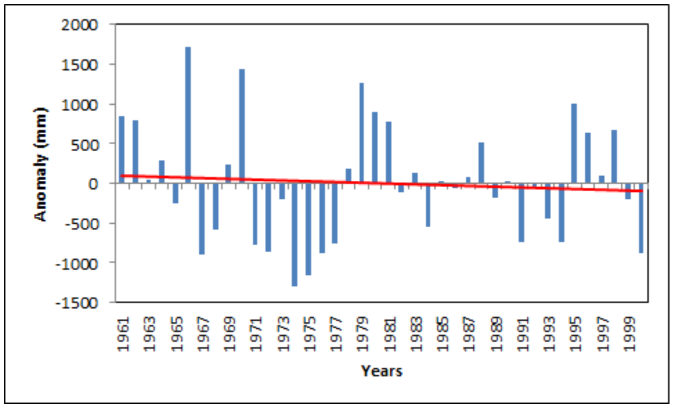
Source: Economic Commission for Latin America and the Caribbean (ECLAC), based on country data

FIGURE 30
ANOMALY OF ANNUAL PRECIPITATION, SAINT LUCIA, 1970-2000



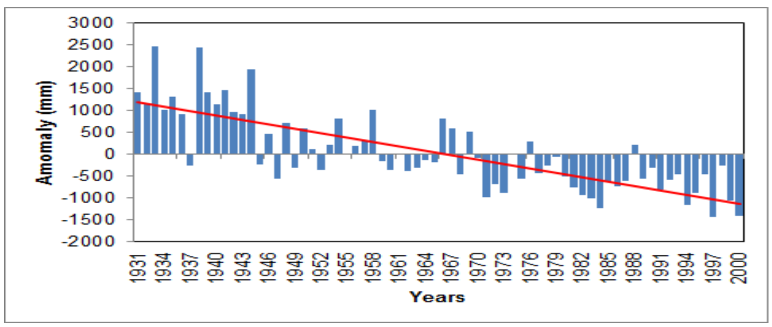
Source: Economic Commission for Latin America and the Caribbean (ECLAC), based on country data

FIGURE 31
ANOMALY OF ANNUAL PRECIPITATION, BARBADOS, 1961-2000



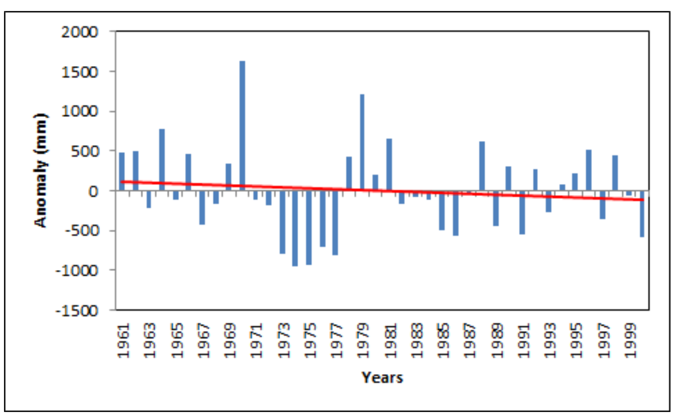
Source: Economic Commission for Latin America and the Caribbean (ECLAC), based on country data

FIGURE 32
ANOMALY OF ANNUAL PRECIPITATION, SAINT VINCENT AND THE GRENADINES, 1931-2000



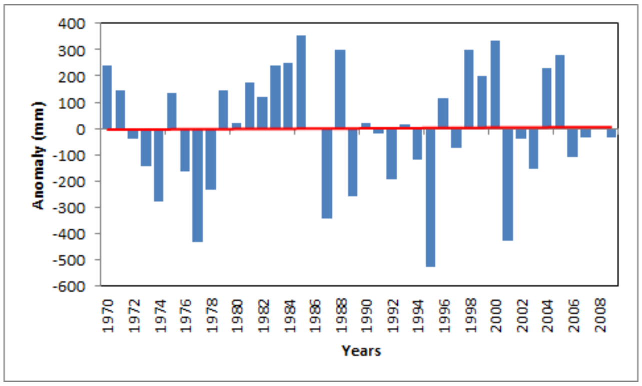
Source: Economic Commission for Latin America and the Caribbean (ECLAC), based on country data

FIGURE 33
ANOMALY OF ANNUAL PRECIPITATION, GRENADA, 1961-2000



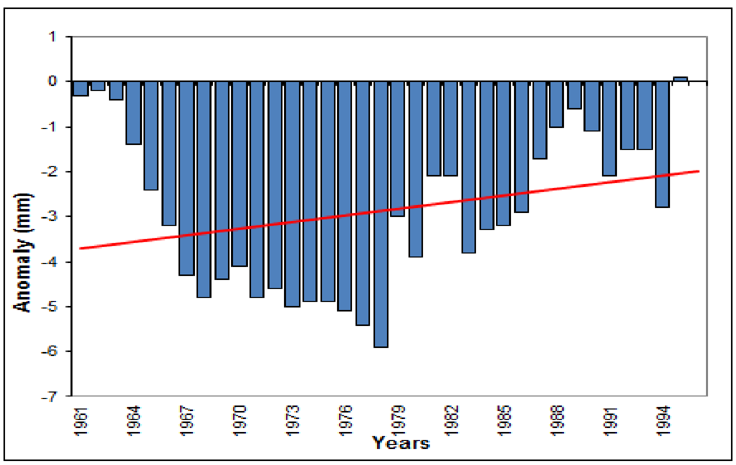
Source: Economic Commission for Latin America and the Caribbean (ECLAC), based on country data

FIGURE 34
ANOMALY OF ANNUAL PRECIPITATION, TRINIDAD AND TOBAGO, 1961-2000



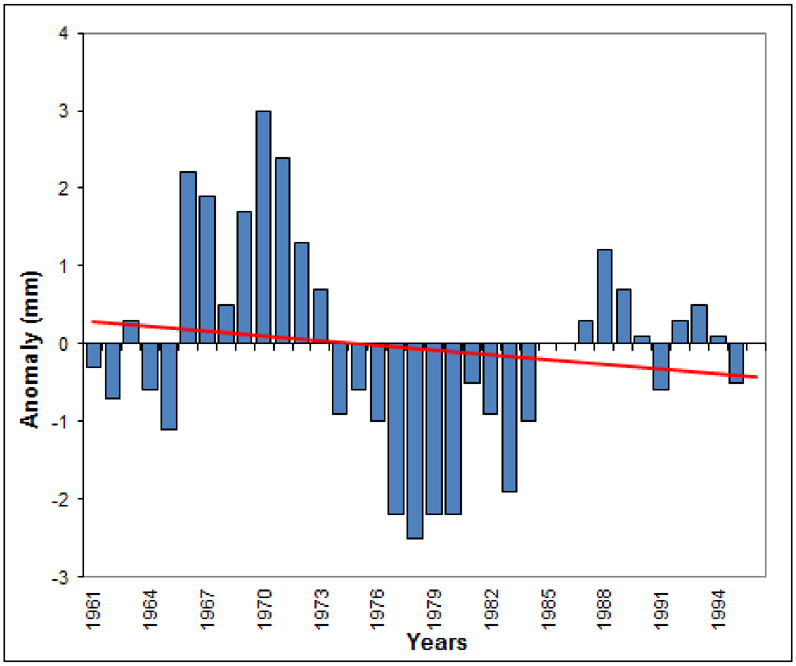
Source: Economic Commission for Latin America and the Caribbean (ECLAC), based on country data

FIGURE 35
TREND OF ANOMALY OF ANNUAL PRECIPITATION, NORTH ANTILLES ARC



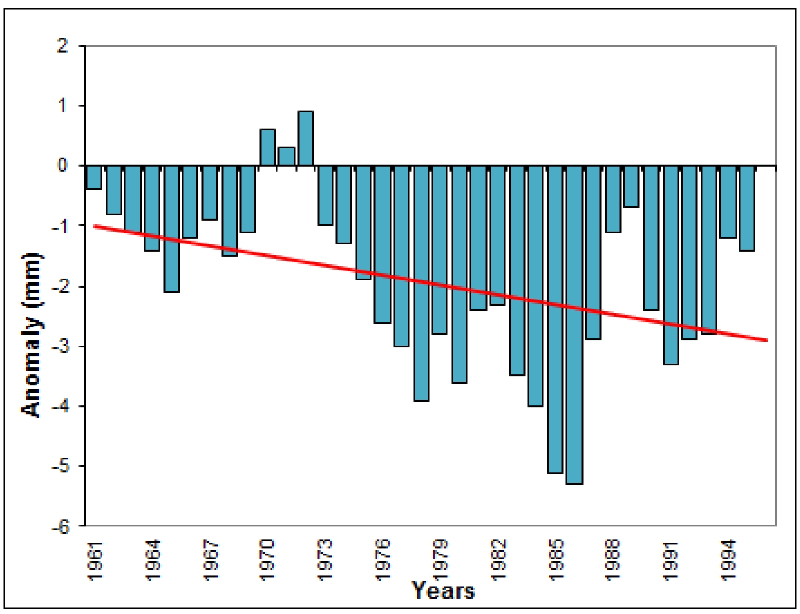
Source: Country data, Author's compilation and estimates

FIGURE 36
TREND OF ANOMALY OF ANNUAL PRECIPITATION, CENTRAL ANTILLES ARC



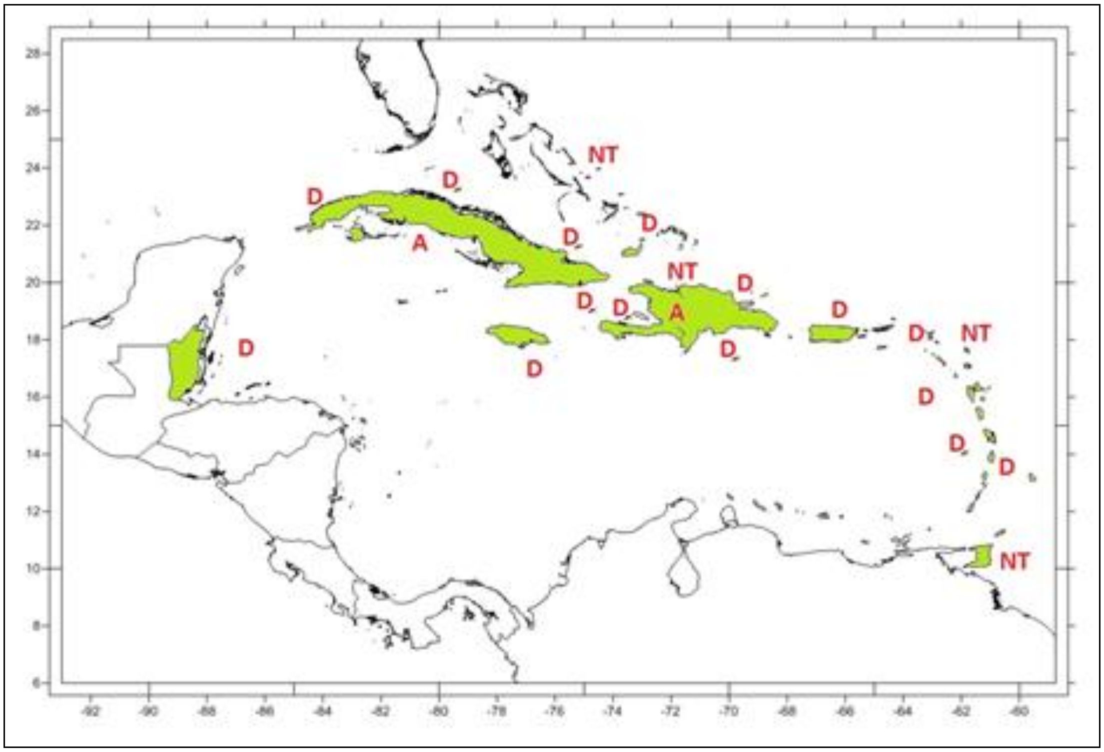
Source: Country data, Author's compilation and estimates

FIGURE 37
TREND OF ANOMALY OF ANNUAL PRECIPITATION, SOUTH ANTILLES ARC



Source: Country data, Author's compilation and estimates

FIGURE 38
REGIONAL TREND OF ANNUAL PRECIPITATION, 1931-2000



Source: Country data, Author's compilation and estimates

D: decreasing trend;
A: increasing trend;
NT: no significant trend

In areas where statistically relevant, negative precipitation trends were observed, the following criteria were found to apply:

- A reduction of the number of rainy days, especially with precipitation levels of more than 50 mm in 24 hours.
- A reduction of the annual precipitation variability.
- An increase of the intensity and frequency of drought processes.

c) Meteorological droughts

The drought diagnosis was based on the determination of the causes of meteorological droughts on both spatial and temporal scales, in which the analysis considered meteorological, oceanic and cosmic processes, using indicators that reflected the impact of the phenomenon on the activities that were carried out in the affected territory. The estimation of the evolution of the drought was based on the prediction of the main processes that caused and modulated that phenomenon, including the evaluation of meteorological forecasts and, more specifically, the prediction of monthly precipitation precisely when the drought began.

The analysis of drought as a region-wide phenomenon would use similar technical procedures to understand and compare the impact of the phenomenon, particularly in terms of precipitation. The systematic monitoring of meteorological processes, and improved capacity of the operative surveillance, could form part of a Caribbean climatic surveillance system. According to Farrell, Leonard and Moseley (2010):

> [the Caribbean] is particularly vulnerable to hydrometeorological and climatic hazards, due to its geology, topography, significant coastal urbanization, small climate-sensitive economies and lack of significant economic diversity. As a result, reducing the vulnerability to climate and hydrometeorological hazards is critical if many of these States are to increase, or sustain, their current levels of socioeconomic development into the future. Drought represents one of the most frequently-occurring climatic hazards in the Caribbean, with recent droughts resulting in economic losses. While droughts are a frequent occurrence in the Caribbean, the region's adaptation to such events is quite poor. [14]

Lapinel and Planos (2002) analysed droughts in the Caribbean during the period 1955-2000, paying special attention to the month of June. They demonstrated that droughts were an environmental process that affected extensive areas (table 3). Later, the same authors prepared a similar study for the whole Caribbean and for all months, corroborating the spatial characteristic of this phenomenon; figure 39 shows the area of the Caribbean affected simultaneously by processes of drought.

TABLE 3

YEARS AFFECTED WITH MODERATE OR SEVERE PRECIPITATION DEFICIT IN JUNE AFFECTING MORE THAN ONE FIFTH OF THE COUNTRY, TERRITORY OR CARIBBEAN AREA

Year	Belize	Cuba	The Bahamas	Jamaica	Haiti	The Dominican Republic
1957		X	X	X*		X
1958	X		X*			
1959		X		X*	X*	X*
1960						
1961	X*	X	X	X*		X*
1962		X				
1963	X*	X	X		X	X
1964		X	X	X		
1965			X*	X*	X	X*
1966						X*
1967	X*		X	X	X*	X
1968	X			X*		
1969	X*					
1970		X*			X	
1971	X*	X*	X	X*	X*	X*
1972				X		
1973	X*		X			X
1974		X		X*	X	X*
1975	X*	X	X*	X*	X*	X*
1976						X
1977		X*	X*	X*	X*	X*
1978				X*	X*	X
1979	X	X	X			
1980		X	X	X		X*
1981		X	X			
1982	X	X*	X	X	X*	X*

(continues)

[14] D Farrell, N. Leonard and L. Moseley,"Managing water resources in the face of Climate Change: a Caribbean perspective". Elements for Life, Tudor Rose, London, United Kingdom, 2010.

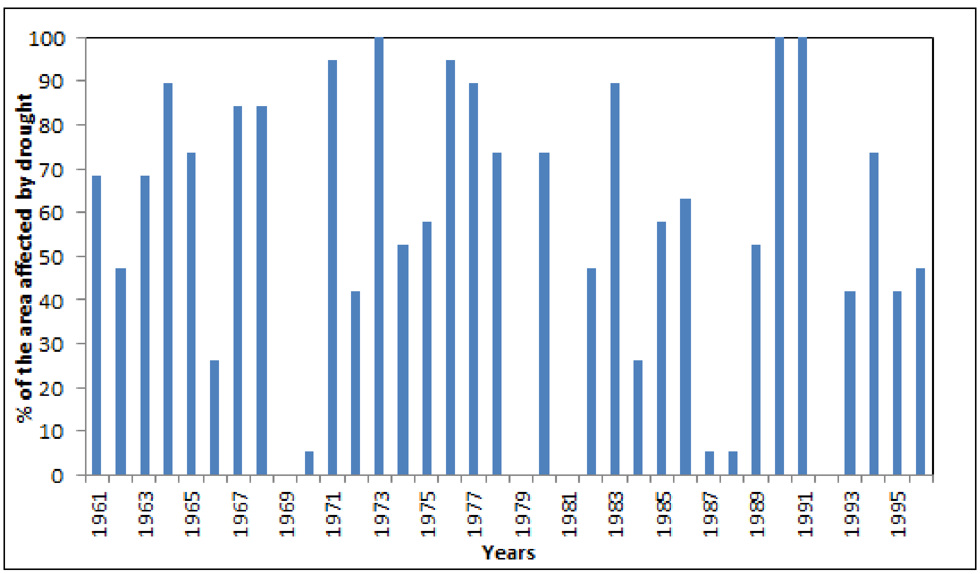
Table 3 (continued)

Year	Belize	Cuba	The Bahamas	Jamaica	Haiti	The Dominican Republic
1983				X		
1984	X	X	X*			
1985		X*	X*	X*	X*	X*
1986	X*	X	X			
1987		X*	X	X*		
1988						
1989	X*	X*	X*	X*		X
1990		X*		X*	X*	X*
1991	X*	X*		X*	X*	X*
1992					X	X*
1993		X*	X	X*		
1994		X*	X	X*		
1995						
1996		X		X*		

Source: B. Lapinel and B. Planos, *Visión de la sequía en Meso América y el Caribe: diagnóstico, impactos y mitigación*. United Nations Educational, Scientific and Cultural Organization International Hydrological Programme (IHP-UNESCO) Flow Regimes International Experimental Network Data (FRIEND) project, 2002

Note: (*) more than 50 % of the territory affected

FIGURE 39
AREAS OF THE CARIBBEAN AFFECTED SIMULTANEOUSLY BY PROCESSES OF DROUGHT, 1961-1996



Source: B. Lapinel and B. Planos, *Visión de la sequía en Meso América y el Caribe: diagnóstico, impactos y mitigación*. United Nations Educational, Scientific and Cultural Organization International Hydrological Programme (IHP-UNESCO) Flow Regimes International Experimental Network Data (FRIEND) project, 2002

Despite the fact that studies usually refer to the year when highlighting any significant annual precipitation deficit, there are many practical limitations to using the annual scale value for precipitation, because it can mask important droughts of short duration that have generated notable hydrological deficits, especially during the first months of the rainy season. In the last years of the

Lapinel study, frequent droughts of short duration occurred in several countries of the Caribbean, linked to the rise in climatic variability. Those events affected the agricultural sectors of those countries severely and, in consequence, had serious impacts on food security. Cuba, for example, was affected by an intense, widespread drought of short duration (April - June, 1998) that affected the whole country, most especially the central and eastern districts. The event in the Cuban eastern district alone caused economic losses evaluated at more than US$ 400 million. From then on, subsequent years have been affected by drought during the same quarterly period. (Lapinel and Planos, 2000).

d) Impacts of hurricanes and high precipitation on water resources

Precipitation from hurricanes and other relevant climate events was examined to determine the relationship between climate events and annual water averages:

TABLE 4
INFLUENCE OF HIGH PRECIPITATION IN ANNUAL PRECIPITATION, 1961-1990, PINAR DEL RÍO. CUBA, WESTERN DISTRICT
(Percentage)

Year	Influence of high precipitation GP in the annual average (%)	Year	Influence of high precipitation GP in the annual average (%)
1961	15	1976	6
1962	4	1977	5
1964	7	1979	19
1965	3	1980	8
1966	6	1981	5
1967	11	1982	25
1968	6	1983	6
1969	12	1984	3
1970	13	1985	3
1971	11	1986	3
1972	11	1987	5
1973	3	1988	8
1974	3	1989	4
1975	4	1990	3

Source: E. Planos and others, *Las Grandes precipitaciones en Cuba*. Reporte científico. Instituto de Meteorología de Cuba, 2011

Based on a range of models, IPCC has suggested that future hurricanes in the tropical north Atlantic are likely to become more intense, with larger peak wind speeds and heavier, near-storm precipitation. It has been projected that there would be an increase in the frequency of hurricanes in Categories 3 to 5, and it would be more likely for a tropical storm to develop into a Category 5 hurricane within a very short time span, such as within 24 hours (ECLAC, 2011).

The Caribbean has been affected frequently by hurricanes, tropical storms, and high precipitation within a 24-hour interval; hurricanes, particularly because of their destructive power and high frequency, are the phenomenon most watched by both authorities and inhabitants. Both hurricanes and tropical storms produce high, intense precipitation that causes huge flash-flow and fluvial floods that generate the main disasters of hydrological and hydraulic origin. However, these phenomena also have a beneficent effect on the Caribbean, by increasing the annual average precipitation of the countries affected. Estimates suggested that hurricanes contributed 10-20 per cent to annual average precipitation (Planos and others, 2011; table 4). Table 4 shows years where precipitation produced by these phenomena represented 25 per cent of the annual precipitation value. For example, in a country the size of Cuba, this kind of precipitation achieves a weight of 10% in the

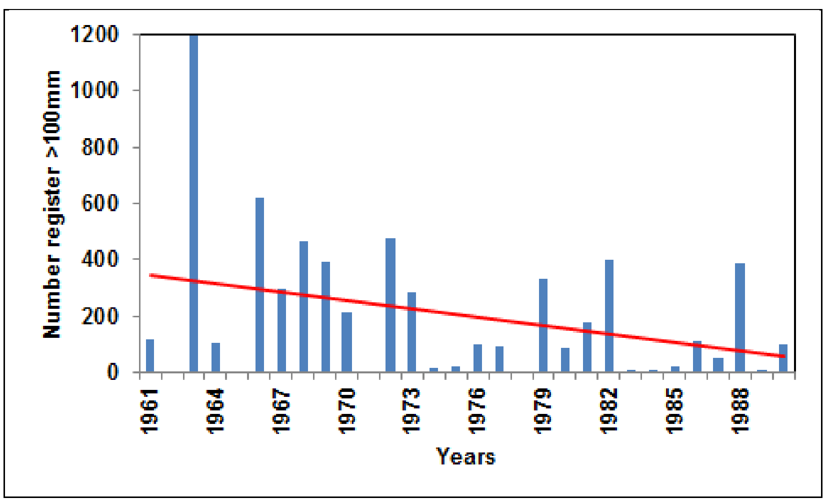
30-year average precipitation; as an average, 71 million cubic metres of water yearly are dependent on the occurrence of this type of precipitation (Planos and others, 2011).

The cyclonic phenomena (including tropical storms) have generated high expectation regarding the way they might behave with climate change. An IPCC technical report has suggested that

> "Variations in tropical and extra-tropical cyclones, hurricanes and typhoons in many small-island regions are dominated by ENSO and decadal variability. These result in a redistribution of tropical storms and their tracks such that increases in one basin are often compensated by decreases in other basins. For example, during an El Niño event, the incidence of hurricanes typically decreases in the Atlantic and far-western Pacific and Australasian regions, while it increases in the central, north and south Pacific, and especially in the western North Pacific typhoon region. There is observational evidence for an increase in intense tropical cyclone activity in the North Atlantic since about 1970, correlated with increases in tropical SSTs. There are also suggestions of increases in intense tropical cyclone activity in other regions where concerns over data quality are greater. Multi-decadal variability and the quality of records prior to about 1970 complicate the detection of long-term trends. Estimates of the potential destructiveness of tropical cyclones suggest a substantial upward trend since the mid-1970s."[15]

Experts on this topic have been noncommittal with respect to the influence of climate change (*Expert meeting on detection and attribution related to anthropogenic climate change*, IPCC, 2009). However, in the past few years, there has been a reduction observed in the precipitation levels equal to or higher than 100 mm in 24 hours caused by hurricanes and tropical storms (figure 40; Planos and others, 2011). In the Caribbean area, more recent trends have indicated that the track of hurricanes drift to the north before arriving to the habitual areas (Planos, personal communication).

FIGURE 40
TREND OF PRECIPITATION REGISTERS EQUAL OR MORE THAN 100 MM IN 24 HOURS, 1961-1990. CUBA



Source: E. Planos and others, *Las Grandes precipitaciones en Cuba*. Reporte científico. Instituto de Meteorología de Cuba, 2011

[15] B.C. Bates and others (eds.), *Climate Change and Water*. Technical Report. Intergovernmental Panel on Climate Change, 2008.

III. Water resources in the Caribbean

The United Nations Environment Programme (UNEP) has indicated that

> "…In 2002, freshwater resources (internal renewable water resources) in the Caribbean (not including LLCS) were 2 532 m^3 per capita. At current population levels, the available water supply in some of the Caribbean is significantly lower than the international limit of 1 000 m^3 per capita per year, below which a country is classified as 'water scarce'."[16]

This limit places Antigua and Barbuda (800 m^3 per capita), Barbados (301 m^3 per capita), and Saint Kitts and Nevis (621 m^3 per capita) in the category of water-scarce countries.

Many Caribbean islands rely almost entirely for their potable water supply on a single source of water, such as groundwater, imports, rainwater, surface reservoirs, rivers and other surface flows. The situation has been critical in the low, limestone islands of the Eastern Caribbean, where seasonal rainfall is very pronounced. In islands such as Anguilla, Antigua and Barbuda, Grenada, and Barbados, more than 65 per cent of total annual rainfall may be recorded in the wet season from June to December (UNEP, 2005).

Recent modelling studies of current and future water resources on several small islands in the Caribbean, using a macro-scale hydrological model and the SRES scenarios, have found that many of these islands would be exposed to severe water stress under all SRES scenarios (UNFCCC, 2007a). Farrell and others (2009) explained that:

> "…The impacts of climate change on water resource management in the Caribbean are tied to the demand for water and the ability of water utilities to supply water from natural and anthropogenic sources. On most Caribbean islands, groundwater and surface water are the primary sources of water used to meet public and industrial demands. However, in countries such as Antigua and Barbuda and the Bahamas, water supplied from desalination is the primary source of potable water. The ability

[16] United Nations Environment Programme (UNEP), *Climate Change in the Caribbean and the Challenge of Adaptation*, Regional Office for Latin America and the Caribbean, 2008.

> of utilities to supply water in the future will be strongly influenced by the impacts of climate change on the hydrological cycle.
>
> Climate change is expected to influence the demand for water by the public and industry in the future. Rising temperatures and changing rainfall patterns are likely to increase the demand for water by households, farmers, tourism, manufacturers and the recreation industry, among others." [17]

The scenario described by Farrell and Trotman (2010) applies to the whole Caribbean basin. Regarding groundwater, Farrell (2010) indicated that

> "...Climate change and climate variability will increase the risk to already-vulnerable groundwater resources. In particular, future climate change and climate variability are likely to impact the quantity and quality of groundwater resources. The speed at which these impacts will occur will be controlled by the location of the aquifer (inland versus coastal), local hydrogeological conditions (including soil characteristics, whether aquifers are confined or unconfined, the size of the aquifer, etc), the forcing climatic conditions, and the degree of utilization of the resource. It is expected that water-scarce islands such as Barbados, which rely exclusively on groundwater to meet national water demand, will be severely impacted by effects of climate change on groundwater resources." [18]

And, in relation to surface water, Farrell and Trotman (2010) said,

> "…Surface water resources are the most vulnerable water resources with respect to climate change and climate variability. Rivers, small lakes, and small impoundments represent the primary surface water bodies in the Caribbean. Surface water resources are the primary sources of potable water in countries such as Saint Vincent, Saint Lucia, and Dominica, among others. On Antigua, surface water contained in the Potworks Reservoir is an important component of the water supply system, but not the primary component."[19]

A. Caribbean hydrological characteristics

The water balance analysed in the present report should be regarded as a potential resource: it is the quantity of precipitation that, potentially, can be used as water, after subtracting evapotranspiration. However, the transformation of precipitation into water is a very complex process that depends on several geographical factors. The real availability of functional water resources is generally between 2 per cent and 30 per cent of potential water resources; for example, in Cuba (where total annual precipitation is approximately 130 000 to 140 000 cubic metres), potential water resources are estimated at 38 000 m^3, but only 24 000 m^3 are hydraulically functional. Generally, withdrawal of up to 20 per cent of the potential water resource availability is considered to be safe. The existent hydraulic infrastructure that determines water availability for multiple uses is another factor that needs to be considered, since other living systems also use water for maintaining life.

In the Caribbean, all water comes from precipitation: the supply sources are surface water and groundwater. The proportion of water use, including the harvesting and the desalination of water, is different from island to island and country to country, depending on its geographical and geological features.

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17 D. Farrell, N. Leonard and L. Moseley "Managing water resources in the face of Climate Change: a Caribbean perspective". *Elements for Life*, Tudor Rose, London, United Kingdom, 2010.

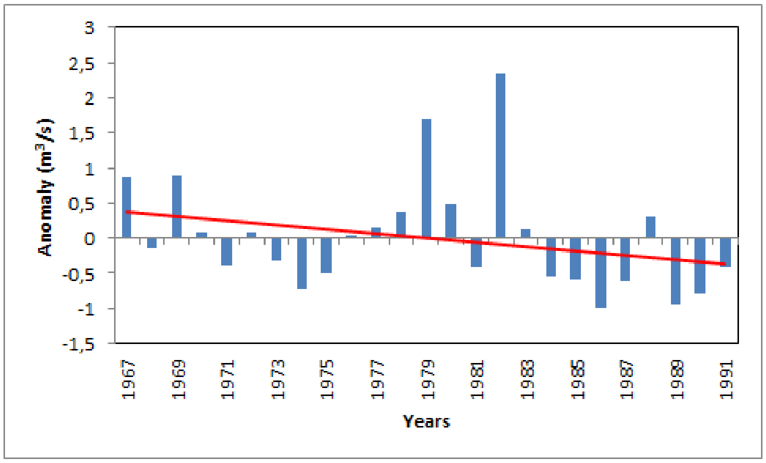
18 Ibid.

19 Ibid.

Generally speaking, the rivers are short and the flow regimes torrential, with great fluctuations in discharge and stage during floods. Many streams do not flow all year round. Specific low water discharges could be of the order of 0.010 m s km to 0.002 m s km (Díaz Arenas, 1982).

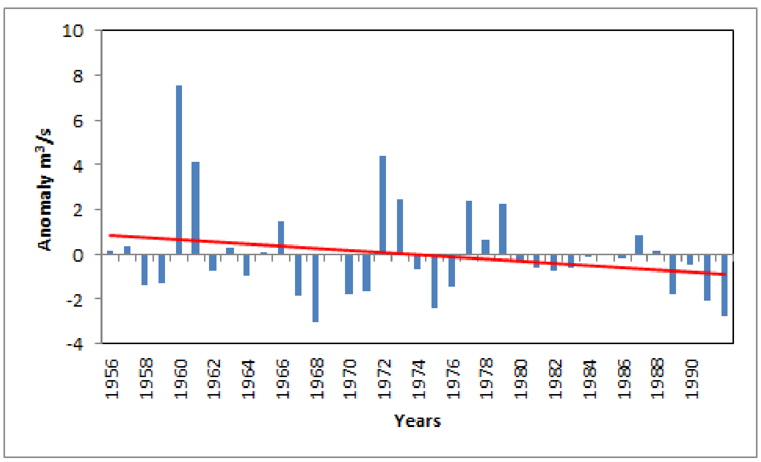
Another outstanding feature in the hydrology of the Caribbean is that many of its aquifers are in direct contact with the sea, so that marine intrusion is an important issue. The water resources' dependence on precipitation, and the relationship between groundwater and sea level, suggests fundamental impacts from climate change, due to the reduction in precipitation and the rise in sea level. There are not enough available data on runoff for the countries involved in the current study; however, based on the direct relationship between precipitation and runoff, the future trend should continue to be negative. Figures 41 to 45 show, for example, that in Cuba, Jamaica and the Dominican Republic, the runoff trend for the past few decades has been negative.

FIGURE 41
ANOMALY RUNOFF, SAN JUAN AND MARTINEZ RIVER, WESTERN CUBA, 1967-1991



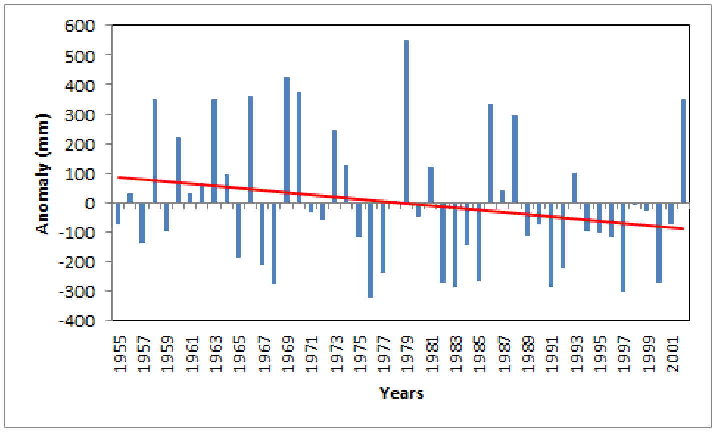
Source: Compiled by Author

FIGURE 42
ANOMALY RUNOFF, TOA RIVER, EASTERN CUBA, 1956-1990



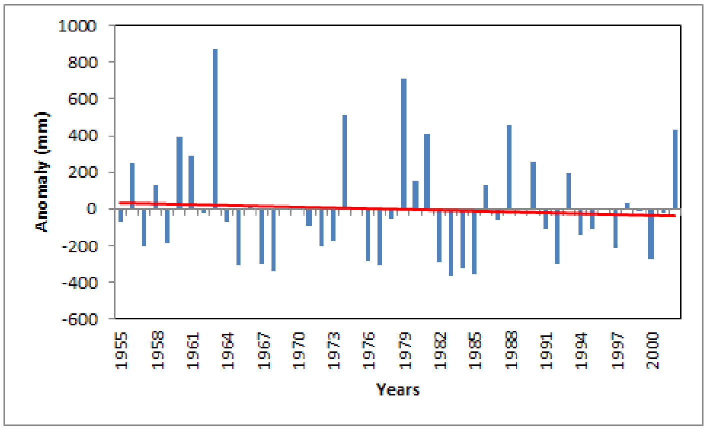
Source: Compiled by Author

FIGURE 43
ANOMALY RUNOFF, COBRE RIVER, JAMAICA, 1955-1999



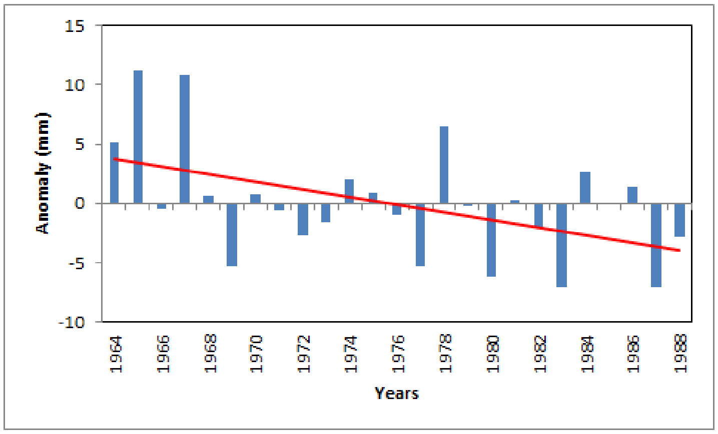
Source: Compiled by Author

FIGURE 44
ANOMALY RUNOFF, HOPE RIVER, JAMAICA, 1955-2000



Source: Compiled by Author

FIGURE 45
ANOMALY RUNOFF, SABANA ALTA. HAINA RIVER. THE DOMINICAN REPUBLIC



Source: Compiled by Author

> "Climate change and climate variability will increase the risk to already vulnerable groundwater resources. In particular, future climate change and climate variability are likely to impact the quantity and quality of groundwater resources. The speed at which these impacts will occur will be controlled by the location of the aquifer (inland versus coastal), local hydrogeological conditions (including soil characteristics, whether aquifers are confined or unconfined, the size of the aquifer), the forcing climatic conditions, and the degree of utilization of the resource. It is expected that water-scarce islands such as Barbados, which rely exclusively on groundwater to meet the national water demand, will be severely impacted by the effects of climate change on groundwater resources." (Farrell and others, 2009).

Two countries currently coping with the magnitude of the problem of saltwater intrusion are Cuba and the Dominican Republic. In Cuba, annual saltwater intrusion ranges from 0.5m to 5m on the vertical axis, and from 0.3 to 3 miles on the horizontal axis (Barros, 2001). In the Dominican Republic, saline intrusion in the Eastern Coastal Plain reaches 23 km in the horizontal direction, especially in the sector of the Casuí River (Planos and Rodriguez, 2001).

B. Hydrological drought

In accordance with Planos and others (2011):

> "Accepting the deficit of precipitation as the general definition of drought helps to outline the problem—from the hydrological point of view—as one of scarcity of water, to aid the good development of environmental and human systems. A close relationship exists between the behaviour of precipitation and the availability of water, so that the management of water resources should be based on premises that take into consideration, as their starting point, the most recent perspectives on climate scenarios.
>
> The possibility of having a hydraulic infrastructure that allows the alleviation of the immediate effects of drought is some guarantee, although not an absolute one, because there are many activities that depend directly on precipitation, mainly in an area where agriculture is the main consumer of water. Yet, good water management is not enough to mitigate the impacts of drought, because that activity is integrated with a group of natural, economic and social factors of the affected territories."

The following recommendations should assure good water management under the scourge of drought:

- Economic and social development adapted to the geographical characteristics, especially climatic and hydrological ones.
- To have a hydraulic infrastructure to supply water that has considered risk management.
- To have watering and drainage systems adapted to the characteristics of the types of cultivation and soils, to guarantee soil conservation.
- Meteorological and hydrological services able to obtain, and to give appropriately, data, analysis, predictions and the necessary warnings to support planning, operative and emergency decisions.
- To maintain economic and social stability, if the possibilities foreseen to alleviate the impacts have been overcome.

However, even having a well-organized system of water management able to confront extreme drought, it would be impossible to foresee all the requirements during the drought process accurately. This explains why the water resources have been drained many times, putting the water management authorities in a very difficult position.

In general, the water resources in the Region of Mesoamerica and the Caribbean are very vulnerable to disastrous negative impacts because, as is pointed out in the report entitled, *Vision on Water, Life and the Environment for the Twenty-first Century*:

> "…for most of the surface water, there are no national management plans or interregional scenarios, and knowledge of groundwater availability is poor. The degradation of water resources is a derivative of the overexploitation of aquifers to satisfy the needs of big cities, industries and irrigation. In most countries, reliable information on these resources doesn't exist. The underground water that supplies the greater part of the urban centres is suffering from growing pollution, due to the inadequate discharge of domestic and industrial waste water. The uncontrolled use of pesticides and fertilizers in agricultural activities has become the main source of pollution. There are also serious problems of pollution due to nitrates and bacteria coming from the systems of septic tanks (Water Center for the Humid Tropics of Latin America and the Caribbean"[20]

Another important element for the hydrological confrontation of drought is the coordination that should exist among meteorological and hydrological services. However, the grade of coordination among these services is yet very low and the grade of deterioration of these institutions, mainly of the observation networks, is high (Stefanaski, 1996).

The hydrological analysis and water management should also be based on an adequate climatic analysis. Habitually, hydrological evaluation and, consequently, water management and protection, is based in the comparative historical behaviour of the hydrological cycle variables, selected for a representative period, and minimizing or ignoring with this procedure climate variability and current trends. The asseverations made in the foregoing paragraphs regarding changes in the behaviour of regional climate are also reflected in the behaviour of the hydrological variables; for example, studies carried out in Caribbean countries have demonstrated a decrease in potential water resources in 1961-1990 with regard to previous statements (Planos and others, 2011; and Planos and Rodriguez, 2001) (table 5).

TABLE 5

VARIABILITY OF POTENTIAL WATER RESOURCES IN COUNTRIES OF MESOAMERICA AND THE CARIBBEAN

(Millions of cubic metres)

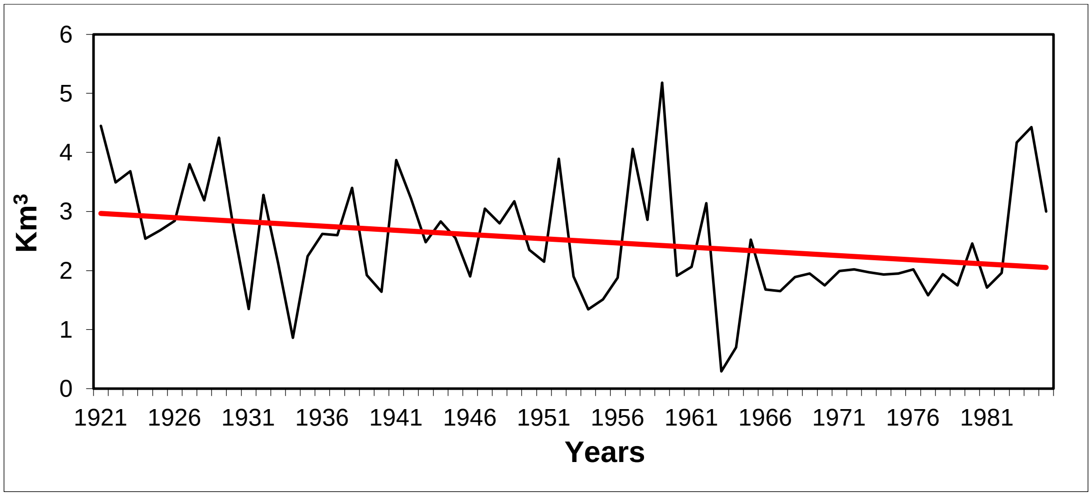
Country	Potential water resources estimate before 1961-1990 (Millions of m^3)	Potential water resources estimate for 1961-1990 (Millions of m^3)
Cuba	38 150	30 067
Haiti	11 000	9 603
The Dominican Republic	22 505	16 559

Source: Planos, 2001 & 2011

Another element corroborates the changes described in Caribbean regional climate, starting from the 1970s: the analysis of the time series of water availability in Mesoamerica and the Caribbean (Shiklomanov, 1998). The dynamics of Caribbean water resources from 1921 to 1985, and the curve of moving-average estimates with sub-series of 10 years, showed the negative trend of water resources from the beginning of the 1960s; and, the statistical tests demonstrated that that series was not homogeneous, breaking in 1970 (figure 46).

[20] *Centro del Agua del Trópico Humedo para America Latina y el Caribe*, (CATHALAC), 2000.

FIGURE 46
DYNAMICS OF WATER AVAILABILITY IN THE REGION OF MESOAMERICA AND THE CARIBBEAN, 1921-1981
(Millions of cubic metres)



Source: N. Shiklomanov, *World water resources: A new appraisal and assessment for the twenty-first century*. International Hydrological programme. United Nations Educational, Scientific and Cultural Organization. Paris, 1998

C. Hydrological balance methodology

Hydrometeorological data were not available for all Caribbean countries. Therefore, the precipitation and air temperature data used have been obtained from the FRIEND project of the UNESCO International Hydrological Programme for Latin America and the Caribbean.[21] These data were reconciled with real data available from various countries. With this information, a climate/water balance was developed using the universal balance equation:

$Q = P - E$, where *Q*= runoff (mm), P= precipitation (mm) and *E*=evaporation (mm).

Since the variable *Q* represented the annual total of the rain water that potentially can be harvested for different uses, the intermediate physical variables needed to be estimated. In this case, the simplest and most well-known methodology was the one proposed by Budyko for which estimates were based on the following considerations:

Determination of annual radiation balance:

$R_o = 3.65 * T$ (R_o in Kcal / cm^2 – year and T in ^oC);

Determination of Index of aridity:

$B = 10 * R_o / L * P$, where P: precipitation (mm) and L=0.59 (condensation latent heat of the water vapour, Kcal/g)

[21] The precipitation and air temperature data used came from the United Nations Educational, Scientific and Cultural Organization /International Hydrological Programme (IHP-UNESCO) Flow Regimes International Experimental Network Data (FRIEND) project. See http://www.insmet.cu/sequia/amigo.htm

Determination of potential evaporation:

$E_0 = 10 * R_o / L$, (mm)

When E_o and B are well known, evaporation E is determined by:

$$E = P * \sqrt{\left(B * \left[1 - \cosh(B) + \sinh(B)\right] \tanh(1/B)\right)}$$

In addition, the Turks and Caicos Islands equation (used for TCI LC/CAR/L 328, ECLAC, 2011) was used to estimate evapotranspiration and potential evaporation (Sokolov and Chapman, 1981).

Using this methodology, the water balance for the period 1961 - 1990 was calculated. The result was not the exact quantity of available fresh water in the Caribbean Region, but could be considered as the potential availability of water from precipitation.

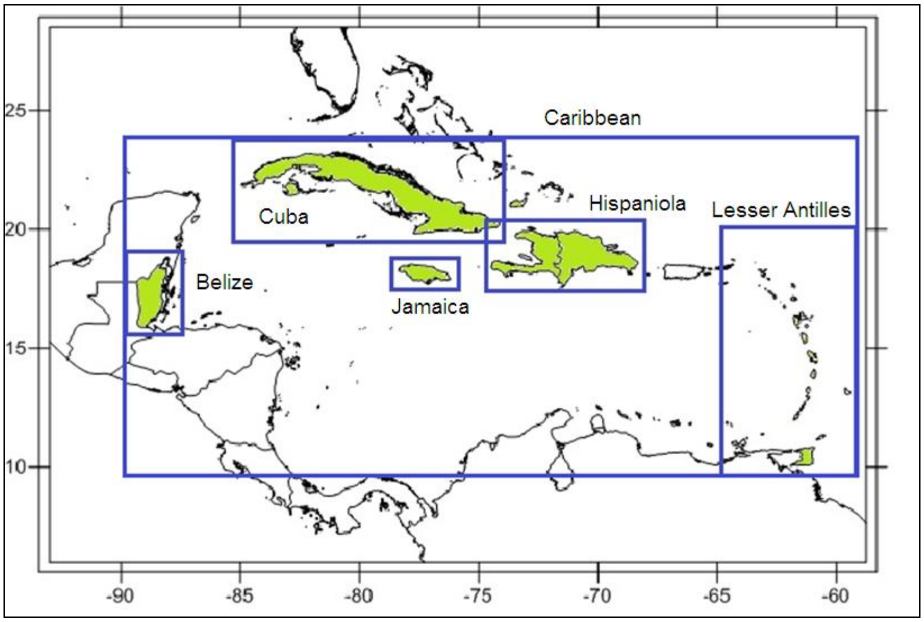
The area considered for the general Caribbean water balance was the area between latitudes 8° North and 23° North, and 85° West and 59.5° West (a total area of 4 160 000 km^2); water balances for Belize, Cuba, Jamaica, Hispaniola, the Lesser Antilles, Guyana and Suriname were also estimated. The approximate area for these countries was taken to be the grid that covered the territory and not the precise land area of each country. Table 6 shows the water balances for the period 1961-1990.

D. Water balance baseline 1961 – 1990

The amount of water obtained from the water balance in the present report represented the amount of water that potentially could be harvested from precipitation for the selected areas. However, this water was not solely for human use: the volume of water available was only a small proportion that was derived from complex geographical and physical factors and the available technology; nevertheless, potential water was a useful indicator for the amount of water that could be harvested directly from precipitation.

Two water balances have been presented in the present report: one is an estimate corresponding to the gridded area that covered, specifically, Belize, Cuba, Jamaica, the island of Hispaniola and the arc of the Lesser Antilles (figure 47 and table 7); and the second (table 8) was for a selection of countries included in one ECLAC Assessment (2011).These two balances have been included, because the first has been carried out with the scenarios obtained directly for the present study from the PRECIS Model, and the second was the result of a combination from PRECIS with those presented in an ECLAC report (2011). This allowed a more detailed country assessment.

FIGURE 47
AREAS SELECTED FOR GRID-BASED WATER BALANCE ESTIMATES OF SELECTED CARIBBEAN COUNTRIES



Source: Author, using PRECIS RCM. See [online]: http://precis.insmet.cu/Precis-Caribe.htm

TABLE 6
WATER BALANCE 1961-1990. SELECTED GRIDDED AREAS IN THE CARIBBEAN

Region	Gridded area km^2	Temperature ^{o}Celsius	Precipitation mm	E_o mm	E mm	Runoff 000 m^3
Caribbean	4 160 000	26.8	1 880	1 633	1 208	2 797.3
Cuba	184 000	24.9	1 326	1 540	989	62.0
Belize	22 500	27.1	2 368	1 677	1 337	23.2
Jamaica	45 000	28.3	1 868	1 751	1 252	27.7
Hispaniola	100 000	24.8	1 469	1 534	1 042	42.7
Lesser Antilles	360 000	27.1	2 368	1 677	1 337	371.0

Source: Data compiled by Author

Note: E_o=potential evaporation (mm); E= evaporation (mm).

The Caribbean countries included in the aforementioned ECLAC report were: Belize, Cuba, Jamaica, the Dominican Republic, Antigua and Barbuda, Barbados, Dominica, Grenada, Saint Lucia, the Bahamas, Saint Vincent and the Grenadines, Trinidad and Tobago, Guyana, and Suriname. The water balances for the period 1961 – 1990 for those countries, with the exception of Guyana and Saint Vincent and the Grenadines, and based in the methodology adopted for the present report, are listed in table 7.

TABLE 7
WATER BALANCE 1961 - 1990. COUNTRIES OF ECLAC REPORT, 2011

Country	T_a ° C	P (mm)	E_o (mm)	Budiko ETP (mm)	Budiko W (‘000 m^3)	TCI ETP (mm)	TCI W (‘000 m^3)
Cuba	24. 9	1 326	1 540. 4	988. 8	35. 7	1 005. 0	34. 0
Belize	25. 12	2 146	1 554. 0	1 230. 5	21. 0	1 258. 7	20. 4
Jamaica	28. 3	1 868	1 750. 8	1 252. 3	6. 7	1 277. 4	6. 4
The Dominican Republic	24. 3	1 486	1 503. 3	1 037. 2	21. 9	1 056. 8	20. 9
Antigua & Barbuda	26	2 394	1 608. 5	1 304. 3	0. 5	1 335. 1	0. 5
Barbados	26	2 612	1 608. 5	1336. 9	0. 5	1 369. 6	0. 5
Dominica	22. 3	3 501	1 379. 6	1246. 4	1. 7	1 283. 5	1. 7
Grenada	26. 6	2 218	1 645. 6	1292. 3	0. 3	1 321. 6	0. 3
Saint Lucia	25. 6	2 887	1 583. 7	1353. 6	0. 9	1 388. 5	0. 9
The Bahamas	24. 6	1 876	1 521. 9	1156. 7	10. 0	1 181. 9	9. 7
Trinidad and Tobago	26. 2	2 532	1 620. 8	1333. 0	6. 1	1 365. 1	6. 0
Suriname	25. 6	3 683	1 583. 7	1414. 2	370. 4	1 454. 9	363. 8

Source: Data compiled by Author

Note: Ta: Average annual temperature; P: Precipitation; Eo: Potential evaporation; ETP; evapotranspiration (Budiko and TCI methodology); W: water volume (estimated with Budiko methodology and with ETP obtained from the Turks and Caicos Islands equation

IV. Climate change impacts on Caribbean water resources

A. IPCC scenarios

The IPCC scenarios considered for the present report were the A2 and B2 scenarios (table 8, figure 48). The A2 storyline represents a differentiated world which is consolidated into a series of economic regions. Self-reliance in terms of resources and less emphasis on economic, social, and cultural interaction between regions are characteristic of this future. Economic growth is uneven and the income gap between now-industrialized and developing parts of the world does not narrow. The A2 world has less international cooperation than the A1 or B1 worlds. People, ideas, and capital are less mobile so that technology diffuses more slowly than in the other scenario families. International disparities in productivity, and hence in income per capita, are largely maintained or increased in absolute terms.

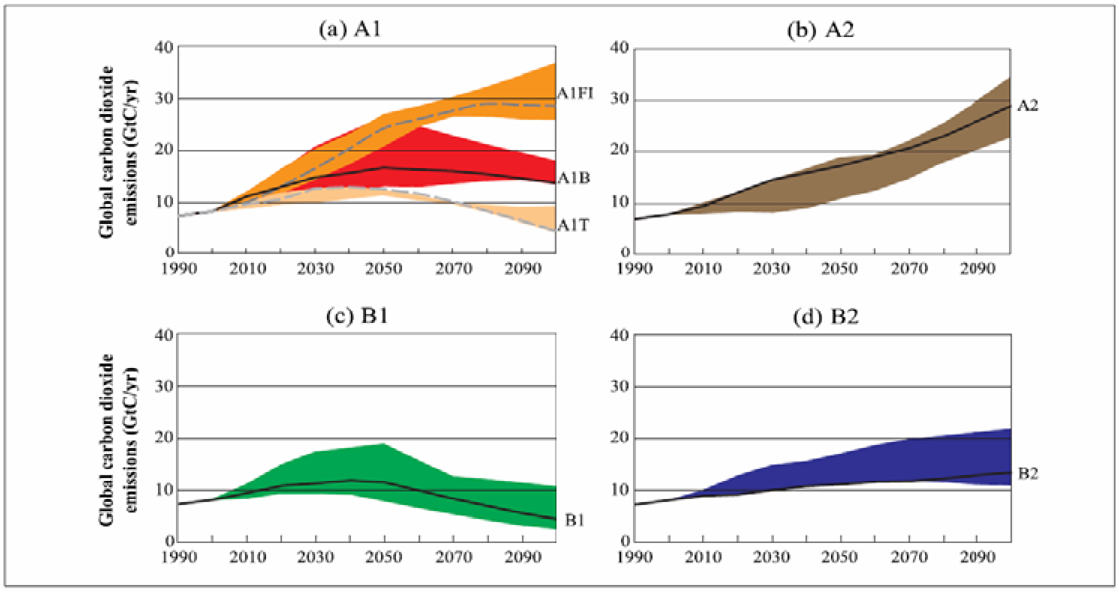
The B2 scenario represents a more divided world, but one that is more ecologically friendly. B2 scenarios are characterized by populations that are continuously increasing but at a slower rate than in A2, and where the emphasis is on local rather than global solutions to economic, social and environmental stability; there is assumed to be an intermediate level of economic development and less rapid, more fragmented technological change than in the A1 scenario.

TABLE 8
SRES A2 AND B2 EMISSIONS SCENARIOS

Storyline	Description
A2	Self reliance, preservation of local identity, continuously increasing population, economic growth on regional scales
B2	Local solution to sustainability, continuously increasing population at a lower rate than A2

Source: United Kingdom UKCIP02 *Climate Scenarios Technical Report.* (http://www.ukcip.org.uk/index.php?option=com_content&task=view&id=161&Itemid=287)

FIGURE 48
SCHEMATIC OF IPCC SCENARIOS



Source: Intergovernmental Panel on Climate Change (IPCC), 2007

B. The use of scenarios in water resource management

TEXTBOX 3
SCENARIOS AND WATER RESOURCES

Special challenges arise when attempting to explore the future of water as a global issue. Firstly, a long-term perspective is needed in order to account for the slow unfolding of hydrological cycles, some critical social processes, and the impacts of new water infrastructure. Secondly, there are methodological problems concerning how to gain this long-term perspective. It would seem logical to use forecasting techniques to estimate future water use and water resources.

Yet, although predictive forecasts may be reliable over the short term, they become untrustworthy as the time horizon expands from months and years to decades and generations, due to error accumulation, our limited understanding of human and ecological processes, and the intrinsic indeterminism of complex, dynamic systems.

The third challenge arises from the dependence of future water conditions on human decisions that are yet to be made.

The term scenario has been introduced into the planning literature to mean a hypothetical sequence of events constructed for the purpose of focusing attention on causal processes and decision points.

Nonetheless, scenarios are neither projections, forecasts nor predictions. Rather, they are stories about the future with a logical plot and narrative governing the manner in which events may unfold. Scenarios usually include images of the future – snapshots of the major features of interest at various points in time – and an account of the causal flow of events leading from the present (or the base situation) to such future conditions.

Source: Gallopin, 2012.

C. The probable future: Caribbean hydrological scenario

1. Caribbean water balance 2050 - 2100

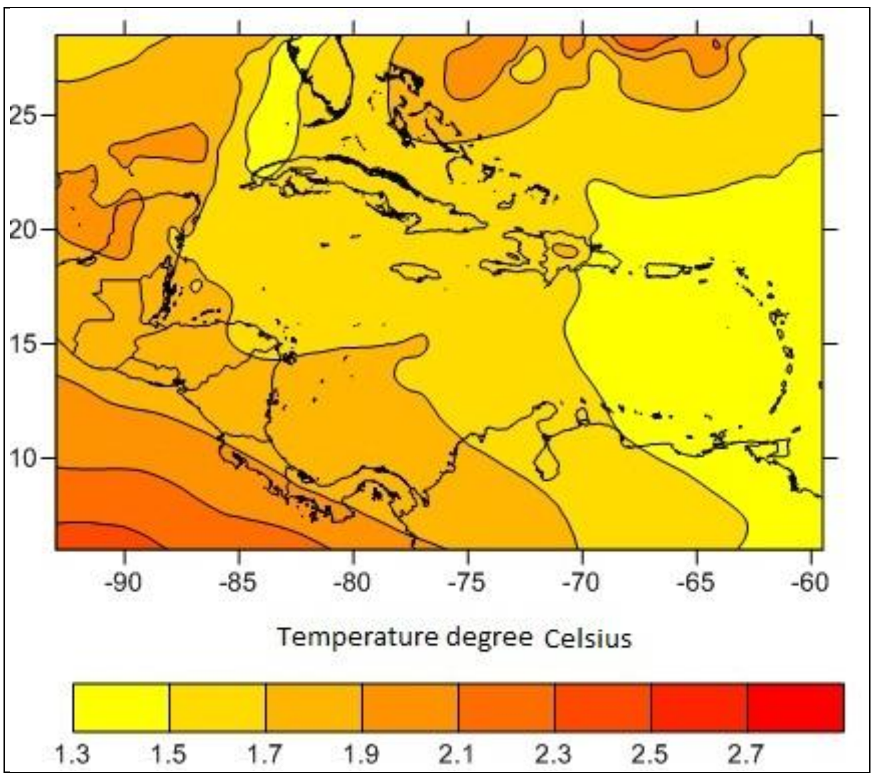
As mentioned in ECLAC (2011),

> "… the temperature and precipitation predictions are from the Regional Climate Modelling system (RCM) for Providing Regional Climates for Impact Studies (PRECIS), driven by two models - ECHAM4 and HadCM3.5. The RCM is maintained by the Institute of Meteorology (INSMET) of Cuba. Baseline references for temperature and rainfall are the 1960-1990 period averages. Sea-level rise projections are generally taken from proposals in the literature that were based on possible futures determined by mitigation and adaptation on a global scale."[22]

The results referred to the A2 and B2 scenario for the periods 2010-2070 and 2071-2100.

Figures 49 to 55 show the patterns of temperature and precipitation in the Caribbean for 2050 and 2100, using the PRECIS Regional Climate Modelling system.[23]

FIGURE 49
PATTERNS OF TEMPERATURE IN THE CARIBBEAN. YEAR 2050. SCENARIO A2

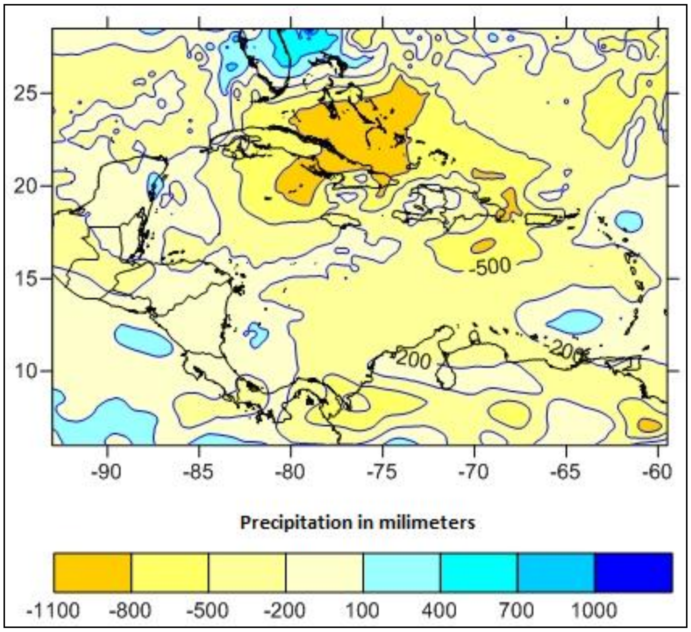


Source: Compiled by Author

[22] Economic Commission for Latin America and the Caribbean (ECLAC), "The economics of climate change in the Caribbean: summary report, Port of Spain, ECLAC, 2011.

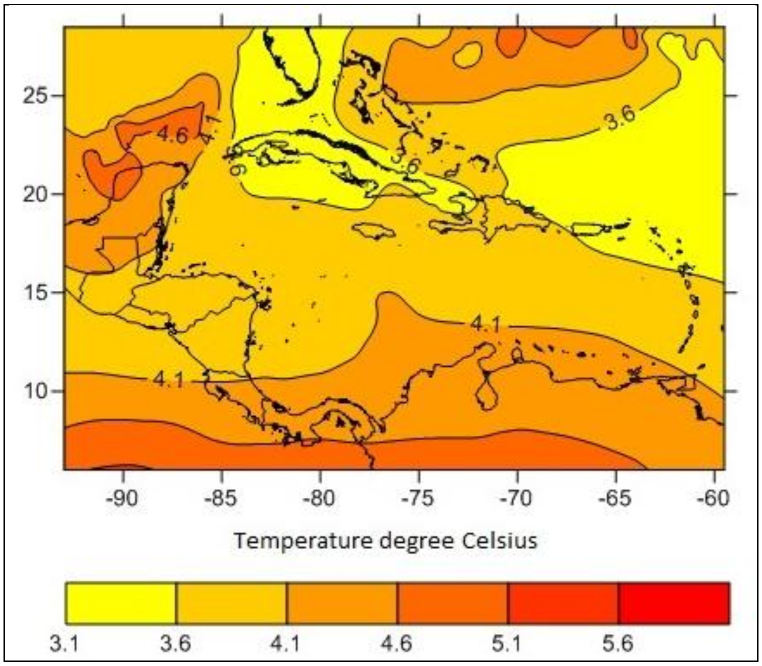
[23] More information is available from http://precis.insmet.cu/Precis-Caribe.htm

FIGURE 50
PATTERNS OF PRECIPITATION IN THE CARIBBEAN. YEAR 2050. SCENARIO A2



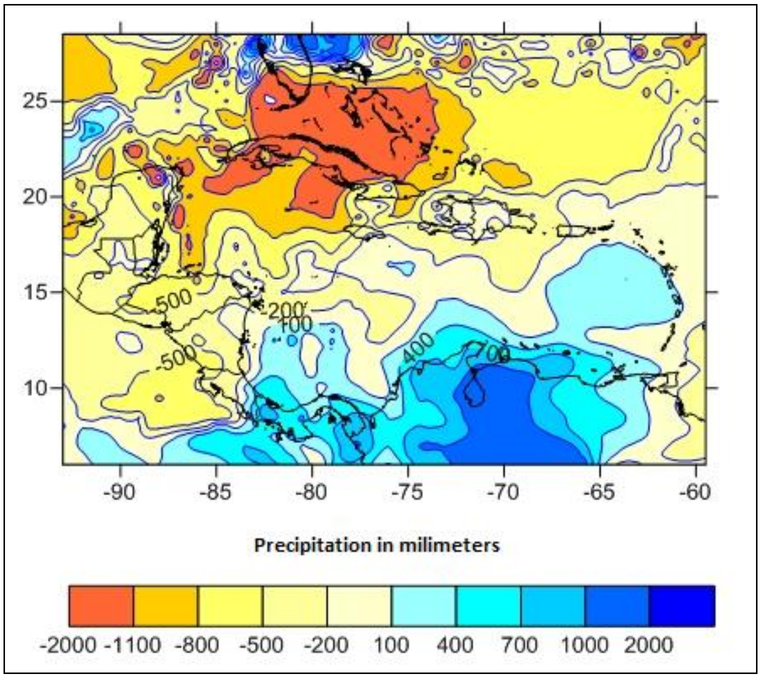
Source: Compiled by Author

FIGURE 51
PATTERNS OF TEMPERATURE IN THE CARIBBEAN. YEAR 2100. SCENARIO A2



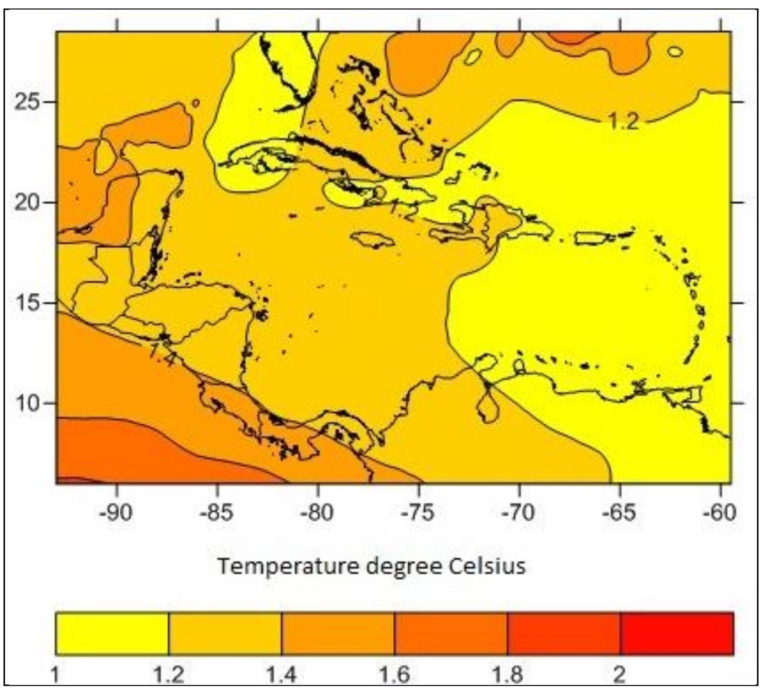
Source: Compiled by Author

FIGURE 52
PATTERNS OF PRECIPITATION IN THE CARIBBEAN. YEAR 2100. SCENARIO A2



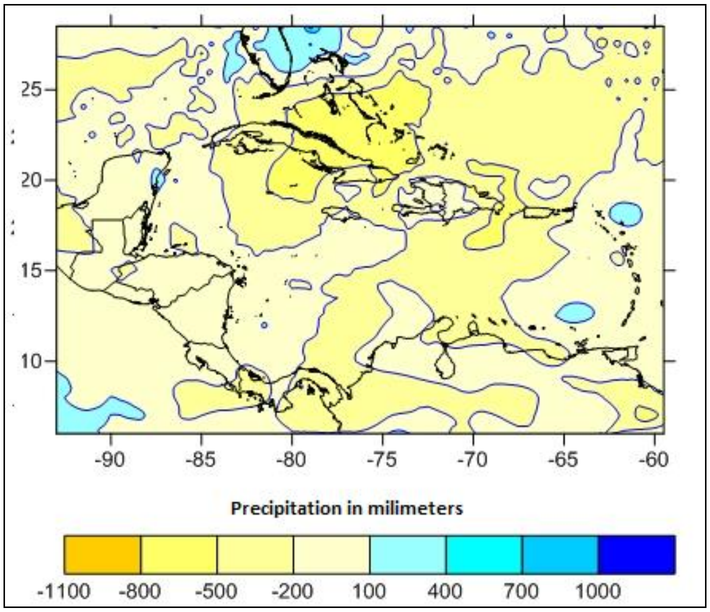
Source: Compiled by Author

FIGURE 53
PATTERNS OF TEMPERATURE IN THE CARIBBEAN. YEAR 2050. SCENARIO B2



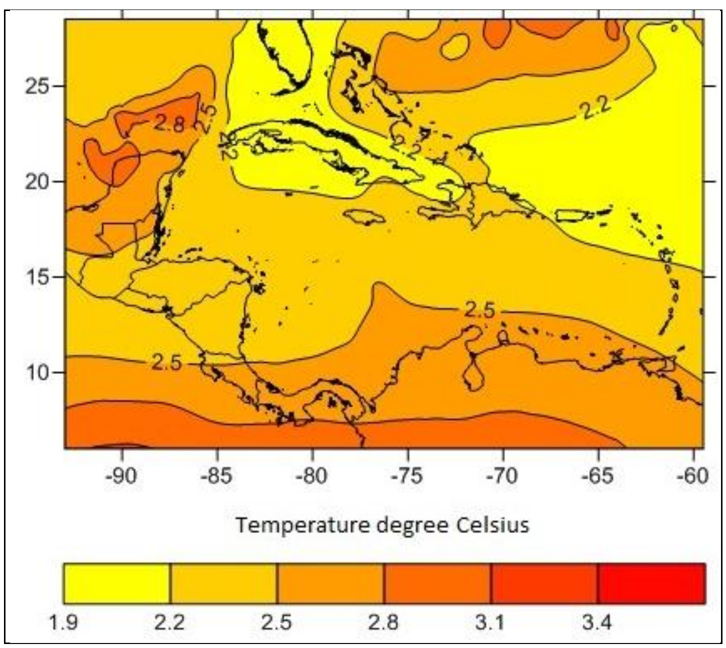
Source: Compiled by Author

FIGURE 54
PATTERNS OF PRECIPITATION IN THE CARIBBEAN. YEAR 2050. SCENARIO B2



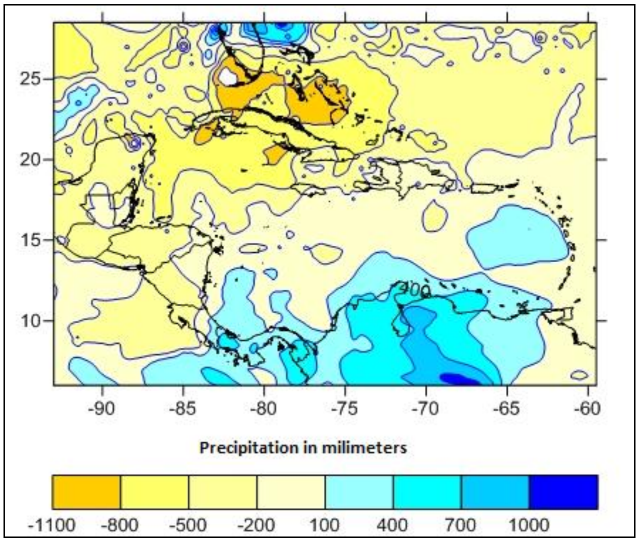
Source: Compiled by Author

FIGURE 55
PATTERNS OF TEMPERATURE IN THE CARIBBEAN. YEAR 2100. SCENARIO B2



Source: Compiled by Author

FIGURE 56
PATTERNS OF PRECIPITATION IN THE CARIBBEAN. YEAR 2100. SCENARIO B2



Source: Compiled by Author

Tables 9 to 14 show the comparative potential volume of water for the baseline and climate change scenarios for selected areas in the Caribbean (figure 46). Table 15 summarizes the comparative impact of climate change in selected geographical (gridded) areas, particularly on water potential. In figures 57 to 64, and table 16, there is a more detailed—and more realistic—vision for a selection of countries in the Caribbean. A downward trend of potential water resources predominated in the Caribbean, taking into consideration the fact that the volume of water was a potential resource, and that not all might be available to be used. Generally, there was a reduction in potential water resources, both under A2 and B2, although that reduction varied spatially. Figure 64 shows, comparatively, the variation in potential water resources between countries; drastic reductions in the A2 scenario in 2100 can be observed, with 40% less with respect to the baseline scenario.

TABLE 9
CARIBBEAN WATER BALANCE. GRIDDED AREA. BASELINE 1961 – 1990. SCENARIOS A2 & B2 (2050 & 2100)

	BASELINE 1961-1990	A2 2050	A2 2100	B2 2050	B2 2100
Increment in temperature (I-T_a) (° C)		1.37	3.78	1.03	1.37
Average annual temperature (T_a) (° C)	26.825	28.47	30.88	28.13	28.47
Precipitation (P) (‘000 mm^3)	1 879.8	1 689.8	1 678.6	1 735.6	1 737.6
Potential evaporation (E_o) (‘000 mm^3)	1 659.5	1 761.3	1 910.4	1 740.2	1 761.3
Evapotranspiration (ETP) (‘000 mm^3)	1 218.7	1 197.3	1 240.24	1 205.9	1 214.0
Water volume (W Budiko) (‘000 mm^3)	2 750.1	2 048.9	1 823.9	2 203.6	2 178.1
Evapotranspiration (ETP/Turks) (‘000 mm^3)	1 244.1	1 219.4	1 260.9	1 228.9	1 236.9
Water volume (W/ Turks) (‘000 mm^3)	2 644.6	1 957.1	1 737.3	2 107.9	2 082.77

Source: Compiled by Author

Note: I-T_a= increment in temperature by scenario in ^{o} C; ETP=evapotranspiration using Budiko and Turks methodology; W/Budiko= water volume estimated with Budiko methodology; W/Turks= water volume estimated with ETP obtained from TCI (Turks & Caicos Islands) equation (ETP/Turks).

TABLE 10
CUBA : WATER BALANCE. GRIDDED AREA. BASELINE 1961 – 1990 SCENARIOS A2 & B2 (2050 & 2100)

	BASELINE 1961-1990	A2 2050	A2 2100	B2 2050	B2 2100
Increment in temperature ($I-T_a$) (° C)		1.6	3.6	1.2	1.6
Average annual temperature (T_a) (° C)	24.9	28.1	30.1	27.7	28.1
Precipitation (P) (‘000 mm^3)	1 326.0	1 247.0	1 097.0	1 232.0	1 209.0
Potential evaporation (E_o) (‘000 mm^3)	1 540.4	1 737.8	1 859.6	1 713.6	1 737.8
Evapotranspiration (ETP) (‘000 mm^3)	988.8	1 001.3	939.4	988.6	981.7
Water volume (W Budiko) (‘000 mm^3)	62.0	45.2	29.0	44.8	41.8
Evapotranspiration (ETP/Turks) (‘000 mm^3)	1 005.0	1 013.1	944.9	1 000.3	992.4
Water volume (W/ Turks) (‘000 mm^3)	59.1	43.0	28.0	42.6	39.8

Source: Compiled by Author

Note: $I-T_a$= increment in temperature by scenario in º C; ETP=evapotranspiration using Budiko and Turks methodology; W/Budiko= water volume estimated with Budiko methodology; W/Turks= water volume estimated with ETP obtained from TCI (Turks & Caicos Islands) equation (ETP/Turks)

TABLE 11
BELIZE WATER BALANCE. GRIDDED AREA. BASELINE 1961 – 1990 SCENARIOS A2 & B2 (2050 & 2100)

	BASELINE 1961-1990	A2 2050	A2 2100	B2 2050	B2 2100
Increment in temperature ($I-T_a$) (° C)		1,4	3.8	1.0	1.4
Average annual temperature (T_a) (° C)	27.1	28.5	30.9	28.1	28.5
Precipitation (P) (‘000 mm^3)	2 368.0	2 272.0	2 376.0	2 292.0	2 343.0
Potential evaporation (E_o) (‘000 mm^3)	1 676.5	1 761.3	1 910.4	1 740.2	1 761.3
Evapotranspiration (ETP) (‘000 mm^3)	1 337.4	1 361.8	1 457.0	1 355.6	1 376.9
Water volume (W Budiko) (‘000 mm^3)	23.2	20.5	20.7	21.1	21.7
Evapotranspiration (ETP/Turks) (‘000 mm^3)	1 368.3	1 392.0	1 488.8	1 386.0	1 407.9
Water volume (W/ Turks) (‘000 mm^3)	22.5	19.8	20.0	20.4	21.0

Source: Compiled by Author

Note: $I-T_a$= increment in temperature by scenario in º C; ETP=evapotranspiration using Budiko and Turks methodology; W/Budiko= water volume estimated with Budiko methodology; W/Turks= water volume estimated with ETP obtained from TCI (Turks & Caicos Islands) equation (ETP/Turks).

TABLE 12
JAMAICA WATER BALANCE. GRIDDED AREA. BASELINE 1961 – 1990. SCENARIOS A2 & B2 (2050 & 2100

	BASELINE 1961-1990	A2 2050	A2 2100	B2 2050	B2 2100
Increment in temperature ($I-T_a$) (° C)		1.7	3.8	1.2	1.7
Average annual temperature (T_a) (° C)	28.3	30.0	32.1	29.5	30.0
Precipitation (P) (‘000 mm^3)	1 868.0	1 516.0	1 430.0	1 602.0	1 601.0
Potential evaporation (E_o) (‘000 mm^3)	1 750.8	1 852.8	1 982.8	1 825.0	1 852.8

(continues)

Table 12 (continued)

	BASELINE 1961-1990	A2 2050	A2 2100	B2 2050	B2 2100
Evapotranspiration (ETP) (‘000 mm^3)	1 252.3	1 155.7	1 146.1	1 184.1	1 191.8
Water volume (W Budiko) (‘000 mm^3)	27.7	16.2	12.8	18.8	18.4
Evapotranspiration (ETP/Turks) (‘000 mm^3)	1 277.4	1 173.3	1 159.8	1 204.0	1 211.4
Water volume (W/ Turks) (‘000 mm^3)	26.6	15.4	12.2	17.9	17.5

Source: Compiled by Author

Note: I-T_a= increment in temperature by scenario in ^{o} C; ETP=evapotranspiration using Budiko and Turks methodology; W/Budiko= water volume estimated with Budiko methodology; W/Turks= water volume estimated with ETP obtained from TCI (Turks & Caicos Islands) equation (ETP/Turks).

TABLE 13
HISPANIOLA WATER BALANCE. GRIDDED AREA. BASELINE 1961 – 1990. SCENARIOS A2 & B2 (2050 & 2100)

	BASELINE 1961-1990	A2 2050	A2 2100	B2 2050	B2 2100
Increment in temperature (I-T_a) (° C)		1.6	3.7	1.6	1.6
Average annual temperature (T_a) (° C)	24.8	26.4	28.5	26.4	26.4
Precipitation (P) (‘000 mm^3)	1 469.0	1 142.0	1 114.0	1 260.0	1 192.0
Potential evaporation (E_o) (‘000 mm^3)	1 534.2	1 631.4	1 765.0	1 631.4	1 631.4
Evapotranspiration (ETP) (‘000 mm^3)	1 041.9	925.3	934.6	983.6	950.7
Water volume (W Budiko) (‘000 mm^3)	42.7	21.7	17.9	27.6	24.1
Evapotranspiration (ETP/Turks) (‘000 mm^3)	1 061.1	935.6	942.1	997.2	962.5
Water volume (W/ Turks) (‘000 mm^3)	40.8	20.6	17.2	26.3	23.0

Source: Compiled by Author

Note: I-T_a= increment in temperature by scenario in ^{o} C; ETP=evapotranspiration using Budiko and Turks methodology; W/Budiko= water volume estimated with Budiko methodology; W/Turks= water volume estimated with ETP obtained from TCI (Turks & Caicos Islands) equation (ETP/Turks).

TABLE 14
LESSER ANTILLES WATER BALANCE. GRIDDED AREA. BASELINE 1961 – 1990 SCENARIOS A2 & B2 (2050 & 2100)

	BASELINE 1961-1990	A2 2050	A2 2100	B2 2050	B2 2100
Increment in temperature (I-T_a) (° C)		1.4	3.8	1.0	1.4
Average annual temperature (T_a) (° C)	27.1	28.5	30.9	28.1	28.5
Precipitation (P) (‘000 mm^3)	2 368.0	2 272.0	2 376.0	2 292.0	2 343.0
Potential evaporation (E_o) (‘000 mm^3)	1 676.5	1 761.3	1 910.4	1 740.2	1 761.3
Evapotranspiration (ETP) (‘000 mm^3)	1 337.4	1 361.8	1 457.0	1 355.6	1 376.9
Water volume (W Budiko) (‘000 mm^3)	371.0	327.7	330.8	337.1	347.8

(continues)

Table 14 (continued)

	BASELINE 1961-1990	A2 2050	A2 2100	B2 2050	B2 2100
Evapotranspiration (ETP/Turks) (‘000 mm^3)					
Water volume (W/ Turks) (‘000 mm^3)	1 368.3	1 392.0	1 488.8	1 386.0	1 407.9
Increment in temperature (I-T_a) (° C)	359.9	316.8	319.4	326.2	336.7

Source: Compiled by Author

Note: I-T_a= increment in temperature by scenario in ^{o} C; ETP=evapotranspiration using Budiko and Turks methodology; W/Budiko= water volume estimated with Budiko methodology; W/Turks= water volume estimated with ETP obtained from TCI (Turks & Caicos Islands) equation (ETP/Turks).

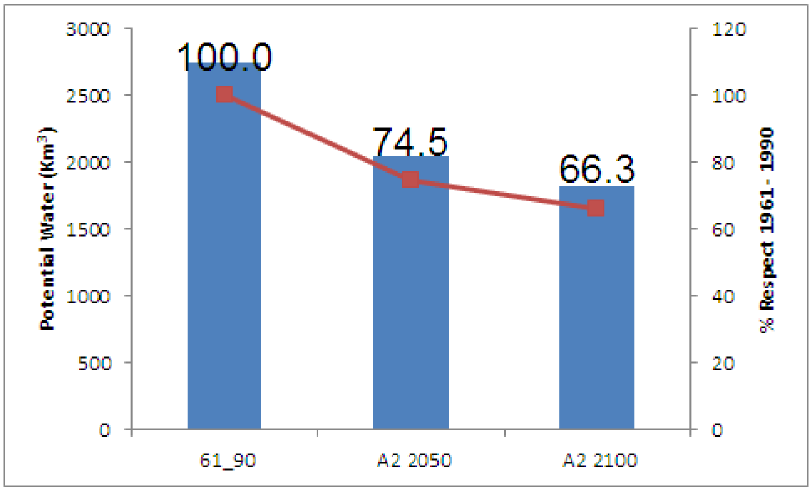
TABLE 15
CARIBBEAN. GRIDDED AREA. POTENTIAL WATER VOLUMES: BASELINE AND IPCC A2 & B2 SCENARIOS
(Thousands of cubic metres and percentage)

Gridded-Area	Parameters	Baseline 1961-1990	IPCC Scenarios			
			A2 2050	A2 2100	B2 2050	B2 2100
	Water volume	2750.1	2048.9	1823.9	2203.6	2178.1
Caribbean	Deficit (‘000 m^3)	0	-701.2	-926.2	-546.5	-572.0
	Reduction (%)	100	-25.5	-33.7	-19.9	-20.8
	Water volume	62	45.2	29.0	44.8	41.8
Cuba	Deficit (‘000 m^3)	0	-16.8	-33.0	-17.2	-20.2
	Reduction (%)	100	-27.1	-0.5	-0.3	-0.3
	Water volume	23.2	20.5	20.7	21.1	21.7
Belize	Deficit (‘000 m^3)	0	-2.7	-2.5	-2.1	-1.5
	Reduction (%)	100	-11.6	-0.1	-0.1	-0.1
	Water volume	27.7	16.2	16.2	16.2	16.2
Jamaica	Deficit (‘000 m^3)	0	-11.5	-11.5	-11.5	-11.5
	Reduction (%)	100	-41.5	-41.5	-41.5	-41.5
	Water volume	42.7	21.7	17.9	27.6	24.1
Hispaniola	Deficit (‘000 m^3)	0	-21.0	-24.8	-15.1	-18.6
	Reduction (%)	100	-49.2	-58.1	-35.4	-43.6
	Water volume	371	327.7	330.8	337.1	347.8
Lesser Antilles	Deficit (‘000 m^3)	0	-43.3	-40.2	-33.9	-23.2
	Reduction (%)	100	-11.7	-10.8	-9.1	-6.3

Source: Compiled by Author

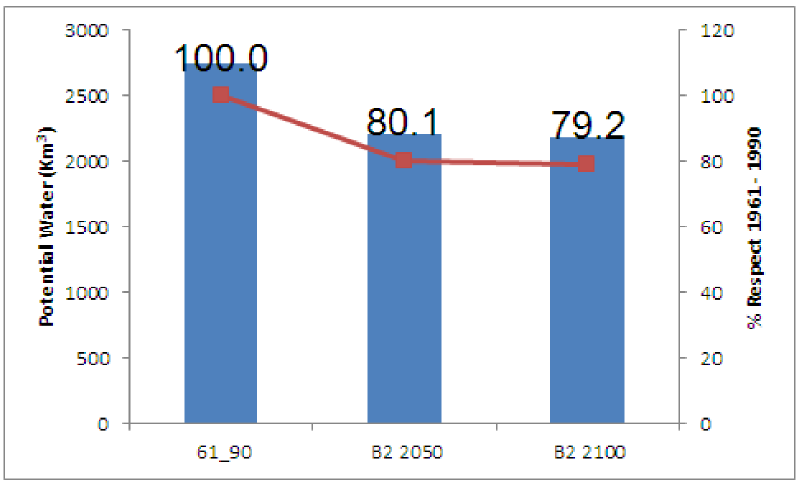
Note: Deficit (‘000 m^3) = Deficit of water volume with respect to baseline. Reduction (%) = Percentage reduction in water volume with respect to baseline.

FIGURE 57
GRIDDED AREA. CARIBBEAN WATER VOLUMES. SCENARIO A2 RELATIVE TO BASELINE
(Thousands of cubic metres and percentage)



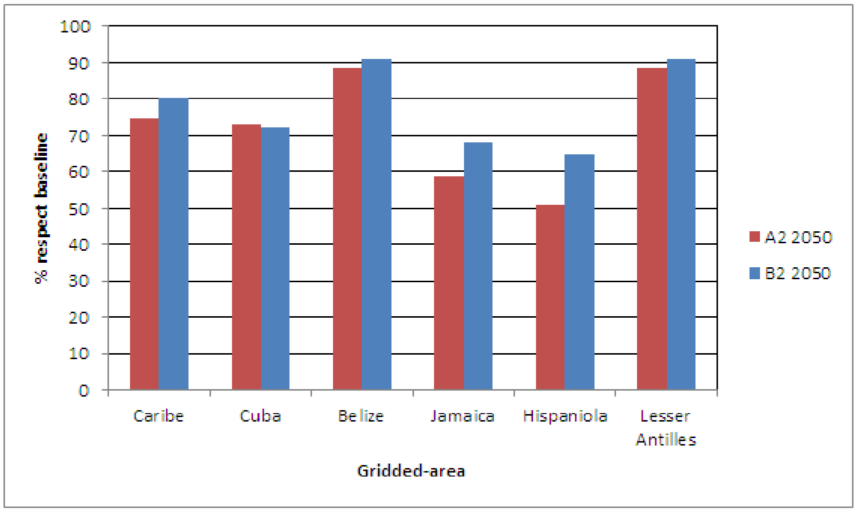
Source: Author's calculations

FIGURE 58
GRIDDED AREA. CARIBBEAN WATER VOLUMES. SCENARIO B2 RELATIVE TO BASELINE
(Thousands of cubic metres and percentage)



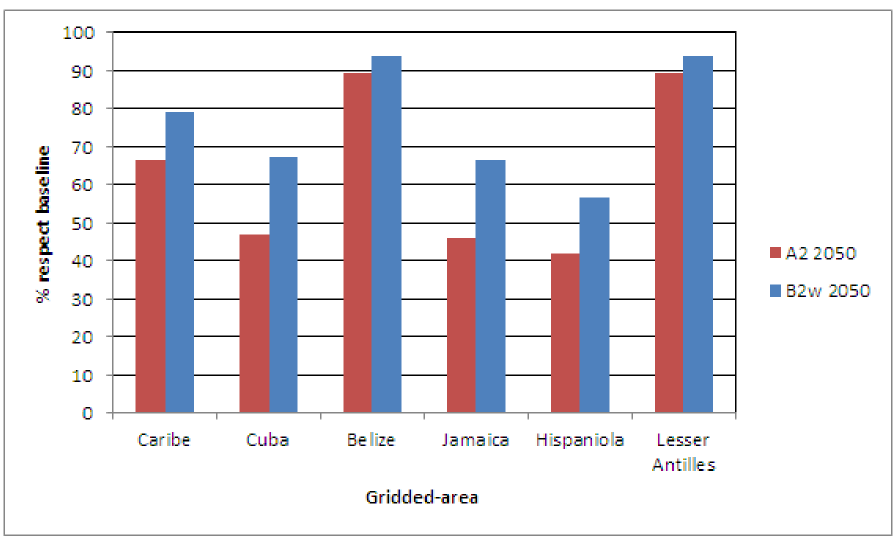
Source: Author's calculations

FIGURE 59
GRIDDED AREA. REDUCTION OF POTENTIAL CARIBBEAN WATER VOLUMES RELATIVE TO THE BASELINE. SCENARIOS: A2, 2050 AND B2, 2050
(Thousands of cubic metres and percentage)



Source: Author's calculations

FIGURE 60
GRIDDED AREA. REDUCTION OF POTENTIAL CARIBBEAN WATER VOLUMES RELATIVE TO THE BASELINE. SCENARIOS A2 2100 AND B2 2100



Source: Author's calculations

TABLE 16
POTENTIAL CARIBBEAN WATER VOLUMES: BASELINE AND IPCC SCENARIOS A2 AND B2, 2050 AND 2100
(Thousands of cubic metres and percentage)

Country	Parameters	Baseline 1961-1990	Scenario A2 2050	Scenario A2 2100	Scenario B2 2050	Scenario B2 2100
Caribbean	Water volume	2750.1	2048.9	1823.9	2203.6	2178.1
	Deficit (‘000 m^3)	0	-701.2	-926.2	-546.5	-572
	Reduction (%)	100	-0.25	-50.8	-24.8	-26.3
Cuba	Water volume	35.7	30.5	26.4	29.6	27.2
	Deficit (‘000 m^3)	0	-5.2	-9.3	-6.1	-8.5
	Reduction (%)	100	-0.15	-35.2	-20.6	-31.3
Belize	Water volume	21	15	6.9	17.5	13.9
	Deficit (‘000 m^3)	0	-6	-14.1	-3.5	-7.1
	Reduction (%)	100	-0.29	-204.3	-20	-51.1
Jamaica	Water volume	6.7	4.1	2.4	3.7	3.2
	Deficit (‘000 m^3)	0	-2.6	-4.3	-3	-3.5
	Reduction (%)	100	-0.39	-179.2	-81.1	-109.4
Haiti	Water volume	14	9.5	7.2	9.6	9.1
	Deficit (‘000 m^3)	0	-4.5	-6.8	-4.4	-4.9
	Reduction (%)	100	-0.32	-94.4	-45.8	-53.8
The Dominican Republic	Water volume	21.9	15.8	11	17.1	17.2
	Deficit (‘000 m^3)	0	-6.1	-10.9	-4.8	-4.7
	Reduction (%)	100	-0.28	-99.1	-28.1	-27.3
Antigua & Barbuda	Water volume	0.5	0.4	0.3	0.3	0.3
	Deficit (‘000 m^3)	0	-0.1	-0.2	-0.2	-0.2
	Reduction (%)	100	-0.20	-66.7	-66.7	-66.7
Barbados	Water volume	0.5	0.4	0.2	0.5	0.4
	Deficit (‘000 m^3)	0	-0.1	-0.3	0	-0.1
	Reduction (%)	100	-0.20	-0.75	0.00	-0.20
Dominica	Water volume	1.7	1.3	0.14	0.6	0.1
	Deficit (‘000 m^3)	0	-0.4	-1.56	-1.1	-1.6
	Reduction (%)	100	-0.24	-1114.3	-183.3	-1600
Grenada	Water volume	0.3	0.3	0.1	0.2	0.1
	Deficit (‘000 m^3)	0	0	-0.2	-0.1	-0.2
	Reduction (%)	100	0.00	-200	-50	-200
Saint Lucia	Water volume	0.9	0.6	0.2	0.4	0.1
	Deficit (‘000 m^3)	0	-0.3	-0.7	-0.5	-0.8
	Reduction (%)	100	-0.33	-350	-125	-800

(continues)

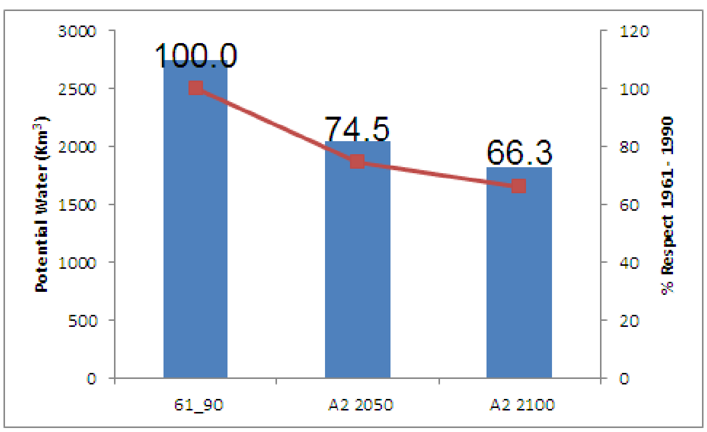
Table 16 (continued)

Country	Parameters	Baseline 1961-1990	Scenario A2 2050	A2 2100	B2 2050	B2 2100
The Bahamas	Water volume	10	7.7	6	7.1	0.6
	Deficit (‘000 m^3)	0	-2.3	-4	-2.9	-9.4
	Reduction (%)	100	-0.23	60.1	70.6	5.8
Saint Vincent & the Grenadines	Water volume	0,4	0,3	0,2	0,5	0,5
	Deficit (‘000 m^3)	0,0	-0,1	-0,2	0,1	0,1
	Reduction (%)	100,0	86,0	49,3	117,1	128,4
Trinidad and Tobago	Water volume	6.1	4.6	2	4	2.7
	Deficit (‘000 m^3)	0	-1.5	-4.1	-2.1	-3.4
	Reduction (%)	100	-0.25	-205	-52.5	-125.9
Suriname	Water volume	370.4	285.8	156	331.7	280.8
	Deficit (‘000 m^3)	0	-84.6	-214.4	-38.7	-89.6
	Reduction (%)	100	-0.23	-137.4	-11.7	-31.9
Guyana	Water volume	198.7	140.3	127.8	155	154.4
	Deficit (‘000 m^3)	0	-58.4	-70.9	-43.7	-44.3
	Reduction (%)	100	-0.29	0.36	0.22	0.22

Source: Author’s calculations

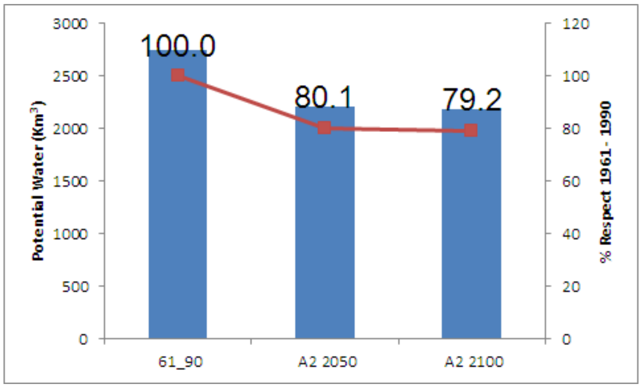
Note: Water volume ‘000 m^3;
Deficit= deficit of water volume respect to baseline in percentage terms (%):
Reduction (%):= Percentage reduction in water volume with respect to baseline.

FIGURE 61
CARIBBEAN. WATER VOLUMES. SCENARIOA2 RELATIVE TO BASELINE



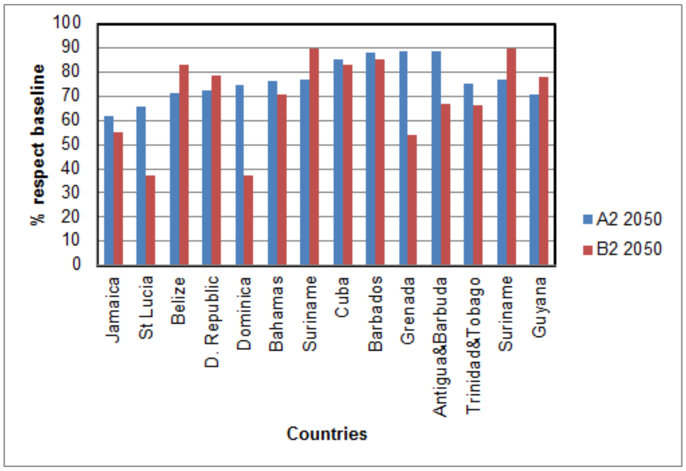
Source: Author’s calculations

FIGURE 62
CARIBBEAN. WATER VOLUMES. SCENARIO B2 RELATIVE TO BASELINE



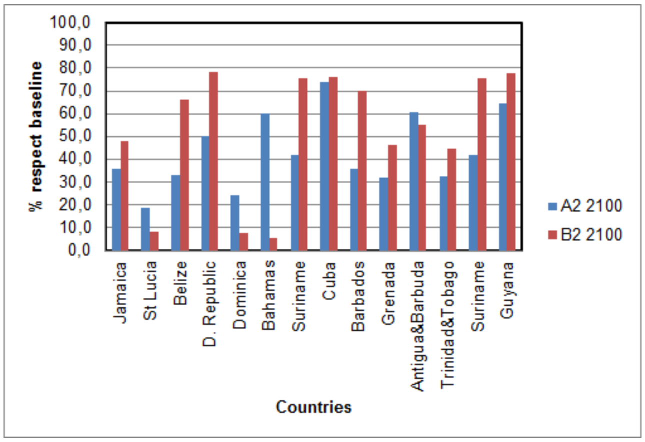
Source: Author's calculations.

FIGURE 63
POTENTIAL CARIBBEAN WATER RESOURCES RELATIVE TO THE BASELINE. SCENARIO A2 2050 AND B2 2050



Source: Author's calculations

FIGURE 64
POTENTIAL CARIBBEAN WATER RESOURCES RELATIVE TO THE BASELINE. SCENARIOS A2 2100 AND B2 2100



Source: Author's calculations

The changes in temperature and precipitation on the monthly scale (using averages for the Caribbean) under the IPCC A2 and B2 scenarios for the years 2050 and 2100 demonstrated that:

- every month, the temperature change surpassed 100 per cent, with more outstanding increases in the months of January, February and December (table 17 and figure 61).
- precipitation increased from February to March, and decreased slightly in the rest of the year (table 18 and figure 62).

TABLE 17

MONTHLY DISTRIBUTION ANNUAL AVERAGE OF TEMPERATURE FOR THE CARIBBEAN. COMPARATIVE ANALYSIS OF SCENARIOS A2 2050 & A2 2100 WITH RESPECT TO BASELINE

(Degrees Celsius, cubic metres and percentage change)

	Temperature			Precipitation			Temperature			Precipitation		
	Hist.	2050	%	Hist.	2050	%	Hist.	2100	%	Hist.	2100	%
January	24.3	25.7	105.7	103.5	56.3	54.4	24.3	27.2	112.1	103.5	131.7	127.2
February	24.8	26.0	104.9	76.9	72.7	94.5	24.8	29.3	118.3	76.9	93.7	121.8
March	26.2	27.6	105.2	70.6	62.1	88.0	26.2	31.1	118.6	70.6	101.1	143.2
April	26.9	28.6	106.3	101.4	55.8	55.0	26.9	30.3	112.5	101.4	112.7	111.1
May	27.1	28.6	105.6	190.3	220.5	115.9	27.1	31.0	114.5	190.3	319.1	167.7
June	27.6	29.2	105.9	199.3	157.0	78.8	27.6	30.8	111.6	199.3	156.6	78.6
July	27.7	29.5	106.5	184.6	130.6	70.7	27.7	31.8	114.7	184.6	112.0	60.7
August	27.1	28.8	106.2	199.6	165.8	83.1	27.1	30.7	113.1	199.6	155.9	78.1
September	27.4	28.8	105.2	222.1	145.5	65.5	27.4	30.8	112.5	222.1	180.2	81.1
October	26.0	27.6	106.2	230.2	218.1	94.7	26.0	29.5	113.3	230.2	170.3	74.0
November	24.5	26.3	107.5	175.7	111.9	63.7	24.5	29.0	118.2	175.7	130.7	74.4
December	25.2	27.2	108.0	125.9	87.0	69.1	25.2	28.8	114.1	125.9	106.3	84.4
Year	26.2	27.8	106.0	1 880.1	1 483.3	78.9	26.2	30.0	114.6	1 880.1	1 770.3	94.2

Source: Author’s calculations

TABLE 18

MONTHLY DISTRIBUTION OF AVERAGE ANNUAL PRECIPITATION FOR THE CARIBBEAN. COMPARATIVE ANALYSIS SCENARIOS B2 2050 & B2 2100 WITH RESPECT TO BASELINE

(Degrees Celsius, cubic metres and percentage change)

	Temperature			Precipitation			Temperature			Precipitation		
	Hist.	2050	%	Hist.	2050	%	Hist.	2100	%	Hist.	2100	%
January	24.3	25.4	104.5	103.5	65.1	62.9	24.3	25.7	105.8	103.5	97.9	94.6
February	24.8	25.8	104.0	76.9	67.4	87.6	24.8	26.0	104.8	76.9	75.5	98.2
March	26.2	27.3	104.2	70.6	63.6	90.1	26.2	27.6	105.3	70.6	88.0	124.6
April	26.9	28.3	105.2	101.4	60.6	59.8	26.9	28.6	106.3	101.4	127.6	125.8
May	27.1	28.3	104.4	190.3	211.6	111.2	27.1	28.6	105.5	190.3	205.2	107.8
June	27.6	28.9	104.7	199.3	165.8	83.2	27.6	29.2	105.8	199.3	170.3	85.4

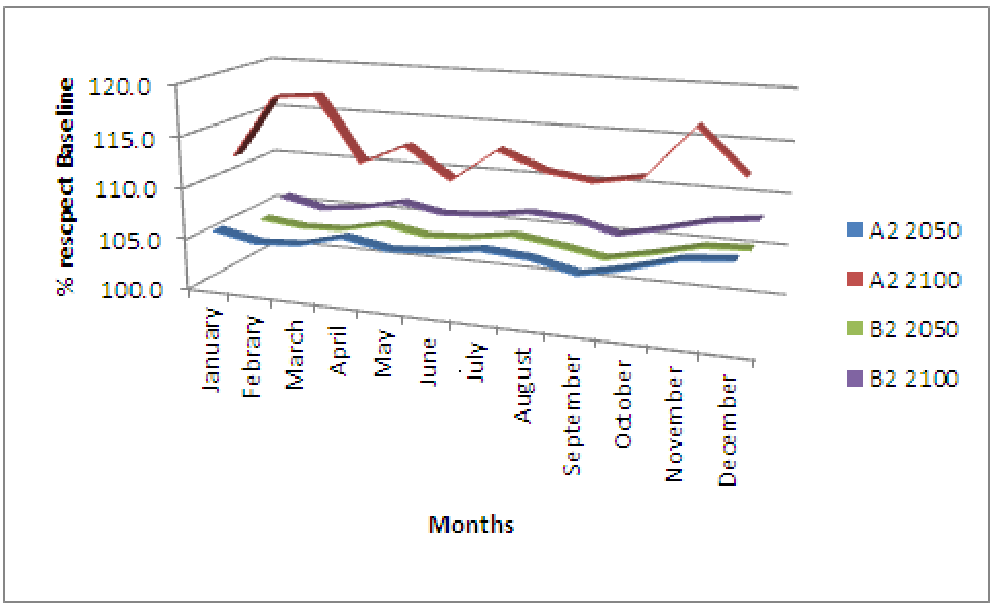
(continues)

Table 18 (continued)

	Temperature			Precipitation			Temperature			Precipitation		
	Hist.	2050	%	Hist.	2050	%	Hist.	2100	%	Hist.	2100	%
July	27.7	29.2	105.4	184.6	142.4	77.1	27.7	29.5	106.5	184.6	154.2	83.5
August	27.1	28.4	104.8	199.6	172.6	86.5	27.1	28.8	106.3	199.6	195.2	97.8
September	27.4	28.5	104.0	222.1	162.6	73.2	27.4	28.8	105.1	222.1	184.7	83.2
October	26.0	27.3	105.0	230.2	219.3	95.3	26.0	27.6	106.2	230.2	171.7	74.6
November	24.5	26.0	106.1	175.7	124.7	71.0	24.5	26.3	107.3	175.7	121.5	69.2
December	25.2	26.8	106.3	125.9	93.7	74.4	25.2	27.2	107.9	125.9	153.0	121.5
Year	26.2	27.5	105.0	1880.1	1549.3	82.4	26.2	27.8	106.1	1880.1	1744.9	92.8

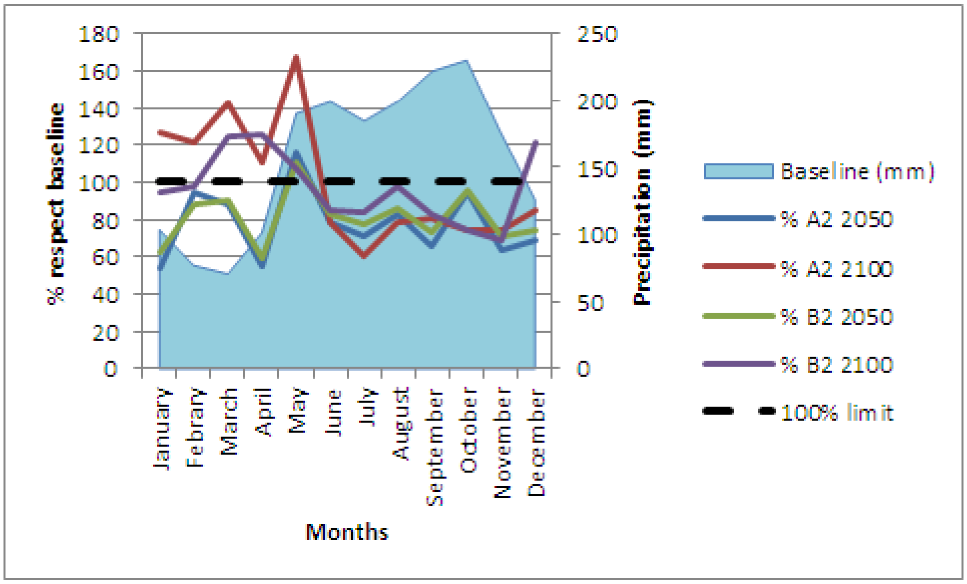
Source: Author's calculations

FIGURE 65
FORECAST MONTHLY TEMPERATURE CHANGE IN THE CARIBBEAN UNDER A2 AND B2 SCENARIOS WITH REGARD TO BASELINE SCENARIO, 2050 AND 2100
(Percentage)



Source: Author's calculations

FIGURE 66
FORECAST PRECIPITATION CHANGE IN THE CARIBBEAN UNDER A2 AND B2 SCENARIOS WITH REGARD TO BASELINE SCENARIO, 2050 AND 2100
(Percentage)



Source: Author's calculations

2. Groundwater

Sea-water intrusion is one of the main problems resulting from the rising sea levels caused by climate change. In the Greater Antilles – and in some countries of the Lesser Antilles – groundwater plays a fundamental role in the water supply and, due the insular nature of the Caribbean basin, major aquifers are in direct contact with the sea, causing saltwater intrusion and great loss of freshwater. Saltwater intrusion is produced by over-pumping, sea-level rise and storm surges. According to the statistical database *Aquastat* (FAO, 2010), groundwater is an important resource in Belize, Cuba, Jamaica, Haiti, the Dominican Republic and Suriname. In the Lesser Antilles, where many of the aquifers are freshwater lenses, the impact of saltwater intrusion is even more significant.

In the present report, there was no information available in relation to saltwater intrusion into the aquifers of the countries involved in the study. It would require very complex calculations and data to determine precisely the dynamics of the seawater/freshwater interface. Therefore, in cases where the aquifers were of great thickness, the geological parameters homogeneous and isotropic, and other considerations were met, the dynamics of the seawater/freshwater interface could be simplified by using the Ghyben-Herzberg model (figure 67). That equation would be applicable if the thickness of the mixture area was small compared with its depth and if the movement of the water was practically horizontal. The model does not consider vertical movements but, in aquifers of great thickness, that limitation does not produce important differences. In the Greater Antilles, given their geological characteristics, the aforementioned model could be used to determine the depth of the seawater/freshwater interface.

> "Continued growth of GHG emissions and associated global warming could well promote sea-level rise (SLR) of 1m-3m in the twenty-first century, with the possibility of a 5m increase if there is an unexpectedly rapid breakup of the Greenland and West Antarctic ice sheets." (Dasgupta and others, 2007).

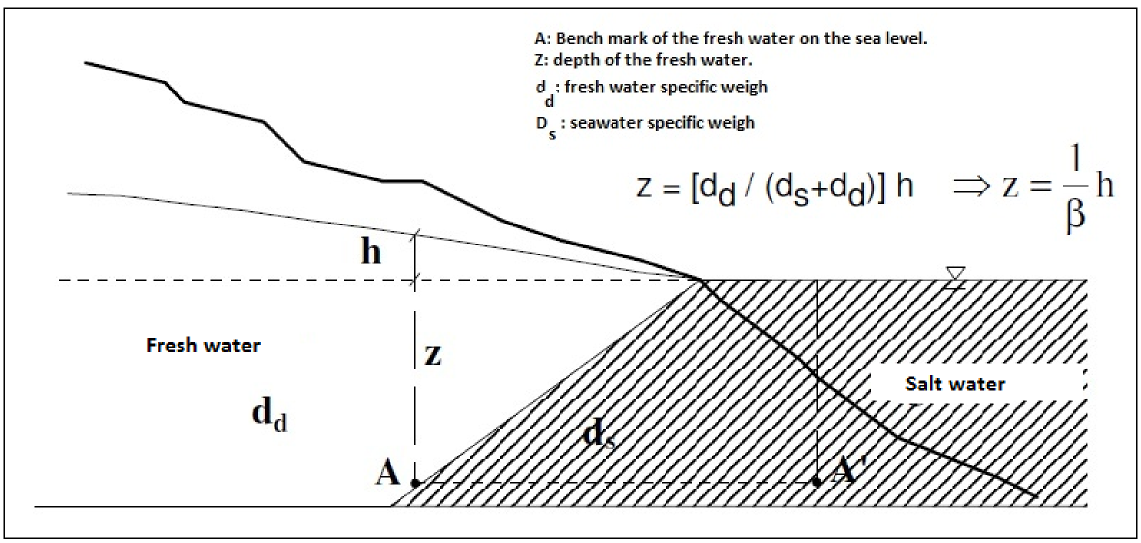
In the *Review of the Economics of Climate Change in the Caribbean* (RECCC) studies (ECLAC, 2011), an estimated sea-level rise (SLR) of two metres corresponded to the high-emissions scenario (A2) and a SLR of one metre corresponded to the low-emissions scenario (B2) (ECLAC, 2011). Considering a maximum sea-level rise of three metres, and using the Ghyben-Herzberg model, it was possible to predict that - exclusively with the change in sea level, and not including any analysis of the regime of pumping and extraction that would cause a reduction in the column of freshwater - the intrusion would come closer to the surface. For each centimetre that the column of freshwater decreased, the seawater would come 0.4 metres closer to the surface; for a sea-level rise of three metres, the ascension of seawater would be 120 m. In such a scenario, many of the current aquifers would disappear, or become unusable.

Saltwater intrusion, in the case of Cuba, and based on observed data over the past 40 years, penetrates between 0.3 km and 3 km on average per year, and rises in the vertical between 0.5 m and 5 m per year. In the First National Communication by Cuba to United Nations Framework Convention on Climate Change, the prediction was that sea-level rise, accompanied by a decrease in precipitation, would cause saltwater intrusion of four to five kilometres; meanwhile, the ascending pressure in the vertical direction would be at least 20 metres, provided there was no excessive pumping (Barros, 2001).

In the case of the Dominican Republic, based on the Ghyben-Herzberg model and field studies and without changes in aquifer management, it was expected that, during the next 30 years, the thickness of the aquifer would be reduced from 210 m to 83 m or 123 m (First National Communication Report of the Dominican Republic to UNFCCC, 2007a).

In Jamaica, saltwater intrusion has resulted in the loss of 100 million cubic metres of groundwater (10 per cent of the local water supply) annually.

FIGURE 67
THE GHYBEN-HERZBERG MODEL



Source: Falkland and Brunel (2009) "Review of Hydrology and Water resources of Humid Tropical Islands" Cambridge University Press

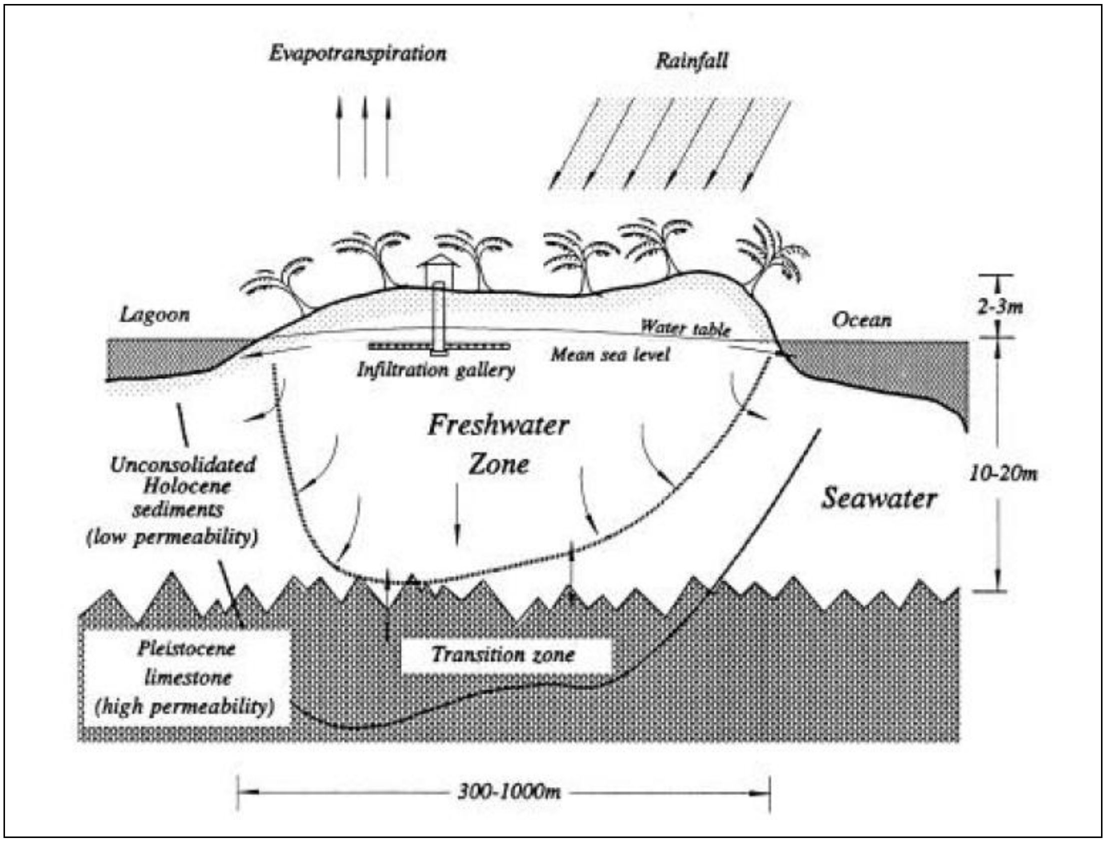
The situation has been more dramatic on islands where the aquifers have not been big enough, mainly where the aquifers were water lenses (Figure 68). The dynamics of groundwater in the aquifers within this structure are related directly to the recharge that produces precipitation and the fluctuations in sea level. The lens of freshwater floats on the seawater, and is generally thin, reason for which these aquifers are very vulnerable and require special management. For example, in the Bahamas,

> "…the extent of freshwater resources is limited to very fragile freshwater 'lenses' in the shallow karstic limestone aquifers. The 'freshwater' is actually derived from precipitation, lying on top of the shallow saline water as a 'lens', less than 5 feet from the ground surface. The freshwater lens aquifers throughout most of the country are

vulnerable to storm surges, causing saltwater inundation of the aquifers in many cases. These damaging storm surges occur during hurricanes, and other severe weather."[24]

In the Bahamas and Barbados, the freshwater lenses are affected periodically by salinity intrusions caused by over-pumping and excess evapotranspiration. Sea-level rise increases the intrusion of saltwater into the freshwater lens. Salinity levels have increased in several coastal aquifers in Trinidad and Tobago due to rapid drawdown exacerbated by sea-level rise. (Vergara W. and others, 2002).

FIGURE 68
CROSS-SECTION THROUGH A SMALL CORAL ISLAND SHOWING THE MAIN FEATURES OF A FRESHWATER LENS



Source: Falkland and Brunel, *Review of Hydrology and Water resources of Humid Tropical Islands*, Cambridge University Press, 2009

D. Water management

The fourth United Nations World Water Development Report (2012) asked, with regard to the future of the water resources:

> "How can water managers plan for, and adapt to, increasingly-uncertain future water-resource conditions? How can water users plan for, and adapt to, the uncertainty of future water supply and quality? How can the people who create, regulate and adapt governance structures, from local to global levels, within which we all operate and interact, meet the needs of all users living now and those who

[24] United States of America Army Corps of Engineers, *Water resources assessment of The Bahamas*, 2004.

will live in the future? This includes the needs of our environment, and the underprivileged and voiceless. How can society work together to increase levels of sustainability given an uncertain future change?"[25]

1. Aspects of water management

Water resource management is very complex. Many of its components would require periodic assessments to provide updated information. Some of the main elements to be considered are the following:

- Hydrology
- Water sources
- Systems of water supply and distribution
- Operational capacity and maintenance of water infrastructure
- Water quality
- Adequate legislation
- Strong national institutions
- Project-implementation capacity
- Ability to assess and tackle the impact of disasters caused by natural phenomena
- Assessing the impact of climate change and the cost of adaptation

The efficiency of operation and environmental sustainability of hydraulic systems – ensuring the hydraulic design, planning and management of water resources – depends on the proper evaluation and update of the abovementioned elements. Climate change is only one of the many elements to be considered in mid- and long-term water management planning.

The main impacts of climate change on water resources can be summarized, as expressed by Planos and others (2011), as follows:

a) Temperature impacts

The increase in air temperature will produce:

- an increase in water demand for both human activity and natural ecosystems, as a consequence of increases in evaporation, evapotranspiration, and animal and human moisture transpiration.
- deterioration of the water quality in reservoirs and supply systems, due to increased biological activity and decreases in the stability of chlorine content in water.
- deterioration of groundwater quality, due to accelerated processes of breakup, mainly in the karstic aquifers.

b) Precipitation impacts

- The reduction in precipitation would decrease the held capacity of reservoirs, and thus affect, not only its operational regime, but also the unregulated use of water, and the operation of water infrastructure designed for more storage or water extraction.

[25] United Nations, *World Water Development. Report 4,* United Nations Educational, Scientific and Cultural Organization, 2012.

- The increase in heavy precipitation could overcome hydraulic infrastructure designed to minimize impacts on extreme situations.
- The increase in the duration, frequency and intensity of droughts may lead to a collapse of the water -supply and -distribution systems.

c) Sea-level rise impacts

- Increase of saltwater intrusion
- Changes in aquifer management
- Impacts on the systems of drainage and coastal discharge
- Coastal floods.

2. Water management and climate change - precipitation reduction, temperature increases and saltwater intrusion

Climate change will affect the Caribbean in the form of reduced water resources due to several factors. Various options have been suggested for minimizing the effects of climate change on freshwater resources; the proposed options include:

- harvesting of rainwater
- more efficient use of surface water
- artificial recharge of aquifers with rainwater or treated wastewater
- more efficient management of existing water supply and hydraulic infrastructure.

Such decisions, before they can be made, must take into consideration the fact that that the design of the current hydraulic infrastructure and water management rules were based on the hydrological behaviour of the past. Thus, in order to project future water management—taking into account the forecast global changes, particularly climate change—it would be necessary to carry out a rigorous evaluation of the available water resources, using a conceptual hydrology that represented the present hydrological behaviour and the observed trends in the hydrometeorological variables. Only with such a hydrological assessment would it be possible to re-evaluate the design of the hydraulic infrastructure, the rules of exploitation, and the management policies. The main objectives would be water management in the context of a protection and conservation vision of water resources, and improving the efficiency of water use.

Another important consideration related to water management and climate change is the existence of different possible climate scenarios in the future. Thus, medium- and long-term hydraulic planning should project water scenarios adapted to each possible climate change scenario (Planos and others, 2011). The task of monitoring the tendencies of the hydrological variables towards one climate change scenario or another is a critical one.

3. Water supply in the Caribbean

There exist several ways of supplying water in the Caribbean. The main ones include:

- Water provided via water authority.
- Water provided via private water companies.
- Water transported by barge from one island to another.
- Fresh groundwater blended with brackish groundwater.
- Desalination.

- Water trucking from one part of an island to another.
- Rainwater harvesting.
- Bottled water for drinking and cooking.

Several evaluations of Caribbean water resources have been carried out that, besides characterizing the status of this natural resource in the Caribbean, may have evaluated policies and strategies and prepared recommendations to improve the protection, conservation and management of water.[26]

The evaluations have identified the following issues:

- A lack of data existed in the water resources area. A lack of compilation, organization, and availability of data, or a combination of the above, could also have contributed to this lack of data. The collection and monitoring of historical data has been weak.
- Comprehensive water resource evaluations needed to be conducted
- There was no wetlands policy. A framework for wetland inventory was required to promote the conservation and wise use of wetlands, and guidelines produced to encourage local participation in the management of wetlands.
- Regulating the resource through integrated groundwater management was recommended.
- Over-exploitation and lack of water-resource protection would have severe repercussions, such as health issues from waterborne diseases and much higher water costs.
- The greatly-increased cost of water would be due to treatment costs incurred as a result of groundwater contamination, from the necessity to use reverse osmosis, and/or bringing in more water by barge to meet demand.
- Proper land-use planning and regulations, which were currently lacking, would play an important role in the protection of the resource.
- Improved water laws and a national strategy on water were needed.
- National capacity for analysing climate and sea-level dynamics and trends needed to be strengthened.
- The immediate and potential impacts of global climate change needed to be determined.
- The areas particularly vulnerable to the adverse effects of climate change and sea level rise needed to be identified.
- An integrated management and planning framework needed to be developed for cost-effective responses and adaptation to the impacts of global climate change.
- Policy options and instruments needed to be developed to initiate a long-term programme of adaptation in vulnerable coastal areas.

[26] Water assessments have been carried out in Jamaica (United States Army Corps of Engineers, 2001), Dominica, Saint Kitts and Nevis and Barbuda (United States Army Corps of Engineers, 2004), the Bahamas (United States Army Corps of Engineers, 2004), Trinidad and Tobago (Trinidad and Tobago Water Resources Agency and Ministry of the Environment, 2001), and a general view on the Caribbean by Trotz, U., (2008) *Climate change and development in the Caribbean subregion*.

E. Scenarios, water demand estimates and water balances for the Caribbean

Information obtained from precipitation under A2 and B2 scenarios and inspecting the future with regard to climate change impact in the Caribbean allowed supply and demand estimates and water balances to be introduced. 'Water supply' was redefined as the result derived from precipitation estimates and the determination of potential resources for human use.

The task of determining water demand estimates and water balances has been conducted in two ways:

1) Estimating water demand from econometric models and the Caribbean Sea Ecosystem Assessment (CARSEA, 2007) Quality over Quantity (Q&Q) scenario (Annex 2)

2) Obtaining data from available scenarios to produce water balances and to guide adaptation policies. In this case, water supply data were obtained from IPCC A2 and B2 scenarios, and from the CARSEA Q&Q scenario. The water balance procedure explained very well the complexity of estimating water supply possibilities and demand since the same water might be used in different ways by different stakeholders.

The literature on estimating water demand, however, has focused on three main users – domestic (household), agricultural (irrigation), and industrial sectors. UNESCO (2003) posited that 10.0 per cent, 8.0 per cent, and 82.0 per cent of water resources in middle- and low-income countries were used, respectively, in the three sectors. While the other uses were important, comprehensive data - that would have allowed water demand for environmental and waste-disposal purposes to be estimated - were generally unavailable for Caribbean countries.

Industrial water is used for cooling in electric power generation, as process water, and as a medium for waste disposal in industry. Industrial water generates competition for alternative uses and drives up overall prices. Industrial water demand was expected to increase, both in terms of the quantity and proportion of total water withdrawn. It was estimated that 22.0 per cent of worldwide water use was industrial, but these data were irrelevant in the Caribbean context. (The World Business Council for Sustainable Development (WBCSD), 2009).

Water use for tourism has been studied[27] and was found to be much higher than domestic water use by inhabitants.[28]

The models used the average annual volume of community water and sewage disposal, in litres per person per day, as the dependent variable for residential water demand. Independent variables included marginal water and sewage prices, a variable to measure the difference in the demand for water resources based on housing and usage patterns, the average age of the population, household size, regional dummies, as well as climatic variables such as temperature, number of rainy days, and others. This was one of many ways of estimating residential water demand. In the study on the Turks and Caicos Islands, population estimates and scenarios were used to estimate water demand. This was less remarkable as a model, albeit useful (Box 1)

There are estimates for the models using a log-log linear specification with the squared (natural log) income to capture how water use was influenced by variances in income. Models also estimated the regression in a level-log linear specification.

[27] See United Nations Economic Commission for Latin America and the Caribbean (2011), *An assessment of the economic impact of climate change on the water sector in Turks and Caicos Islands*, LC/CAR/L.328.

[28] Arbués and others (2003) provided a survey of studies that estimated residential water demand. Most studies, it was argued, used time series analysis, but some combined regression analysis with neural network systems. (See LC/CARL/L.328, United Nations ECLAC, 2011).

The aforementioned studies discussed the types of explanatory variables and estimation techniques that provided robust results when there were long time series data. One of the problems with conducting empirical studies in the Caribbean has been the lack of long, consistent, and reliable data series. Given such limitations, the methodology for costing and forecasting the effect of climate change on water demand had to be adjusted.

In a recent regional study, Hutchinson (2010) estimated the cost of the impact of climate change on the water sector in a number of Caribbean countries – Aruba, Barbados, the Dominican Republic, Guyana, Jamaica, Montserrat, Netherlands Antilles, Saint Lucia, and Trinidad and Tobago. Hutchinson used a log-log specification and was able to employ panel techniques to estimate water demand by user – residential, industrial, and agricultural.

Galindo used a traditional equation (log-log panel data specification) to estimate the water demand for the three sectors (residential, agricultural and industrial) in Mexico. His study used population size, income level and relative price of water as explanatory variables. Another approximation to identifying the potential effect of climate change on water availability would be an econometric model of panel data that considered the natural availably of water as a function of temperature and rainfall.

In consequence, the present report has used an econometric model of panel data—similar to that used by Galindo (2010)—to estimate the availably of renewable water resources as a function of temperature and rainfall, but with the addition of gross domestic product (GDP) per capita to measure the impact of global activity levels on water resources.

The econometric model comprised 15 Caribbean countries and its specification responded to a panel of fixed effects:

Where: *i (I =1 to 15) and t (T = 1982; 1987; 1992, 1997; 2002; 2007; 2010).*

The methodology used for estimating water balances was applied to selected Caribbean countries where enough information was available or compiled to obtain a balance.[29] The medium scenario was based mainly on the baseline scenario while the low scenario suggested an important precipitation reduction (Caribbean Water Outlook, 2010). Tables 19 to 22 refer to water balances for selected countries. Results of the model in general, and estimates of sectoral water demand, can be found in Annex 2.

TABLE 19
WATER BALANCE FOR CUBA
(Thousands of cubic metres)

	Cuba	BAU			SRES	
	2010	High	Mean	Low	A2	B2
Rainfall	114 559	274 942	114 559	57 280	107 734	106 438
Evapotranspiration	64 497	154 792	64 497	32 248	65 312	64 484
Surface water runoff	30 129	72 310	30 129	15 065	30 165	29 803
Groundwater discharge	19 933	47 840	19 933	9 967	12 282	12 134
Water resource: Total renewable	38 120	91 488	38 120	19 060	35 849	35 418
Exploitable surface water	9 192	22 062	9 192	4 596	17 649	8 541

(continues)

29 The Author used different data sources: FAO AQUASTAT, country statistical yearbook, National Oceanic and Atmospheric Administration (NOAA), Global Water Partnership, Caribbean Water Outlook (mainly for the higher scenario) and many other sources.

Table 19 (continued)

	Cuba	BAU			SRES	
	2010	High	Mean	Low	A2	B2
Exploitable groundwater	4 475	10 741	4 475	2 238	4 209	4 158
Total exploitable	13 668	32 802	13 668	6 834	21 858	12 699
Extraction	7 588	18 210	7 588	3 794	12 135	14 167
Non-agricultural sector	2 849	6 022	3 100	2 056	4 624	4 933
Industrial	751	1 803	751	376	1 201	1 403
Tourism	926	1 406	1 176	1 094	1 548	1 342
Municipal	1 172	2 814	1 172	586	1 875	2 189
Agricultural sector:	5 664	13 594	5 664	2 832	9 059	10 576
Total demand	8 514	19 616	8 764	4 888	13 683	15 509
Balance	-926	-1 406	-1 176	-1 094	-1 548	-1 342

Sources: FAO AQUASTAT, country statistical yearbook, National Oceanic and Atmospheric Administration (NOAA), Global Water Partnership, Caribbean Water Outlook, and other

TABLE 20
WATER BALANCE FOR THE DOMINICAN REPUBLIC
(Thousands of cubic metres)

	The Dominican Republic	Business As Usual			SRES SCENARIOS	
	2010	High	Mean	Low	A2	B2
Rainfall	68 620	164 688	68 620	34 310	53 345	58 857
Evapotranspiration	38 642	92 740	38 642	19 321	41 347	41 090
Surface water runoff	18 038	43 292	18 038	9 019	6 130	8 939
Groundwater discharge	11 940	28 657	11 940	5 970	5 868	8 939
Water resource: Total renewable	21 000	50 400	21 000	10 500	16 325	18 012
Exploitable surface water	2 154	5 171	2 154	1 077	1 675	1 848
Exploitable groundwater	11 060	26 545	11 060	5 530	8 598	9 487
Total exploitable	13 215	31 716	13 215	6 607	10 273	11 335
Extraction	5 800	13 919	5 800	2 900	4 509	4 974
Non-agricultural sector	2 606	4 729	4 107	3 360	5 942	5 160
Industrial	80	123	107	88	185	161
Tourism	1 045	1 343	1 122	1 045	1 656	1 468
Municipal	1 481	4 606	4 000	3 272	5 757	5 000
Agricultural sector:	2 241	5 378	2 241	1 120	1 742	1 922
Total demand	4 846	10 107	6 347	4480	7 684	7 082
Water balance	953	3 812	-548	-1 581	-3 175	-2 108

Sources: FAO AQUASTAT, country statistical yearbook, National Oceanic and Atmospheric Administration (NOAA), Global Water Partnership, Caribbean Water Outlook

The construction of water balances (water availability and water supply with regard to water demand) in the present section used a different approach to the section on the hydrological balance methodology (page 40) and water balance baselines (page 41) where the resource base was assessed. In the case of water balances in the present section, demand was estimated from the model results (elasticity), and supply was derived from hydrological balances adjusted to country size.

TABLE 21
WATER BALANCE FOR JAMAICA
(Thousands of cubic metres)

	Jamaica		BAU			SRES	
	1990	2010	High	Mean	Low	A2	B2
Rainfall	21 212	22 540	54 096	22 540	11 270	17 215	18 191
Evapotranspiration	11 945	12 693	30 463	12 693	6 346.415	11 024	11 294
Surface water runoff	5 576	5 925	14 220	5 925	2 962.546	3 615	4 184
Groundwater discharge	3 691	3 922	9 413	3 922	1 961.04	2 582	2 729
Water resource: Total renewable	9 404	9 404	22 570	9 404	4 702	7 632	8 065
Exploitable surface water	666	666	1 598	666	333	541	571
Exploitable groundwater	3 419	3 419	8 206	3 419	1 709.5	2 775	2 932
Total exploitable	4 085	4 085	9 804	4 085	2 043	3 315	3 503
Extraction	928	612	1 470	612.4	306	753	796
Non-agricultural sector	1365	1 082	2 121	1 368	1 100	1 650	1 489
Industrial	346	138	322	134	67	165	174
Tourism	337	669	1 154	966	899	1 154	966
Municipal	682	275	645	269	134	330	349
Agricultural sector	1 338	200	503	209	105	258	272
Total demand	2 703	1 282	2 624	1 578	1 205	1 907	1 761
Water balance	1 382	-669	-1 154	-966	-899	-1 154	-965

Sources: FAO AQUASTAT, country statistical yearbook, National Oceanic and Atmospheric Administration (NOAA), Global Water Partnership, Caribbean Water Outlook

TABLE 22
WATER BALANCE FOR BELIZE
(Thousands of cubic metres)

	Belize	BAU			SRES	
	2010	High	Mean	Low	A2	B2
Rainfall	39 160	93 984	39 160	19 580	37 572	37 903
Evapotranspiration	19 972	47 932	19 972	9 986	20 336	20 243
Surface water runoff	10 299	24 717.79	10 299	5 150	9 769	9 855
Groundwater discharge	6 814	16 353	6 814	3 407	7 514	7 960

(continues)

Table 22 (continued)

	Belize	BAU			SRES	
	2010	High	Mean	Low	A2	B2
Water resource: Total renewable	18 550	44 520	18 550	9 275	17 798	17 955
Exploitable surface water	1 175	2 820	1 175	587	1 127	1 137
Exploitable groundwater	6 266	15 037	6 266	3 133	6 012	6 065
Total exploitable	7 440	17 857	7 440	3 720	7 139	7 202
Extraction	1 723	4 135	1 723	862	1 653	1 668
Non-agricultural sector	1 467	3 422	1 473	778	1 436	1 429
Industrial	1 263	3 031	1 263	631	1 212	1 222
Tourism	88	114	95	88	114	95
Municipal	115	277	115	58	111	112
Agricultural sector:	345	827	345	172	331	334
Total demand	1 811	4 249	1 818	950	1 767	1 763
Water balance	-88	-114	-95	-88	-114	-95

Sources: FAO AQUASTAT, country statistical yearbook, National Oceanic and Atmospheric Administration (NOAA), Global Water Partnership, Caribbean Water Outlook

Despite having some isolated results for specific scenarios/sectors that might have appeared contradictory, the general trend was relevant for the design of adaptation policies. Annex tables A9 to A12 (annex 2) show the demand for water by different sectors (residential, agricultural, industrial and tourism). The highest increase in water demand was considered to be under scenario Q&Q.

The most relevant result derived from the present study was that a framework has been developed that would link resource-based availability with demand estimates, one that might be improved with increasing availability of country data and some refining of the model.

V. Cost benefit analysis of adaptation and mitigation: levelized costs and multi-criteria assessment

The design of adaptation options for shortages in water availability was a complex task, due both to the role of water in society and the economy, and the choices that needed to be considered. Many options designed needed to take into consideration the monetary costs and energy consumption involved. There were little or no monetary data for most of the alternatives, and those that did exist were either controversial or dependent on local markets. Hugh differences also persisted because of economies of scale that made decisions uncertain. The increasing level of energy use, volatile fossil fuel prices and dependence on them needed to be carefully assessed, and emissions reduction studies considered.

As a result, adaptation alternatives to mitigate the impact of climate change on water resources differed from adaptation in other sectors. Traditional adaptation could also be either short-term or long-term.

A portfolio of adaptation (and mitigation) measures can diminish the risks associated with climate change. Such adaptation measures can be as follows:

- Purely technical (e.g. infrastructure defenses against sea-level rise and saltwater intrusion, improved water use efficiency, demand side management).
- Behavioural (e.g. changed water use choices).
- Managerial (e.g. changed water supply conditions and practices).
- Policy (e.g. grid extension regulations, water catchment devices construction for isolated systems).

Adaptation activities can be categorized as shown in table 23.

TABLE 23
ADAPTATION ACTIVITIES

Category	Description
Relocation	Shifting current activities or structures to another location
Acceptance of loss	Not implementing vulnerability and adaptation measures and bearing the burden of loss.
Prevention of loss	Reduce vulnerability to climate change by engineering or other measures.
Activity changes	Replace current activities with more sustainable ones
Spreading of losses	Distribution of the burden of losses through property insurance, Government relief and other measures.
Research and monitoring	To inform the adaptation process, improve knowledge of processes by using data and information and observe trends.
Public awareness and education	Sensitize and increase the population's awareness, including selected target audiences, to obtain their support or change their behaviour

Source: UNEP, 2010, Latin America and the Caribbean 2010. Environment Outlook, Geo Outlook 3

The present study follows the adaptation framework outlined in table 24.

TABLE 24
ADAPTATION FRAMEWORK

Adaptation options		
Supply side	Policy tools	Demand side
• Piped water import	• Differentiated water pricing	• Recycling and wastewater reuse
• Direct water import	• Water and wastewater legislation	• Tech improvements (smart water use devises)
• Indirect water import (crops)	• Law enforcement policies	• Crop policies
• Desalination		
• Water catchment devises		
• Update and monitoring of water supply infrastructure		
• Use of non-potable water systems		
• Potable water enhancement techniques		

Source: Compiled by Author

From those alternatives, desalination, water catchment devices, updating and monitoring of potable water systems (grids), wastewater reuse, and crop policies have been studied under various conditions using different tools. Finally, a multi-criteria assessment was conducted so as to include criteria other than monetary ones.

A. Desalination

Desalination to obtain freshwater for human use requires that salt contained in water not exceed 500 parts per million (ppm) (from 35 000 ppm in sea water to 10 000/ 5000 ppm contained in brackish water). Desalination is an alternative to water supply by means of piped, rail and truck supply.

Reverse osmosis (RO) is a process that uses selective membranes and is widely in use in several regions throughout the world. RO uses a membrane-separation process, in which pure water is "forced" out of a concentrated saline solution by flowing through a membrane at a high static trans-membrane pressure difference. This pressure difference must be higher than the osmotic pressure between the solution and the pure water. The saline feed is pumped into a closed vessel where it is pressurized against the membrane. As a portion of the water passes through the membrane, the salt content in the remaining brine increases. At the same time, a portion of this brine is discharged without passing through the membrane.

Desalination is known to be an energy-intensive process, requiring mainly low-temperature steam for distillation and high-pressure pumping power for membrane systems. Traditionally, fossil fuels—such as oil and gas—have been the major energy sources. However, fuel price hikes and volatility, as well as concerns about long-term supplies and environmental release, is prompting consideration of alternative energy sources for seawater desalination, such as nuclear desalination[30] and the use of renewable energy sources.

Added to this, the coupling methods between power and desalination units can also vary, so there is clearly need for a performance- and cost- analysis tool to assist in design selection and optimization.

The present report has considered desalination by means of renewable energy for the supply of power and steam as a proposed adaptation measure. The climatic characteristics of the Caribbean favour the use of renewable resource technologies. Average wind speed at the 10-metre altitude was estimated to be 5.7 metres per second, while average solar radiation was 5 kWh/m^2year.

TABLE 25

SUMMARY OF WATER DESALINATION USING DIFFERENT ENERGY TECHNOLOGIES (DIESEL AND HYBRID SYSTEM)

Capacity plant inverse osmosis plant	Water cost Diesel	Water cost (US$/$m^3$) Hybrid power plant (diesel, wind, battery and convertor)			Water cost hybrid power plant diesel, photovoltaic panel, battery and convertor	Water cost (US$/m3) hybrid power plant diesel, wind, photovoltaic, battery and convertor		
(m^3/day)	(US$/$m^3$)	Wind speed (7 m/sec)	Wind speed (6 m/sec)	Wind speed (5 m/sec)	(US$/$m^3$)	Wind speed (7 m/sec)	Wind speed (6 m/sec)	Wind speed (5 m/sec)
100	0,87	0,83	0,85	0,88	0,88	0,83	0,87	0,88
500	0,74	0,73	0,74	0,74	0,74	0,73	0,74	0,74
1000	0,63	0,69	0,70	0,71	0,71	0,69	0,70	0,63
10000	0.100	0.109	0.111	0.113	0.113	0.109	0.111	0.100
30000[1]	0.041	0.045	0.046	0.047	0.047	0.045	0.046	0.041
40000	0.033	0.036	0.037	0.037	0.037	0.036	0.037	0.033

Source: J.F. Zuñiga and others, “Evaluación de diferentes fuentes de energía renovable a utilizar en la desalinización en Cuba.” Proyecto Nacional Factibilidad de la desalinización de agua de mar en Cuba, CUBAENERGIA, CITMA, La Habana, Cuba., 2008

Note that the costs of 100 m^3/day, 500 m^3/day and 1000 m^3/day were estimated from the HOMER software used by Zuñiga and others for scales of 10 000 m^3/day, 30 000 m^3/day and 40 000 m^3/day. For economies of scale, the value for $\alpha = 0.8$ was used.

1. Energy options considered for systems of sea and brackish water desalination

Desalination: Facility capacity: 40 000 m^3/day at a discount rate of 7 per cent.

[30] The Desalination Economic Evaluation Program (DEEP) is a widely used spreadsheet tool originally developed for the International Atomic Energy Agency (IAEA) by General Atomics and later expanded in scope by IAEA.

TABLE 26
OPTION 1: HYBRID DIESEL/WIND ENERGY

Unit capital cost ($/m^3)	$0.036	$0.033	$0.003
Total capital cost (1000 $)	$525 600	$481 800	$43 800
Lifetime (years)	35	35	0.0
Total investment cost (1000 $)	$38 402	$35 201	$3 200
Variable O&M cost ($/m^3)	$2 688	$2 464	$224
Total annual O&M cost ($)	$31 397 086	$35 975 828	-$4 578 742
Annual fuel cost ($)	$0	$17 990	-$17 990
Total annual cost ($)	$31 435 488	$36 029 020	-$4 593 532

Source: Author's calculations

TABLE 27
OPTION 2: MITIGATION WITH PHOTOVOLTAIC AND HYBRID DIESEL

Unit capital cost ($/m^3)	$0.037	$0.033	$0.004
Total capital cost (1000 $)	$540 200	$481 800	$58 400
Lifetime (years)	35	35	0
Total investment cost (1000 $)	$39 468	$35 201	$4 267
Variable O&M cost ($/m^3)	$2 763	$2 464	$299
Total annual O&M cost ($)	$32 269 227	$35 975 828	-$3 706 600
Annual fuel cost ($)	$0	$17 990	-$17 990
Total annual cost ($)	$32 308 696	$36 029 020	-$3 720 324

Source: Author's calculations

TABLE 28
OPTION 3: MITIGATION WITH GEOTHERMAL ENERGY

Unit capital cost ($/m^3)	$0.076	$0.033	$0.043
Total capital cost (1000 $)	$1 109 600	$481 800	$627 800
Lifetime (years)	40	35	5
Total investment cost (1000 $)	$78 442	$35 201	$43 240
Variable O&M cost ($/m^3)	$152	$40	$112
Total annual O&M cost ($)	$1 775 360	$584 000	$1 191 360
Annual fuel cost ($)	$0	$17 990	-$17 990
Total annual cost ($)	$1 853 802	$637 192	$1 216 610

Source: Author's calculations

TABLE 29

LEVELIZED COST OF ENERGY OPTIONS FOR SYSTEMS OF SEA AND BRACKISH WATER DESALINATION

(Thousands of United States dollars)

	Incremental (Levelized) Cost of Energy (LCOE) (Reference option: Diesel)					
	Total investment cost(1000 $)			Annual total cost (1000 $)		
Technology	r=7%	r=4%	r=1%	r=7%	r=4%	r=1%
Hybrid diesel/wind energy	3 383	2 347	1 489	-4 855	-3 373	-2 147
Hybrid diesel/photovoltaic	58 400	3 129	1 986	-3 932	-2 733	-1 741
Geothermal energy	46 019	30 247	17 411	1 219	1 204	1 191

Source: Author's calculations

Note: r= discount rate

B. Economies of scale

For the same technology, direct equipment costs show economies of scale with respect to installed capacity in the following relationship:

INVB/INVA = (KB/KA)α (1)

where INVX = total investment in plant or equipment X

KX = Capacity of plant or equipment X

α = Coefficient of scale economy (<1)

This expression means that investment increases in a smaller proportion than the increase in planned capacity, and that revenue will increase with capacity growth to a certain point α, which represents the scale effect. Economies of scale exist in almost all industrial projects where α lies between 0.8 and 0.7: this means that, if the capacity is doubled, the additional investment would require only smaller increases in investment (table 30).

TABLE 30

EFFECT OF DOUBLING OF CAPACITY IN INVESTMENT

K_B/K_A	INV_B/INV_A $\alpha = 0.7$	INV_B/INV_A $\alpha = 0.8$
1.5	1.33	1.38
2.0	1.62	1.74
2.5	1.90	2.08
3.0	2.16	2.41
4.0	2.64	3.03

Source: Compiled by Author

Equation (1) can be expressed in terms of a unit of investment (C):

CBKB/CAKA = (KB/KA)α ,

This equation is equivalent to:

CA/CB = (KB/KA) 1- α

The relationship of scale economies can be used to estimate investment costs when only the cost of identical systems of different capacity is known. For instance, should the capacity of a desalination facility double, capital investment would increase by between 62% and 74%, implying important savings in resources. This analysis would apply to each case in which technological costs were relevant to the investment, given that small island technical development requires that economies of scale be sought.

1. Adaptation in agriculture: changing crop policies

Initiatives that seek to change traditional crops, like rice, for others that demand less water and have more capacity to adapt to droughts—and probably increase profits—need to be inspected. That is the challenge of replacing rice with bean crops. Rice, together with bananas, is one of the crops having the highest demand for water. Rice is an important crop for the Caribbean. The Dominican Republic is the largest Caribbean rice producer, and rice is a significant source of income for Guyana and Belize. Rice is a main, traditional component of diet in most Caribbean countries.[31]

In Barbados, Jamaica and Cuba, irrigation is the second-highest water consumer. In Barbados, for example, irrigation uses 16.2 million m^3 per year. In the Dominican Republic, irrigation agriculture was responsible for more than 85 per cent of water use in 2001. In Jamaica, water demand for the agricultural sector was estimated to be 60 per cent of total water demand; and, in Cuba, about 52 per cent of water resources were used in 2007 for irrigating rice, sugarcane, fresh vegetables, citrus and root crops.

The general purpose of the proposed adaptation is to diversify production, thereby reducing water use and generating increased incomes. A change in cultivation practices would be to reduce from two yearly rice harvests to a single one. The economic and social feasibility is based on the estimation of costs and benefits arising from this policy, comparing a baseline of two rice harvests yearly with a second scenario combining one harvest of rice with one harvest of beans. Table 31 demonstrates the results of the cost/benefit analysis.

TABLE 31
COSTS AND BENEFITS OF PROPOSED RICE CULTIVATION ADAPTATION STRATEGY
(United States dollars per hectare per year)

	Baseline (2 rice harvests per year)	Adaptation (1 rice harvest, 1 bean harvest)
Labour costs (including labour for yielding cultivating, fertilizing and other crop-related jobs but also for preparing conditions for groundwater pumping.	1 053	682
Machinery and equipment (including all machinery needed for two rice harvests per year)	241	277
Others (seeds, fertilizers pesticides and water)	1 174	555
Harvesting and trading	175	103
Soil analysis, transportation, additional equipment etc.	24	7
Technical assistance and capacity-building (for introducing a new crop and efficient water use)		18
Total costs	2 667	1 642

Source: Compiled by Author

Wet harvest incomes are larger than incomes in the dry season under rice cultivation: thus, the substitution of a dry harvest of bean crops instead of rice would suggest increased revenue. Benefits, as avoided costs, would include water savings at a rate of approximately 4 000/m^3/ha/yr (tables 32 and 33).

31 United Nations Environment Programme (UNEP), *Climate Change in the Caribbean and the Challenge of Adaptation*, Regional Office for Latin America and the Caribbean, (2008.

TABLE 32
WATER USE IN CARIBBEAN AGRICULTURE AND DIRECT BENEFITS PER HECTARE

Yields	Yield (tons/ha.)	Water use (m^3/ha.)	Market price US$/ton
Rice dry harvest	2.61	5 950	560- 590
Rice wet harvest	3.23	9 566	560- 590
Beans	1.2	1 983	1430- 2140

Source: Author's calculations

TABLE 33
DIRECT BENEFITS PER HECTARE
(US$ per hectare)

	Lower price limit	Higher price limit
Rice (two harvests)	3 270	3 446
Rice and bean crops	3 529	4 474
Incremental benefits	259	1 028

Source: Author's calculations

Cost benefit analysis indicated a net added value of 2.7 (> 1) over ten years using a discount rate of 4 per cent per 100 hectares. The change from two rice harvests to only one mixed with a bean crop suggested water savings of 758.3 thousand m^3 of water and a cost reduction of US$ 102,000 in water savings to the amount of 0.135 US$/$m^3$.

2. Water harvesting and the construction of small water reservoirs

Almost 80 per cent of water use in the Caribbean is devoted to agriculture. High technology irrigation is an important condition for good agricultural performance. The construction of small dams and reservoirs is basic both to helping farmers to increase crop yields and to stabilizing social benefits by means of public investment. Small dams and reservoirs may lessen the need for farmers to use water from the grid and increase water-use efficiency. One of the main problems of small-farmer agriculture is low physical productivity due to the lack of appropriate resources and technology. A secure water supply that may circumvent droughts and improve water quality creates the conditions for a significant improvement in physical output. Thus, one key adaptation option is the construction of small reservoirs.

a) Cost benefit analysis for the construction of small reservoirs and dams

Two options were inspected: (i) baseline option and (ii) adaptation option, in this case, the construction of reservoirs and small dams.[32]

Costs:

a) Reservoir or small dam construction: cost estimates depend on water storage capacity. A water storage capacity of 1,300 m^3 would be sufficient to service 1.5 hectares.
b) Installation of a high-technology irrigation grid.
c) Operation and maintenance costs over the equipment lifetime.
d) Other maintenance costs associated with operation.

[32] Elsa Galarza, Milton von Hesse (2011). *Costos y Beneficios de la Adaptación al Cambio Climático en América Latina*. The study presents a cost benefit result of the adaptation option on the basis of private versus public investment.

e) Technical assistance for optimal use and performance.

The results are shown in table 34 and table 35.

TABLE 34
COSTS PER HECTARE AND DIRECT COSTS ASSOCIATED WITH AGRICULTURAL RESERVOIR PROJECT
(United States dollars per hectare)

Option	Cost per ha. (US$)
Reservoir construction	1 667
Irrigation grid	289
Operation and maintenance costs	33
Other maintenance costs associated with operation	222
Technical assistance	63

Source: Author's calculations

TABLE 35
DIRECT COSTS ASSOCIATED WITH A 42-HECTARE AGRICULTURAL PROJECT

Years	Reservoir	Irrigation grid	Other maintenance costs	Operation and maintenance costs	Technical assistance
0	-46 676	-12 136			
1				-1 386	-2 646
2				-1 386	-2 646
3			-9324	-1 386	-2 646
4				-1 386	-2 646
5			-9 324	-1 386	-2 646
6				-1 386	-2 646
7			-9 324	-1 386	-2 646
8				-1 386	-2 646
9			-9 324	-1 386	-2 646
10				-1 386	-2 646

Source: Author's calculations

Benefits:

a) Improved yields in year Q_1 with respect to year Q_0, with respect to C numbers of harvests given by the formula: productivity (physical output)

$$\text{Productivity Gain} = \sum_{i}^{n} (\text{Pculti} * \text{Q1culti} * \text{C1culti} - \text{Pculti} * \text{Q0culti} * \text{C0culti})$$

b) Water saving: due to improved irrigation methods, improved water-use efficiency suggests less water use (replacing irrigation by means of the inundation technique). Benefits from water savings depend on local water tariffs.

$$\text{Water Saving} = \sum_{i}^{n} (\text{Pwaterm3} * \text{Q0water culti} - \text{Pwaterm3} * \text{Q1water culti})$$

TABLE 36
COST BENEFIT ANALYSIS FOR THE AGRICULTURAL RESERVOIRS PROJECT: NET PRESENT VALUE AT DISCOUNT RATES OF 4% AND 1% AND 10-YEAR LIFETIME

			Net present value estimate (50 ha.)	
Year	Investment	Net income	NPV	
0	-58 812.0		r=4%	r=1%
1		176 677.4	-2 944.1	58 072.4
2		176 677.4		
3		167 353.4		
4		176 677.4		
5		167 353.4		
6		176 677.4		
7		167 353.4		
8		176 677.4		
9		167 353.4		
10		176 677.4		

Source: Author's calculations

Economic viability would depend on the discount rate r over a longer lifetime of the project. Estimated water savings over ten years are around 180.8 thousand m^3, with a total savings of 1.8 million m^3, with an avoided cost of 0.32 US$ per m^3.

3. Wastewater reuse and recycling

Empirical observations on general trends in land use and sanitation have indicated that elevated levels of organic matter, faecal coliform bacteria, nutrients, pesticides, fertilizer, hydrocarbons, and other pollutants likely to be found in surface waters as wastewater from agriculture, industry and urban areas, are impacting the health and functioning of ecosystems negatively in many parts of the Caribbean, affecting coastal areas and marine life.

Wastewater treatment has been beset by the common problems of low efficiency and not accounting for the benefits of avoided water use. A typical wastewater treatment plant with a capacity of 10 litres per second (540 cubic metres per day) can serve a population of 5 000 inhabitants, or small industries, hotels and industrial facilities. Investment costs for these technologies (and for recycling) are 30-40 per cent lower than the cost of desalination plants.

Using the economies of scale theory, cost savings of US$ 5 per 1 000 m^3 may be obtained; between US$ 0.32 /m^3 and US$ 0.05 /m^3 would be obtained with operational costs equivalent to 7 per cent of capital costs and a lifetime of 20 years. Benefits considered were the possibility of water reuse for agricultural purposes, and avoided energy costs. The estimated water use for a population of 5 000 inhabitants, would be between 145 m^3 and 170 m^3 per year (table 34). NPV was negative with a high discount rate, thus the maximal discount rate suggested would be 2 per cent in this case.

4. Water harvesting and catchment

With growing demand for water and increasing costs of water supply, a number of Caribbean countries have ventured into non-traditional water-resource harvesting for irrigation. Rainwater harvesting, in the form of rooftop or communal catchments, is being undertaken on several island in the Caribbean. For some years now, many Caribbean countries (Jamaica, Barbados, Martinique, Turks and Caicos Islands) have considered rainwater harvesting to be important for decentralized water supply. The practice lost importance due to improved supply from other sources, and health considerations. Currently, the Caribbean Environmental Health Institute, supported by UNEP, has

TABLE 37
NET PRESENT VALUE OF WATER TREATMENT PLANT COST USING DISCOUNT RATES OF 1% & 4%

	Investment costs	O&M Costs	Income	Net income
0	-93.66			
1		-6.556	215.7	209.1
2		-6.556	215.7	209.1
3		-6.556	215.7	209.1
4		-6.556	215.7	209.1
5		-6.556	215.7	209.1
6		-6.556	215.7	209.1
7		-6.556	215.7	209.1
8		-6.556	215.7	209.1
9		-6.556	215.7	209.1
10		-6.556	215.7	209.1
11		-6.556	215.7	209.1
12		-6.556	215.7	209.1
13		-6.556	215.7	209.1
14		-6.556	215.7	209.1
15		-6.556	215.7	209.1
16		-6.556	215.7	209.1
17		-6.556	215.7	209.1
18		-6.556	215.7	209.1
19		-6.556	215.7	209.1
20		-6.556	215.7	209.1
	Net present value			
	4%	-8.3		
	1%	8.8		

Source: Compiled by Author

developed a national, rainwater-harvesting, promotional programme for the pilot island of Grenada, and a programme for all Caribbean countries (Chase, 2008).

The results show the rationale of sensitivity analysis when using units of different capacity and different discount rates. These results can be adapted to country data and performance (table 38).

TABLE 38
CONSTRUCTION COST OF ELEVATED, STORM-RESISTANT WATER RESERVOIRS

Capacity unit (m³)	1 400	1 500	500	125
Lifetime (years)	25	25	25	25
		Discount rate: 12%		
Capital costs (US$ 000)	2 800	2 497.4	2 698.1	1 802.7
O&M costs (US$ 000)	50	46.8	139.3	559.6
Energy cost (US$ 000)				10.7
NPV of capacity unit (m³)	401 500	430 145	143 382	35 845
NPV O&M (US$)	2 941	2 753	8 195	32 917
NPV energy (US$)				15 735
Discounted cost of investment (US$/m³)	6.97	5.81	18.82	77.37
Discounted costs of O&M (US$/m³)	0.007	0.006	0.057	0.918
Discounted costs of energy (US$/m³)				0.439
Unit capacity costs (US$/m³)	6.977	5.812	18.875	78.7
		Discount rate: 4%		
Capital costs (US$ 000)	2 800.0	2 497.4	2 698.1	1 802.7
O&M costs (US$ 000)	50.0	46.8	139.3	363.6
Energy costs (US$ 000)				10.7
NPV of capacity unit (m³)	2 743 042	2 743 042	2 743 042	2 743 042
NPV O&M (US$)	18 756	17 555	52 258	136 384
NPV Energy (US$)				100 344
Discounted cost of investment (US$/m³)	1.0208	0.9104	0.9836	0.6572
Discounted costs of O&M (US$/m³)	0.007	0.006	0.019	0.050
Discounted costs of energy (US$/m³)				0.037
Unit capacity costs (US$/m³)	1.0276	0.9168	1.0027	0.7435
		Discount rate: 1%		
Capital costs (US$ 000)	2 800.0	2 497.4	2 698.1	1 803
O&M costs (US$ 000)	50.0	46.8	139.3	363.6
Energy costs (US$ 000)				10.7
NPV of capacity unit (m³)	5 321 920	5 702 057	1 900 686	475 171
NPV O&M (US$)	38 988	36 493	108 622	283 532
NPV Energy (US$)				208 588
Discounted cost of investment (US$/m³)	0.5261	0.4380	1.4195	3.7938
Discounted costs of O&M (US$/m³)	0.007	0.006	0.057	0.597
Discounted costs of energy (US$/m³)				0.439
Unit capacity costs (US$/m³)	0.5335	0.4444	1.4767	4.8295

Source: Author’s calculations

Note: O&M costs each 5 years. Option of 125 m³ is not elevated, thus electricity cost is involved. Investment and O&M costs are reduced notably.

5. Water saving

Water saving in grids is probably the most profitable investment for saving water and energy. A grid system for a city of 175 000 inhabitants requires around 100 km of distribution grid to supply around 40 million cubic metres. The same proportions of supply, using an older grid with water losses, would require almost 56 million m^3 (30 per cent more). Savings are fuel costs and water at local price or supply costs. Energy use in water pumping estimates at: 1.5 kilowatt hours per cubic metre (kWh/m^3): 0.45 kilograms of oil equivalent per cubic metre ($kgoe/m^{3)}$ (with fuel use of electricity supply system of 300 grams of carbon dioxide equivalent per kilowatt hour (grs/ kWh).

TABLE 39

REDUCTION OF WATER LOST IN GRID

(Thousands of United States dollars)

Reduction of water lost in grid	Discount rate: 4%		
	Repaired grid	Existing grid	Total savings
Unit capital costs (1000$/km)	$600.000	$0.000	$600.000
Total capital costs (US $)	$60 000 000	$0	$60 000 000
Lifetime (years)	20	20	0
Total investment costs (US $)	$4 414 905	$0	$4 414 905
O&M costs($/km)	$100	$100	$0
Total annual costs O&M ($)	$104 000	$10 000	$94 000
Annual fuel costs ($)	$139 794 720	$195 712 608	-$55 917 888
Total annual costs ($)	$144 313 625	$195 722 608	-$51 408 983
CO_2	501 50	702 030	
N_2O	5	7	
CH_4	6	8	
Total CO_2 equivalent	503 336	704 670	- 201 334
$/Ton CO_2 equivalent			$ (-255.34)

Source: Author's calculations

Lifetime: 20 years. Discounted recovery period was 0.88 years (10 months) at a 4 per cent discount rate.

Lifetime: 20 years. Discounted recovery period was 0.49 years (6 months) at a 1 per cent discount rate.

This was a very good result for an adaptation option (−US$ 255.34/ton Co_2 equivalent) in carbon savings and total savings of US$ 51.4 million. Benefits could be increased by carbon trading that would be easily verifiable in this case. Thus, water saving in grid is a powerful adaptation option, due to savings in water and electricity/ fuel costs.

6. Multi-criteria assessment

The Novel Approach to Imprecise Assessment and Decision Environments (NAIADE) multi-criteria assessment method[33] helps decision making by including non-monetary, deterministic, stochastic and

[33] NAIADE (Novel Approach to Imprecise Assessment and Decision Environments) is a discrete, multi-criteria assessment tool for decision making under uncertainty, developed by G. Munda in 1995 at the AutonomousUniversity of Barcelona in Spain. NAIADE organizes alternatives without considering their relative degree of importance. At the end of the assessment, an aggregation of criteria is conducted to enable an overall ranking of

fuzzy criteria in the decision matrix. It is widely used for mitigation assessment and adaptation options due to the possibility it provides for assessing alternatives and decision criteria as a whole, using the theory of fuzzy sets.

The following six alternatives were used in the NAIADE multi-criteria water assessment:

i) Desalination with three different energy systems

ii) Adaptation in agriculture: changing crop policies

iii) Water harvesting and the construction of small water reservoirs

iv) Water harvesting and catchment using storm- resistant reservoirs of 1500 m^3, 500 m^3 and 125 m^3 capacity

v) Wastewater reuse and recycling

vi) Water saving in water-supply grids

TABLE 40

CLIMATE CHANGE WATER IMPACT MATRIX: ADAPTATION/MITIGATION OPTIONS

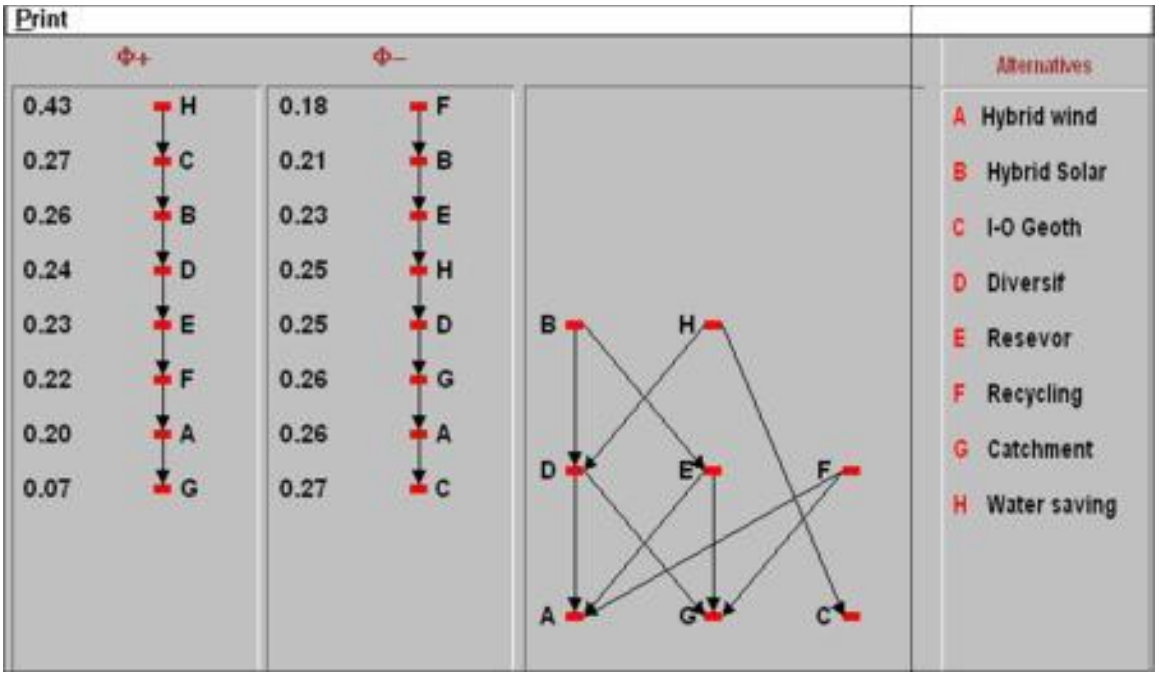
Alternatives/ Criteria	Hybrid Wind	Hybrid solar	I-O geothermic	Divers Ification	Reservoir	Recycling	Water Catchment	Water saving
Levelized cost	0.036	0.037	0.076	-0.135	0.32	0.62	0.44	0.82
Facilities to financial Access	Low	Low	Low	High	High	Low	Low	Average
Implementation capacity	Low	Low	Low	High	Average	Average	Average	High
Welfare	Average	Average	Average	High	High	Very High	Average	Very High
Payback	3	3.1	4	0.5	1.1	2.5	1.6	0.9
Additional benefits	Average	Average	Average	High	High	High	Average	High
Negative impacts on other systems	High	Average	Average	Low	Average	High	Average	Low
Technological barriers	High	High	High	Low	Average	High	Average	Low
Social and cultural barriers	Average	Average	High	Low	Low	Average	Low	Low
Spatial requirements	Low	High	High	Low	Average	High	Average	Low
Vulnerability	High	High	Average	Average	Average	Average	Average	Low
Sustainability	High	High	High	High	High	High	High	High
Water saving	14.6	14.6	14.6	3.8	0.2	0.2	0.4	16
Energy saving	0.02	0.02	0.02	0.2	0.2	0.2	0.2	195

alternatives considering all the criteria involved. The alternatives are then compared for each criterion, taking into consideration the personal preferences of the experts involved. Preference relationships are defined by six functions that allow a credibility index for each criterion to be obtained: the alternatives are much better (>>), better or (>), more or less equal (≅), equal (==), worse(<) and worst (<<) than any. For the partial or total ordering of alternatives, two different, independent orderings are considered. The first is based on preferences φ+(a),>> (much better) and > (better), whose values range from 0 to 1, where 1 suggests that alternative "a" is better than other alternatives. The second, φ -(a), is also based on the preference relationships << (much worse) and < (worst), and the values are also ranked from 0 to 1 indicating how much worse is "a" than other alternatives.

Source: Compiled by Author

FIGURE 69

MULTI-CRITERIA ASSESSMENT RESULTS USING NOVEL APPROACH TO IMPRECISE ASSESSMENT AND DECISION ENVIRONMENTS (NAIADE)



Source: Author's calculations

TABLE 41

NOVEL APPROACH TO IMPRECISE ASSESSMENT AND DECISION ENVIRONMENTS (NAIADE) RESULTS

φ +		φ -			Alternatives
0.43	H ↓•	0.18	F ↓•		A Hybrid wind
0.27	C ↓•	0.21	B ↓•	B • H •	B Hybrid solar
0.26	B ↓•	0.23	E ↓•		C I-O Geothermic
0.24	D ↓•	0.25	H ↓•		D Diversification
0.23	E ↓•	0.25	D ↓•	D • E • F•	E Reservoir
0.22	F ↓•	0.26	G ↓•		F Recycling
0.2	A ↓•	0.26	A ↓•		G Catchment
0.07	G↓•	0.27	C ↓•	A • G • C•	H Saving Water

Source: Compiled by Author

The ranking of options, considering all criteria, suggested three levels (B, H then D, E, F and lastly, A, G, C), with three options that might be considered independent of the others. The options considered best were, firstly, desalination with solar-diesel energy, and secondly, wastewater treatment for recycling. The third best option was water saving.

VI. Conclusions and recommendations

Despite the various types of uncertainties with respect to available data sets, scenarios and models, there was an important conclusion to be made from the present study: water availability in the Caribbean has been decreasing for more than 60 years, and climate change will exacerbate that situation and, probably, accelerate the process.

The IPCC A2 and B2 scenario perspectives towards 2100 of potential water availability and water balances expressed deficits with respect to baselines, reason for the report to conclude that this trend was unequivocal and irreversible. The situation may be worse if greenhouse gas emissions continue to increase over time.

Another conclusion was that in the future, water should not be seen as a sector. Authorities should recognize the central role of water, a resource difficult to manage. While many economic resources are “ordinary”, water is indispensable to life. Water is connected to energy, health, food security, and extremes, in an indissoluble way.

The reduction of precipitation within the Caribbean is not, strictly speaking, directly related to warming in the Caribbean. It is more a consequence of changes in global and regional atmospheric circulation, with an increase in the influence of the NAO (north Atlantic oscillation) suggesting the increase and dominance of regional eastward and vertical downward currents in the Caribbean, both phenomena that may lead to precipitation decrease. There will be changes in global scale circulation systems like NAO as well, stronger in winter months, which may reduce circulation in the Caribbean and create an increased drought influence. This whole situation is one of the main findings of the report.

Changes in sea-level temperature would impact mainly on air temperature and humidity, generating important changes in pressure fields and atmospheric circulation.

The rise in sea level will cause the expansion of saltwater intrusion which, together with the increases in temperature, may impact negatively the quality and availability of groundwater. These suggest a complex scenario for the Caribbean.

Climate variability is expected to increase, with increased frequency and intensity of extreme events, particularly droughts, which will become more intense, prolonged and extensive. Increased ENSO influence was a main factor determining climate variability and reducing likely hurricanes occurrence, one important source of precipitation (10 per cent to 20 per cent) in the Caribbean.

Estimated water balances (hydrological and from supply/demand estimates) for the Caribbean indicated that most Caribbean countries may face strong water shortages in the future, thus suggesting that early adaptation is an imperative. Most of the adaptation options for saving water are strongly related to energy use and energy efficiency.

Two important facts limited a more accurate adaptation analysis: not only was there a (1) lack of accurate data sets about water: precipitation, water use, and water quality; but also (2) lack of data about water supply infrastructure, recycling, pollution control and alleviation, and the costs related to technological options.

Nevertheless, a portfolio of adaptation options has been presented: by means of a combination of cost benefit analysis, a levelized costs approach to energy solutions to reduce GHG emissions, and a multi-criteria assessment. The adaptation/ mitigation options should be seen as a portfolio of credible policies that may be enhanced and modified when applied to specific countries.

The multi-criteria assessment is a useful tool when different criteria cannot be expressed in monetary terms or when there is a significantly high number of criteria from communities and specific users.

Water-management practices need to change, avoiding such practices that increase pressure on the resource that seems unlimited, until a threshold is surpassed which has important consequences for wealth and sustainability within the Caribbean.

This new perspective suggests that there must be a policy change with regard to information, data collecting, and improving the protection, conservation and management of water resources. This should include the implementation of early adaptation and mitigation options, community participation in decision making, and creating information and research infrastructure.

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Annexes

Annex 1
Extreme events

The following definition of extreme events was adapted from the Intergovernmental Panel on Climate Change *Special Report on Emissions Scenarios.*

TEXTBOX A1
EXTREME EVENTS DEFINITION IN PHYSICAL TERMS

Some of the literature has reserved the term 'extreme event' for the initial, meteorological phenomena (Easterling and others, 2000; Jentsch and others, 2007); others include the consequential, physical impacts, like flooding (Young, 2002), and some others, the entire spectrum of outcomes for humans, society, and ecosystems (Rich and others, 2008). In the present report, 'extreme (weather or climate) event' refers solely to the initial, and consequent, physical phenomena, including some (e.g. flooding) that may have human components other than those related to climate (e.g. land use or land cover change, or changes in water management).

The spectrum of outcomes for humans, society, and physical systems, including ecosystems, are considered 'impacts' rather than part of the definition of 'events'. In addition to providing a long-term mean of weather, 'climate' characterizes the full spectrum of means and uniqueness associated with 'unusual'—and unusually persistent—weather.

The World Meteorological Organization (WMO, 2010) differentiates the terms in the following way:

"At the simplest level, the weather is what is happening to the atmosphere at any given time. Climate, in a narrow sense, is usually defined as the 'average weather,' or, more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period of time."

Weather and climate phenomena reflect the interaction of dynamic and thermodynamic processes over a very wide range of spatial and temporal scales.

This complexity results in highly variable atmospheric conditions, including temperature, motion and precipitation, a component of which is referred to as 'extreme events.' Extreme events include the passage of an intense tornado lasting minutes and the persistence of drought conditions over decades – a span of at least seven orders of magnitude of timescales. An imprecise distinction between extreme 'weather' and 'climate' events is also based on their characteristic timescales. The spatial scale of extreme climate or weather varies from local to continental.

Where there is sufficient, long-term, recorded data to develop a statistical distribution of a key weather or climate variable, it is possible to find the probability of experiencing a value above or below different thresholds of that distribution, as is required in engineering design (trends may be sought in such data to see if there is evidence that the climate has not been stationary over the sample period).

The extremity of a weather or climate event of a given magnitude depends on geographical context: a month of daily temperatures corresponding to the expected spring climatological daily maximum in Chennai, India, would be termed a heat wave in France; a snow storm expected every year in New York, in the United States of America, might initiate a disaster when it occurs in southern China. Furthermore, according to the location and social context, a 1-in-10 or 1-in-20 annual probability event may not be sufficient to result in unusual consequences.

Nonetheless, universal thresholds can exist – for example, a reduction in the incidence or intensity of freezing days may allow certain disease vectors to thrive. These various aspects are considered in the definition of 'extreme (weather and climate) events. The availability of observational data is of central relevance for defining climate characteristics and for disaster risk management; and, while data for temperature and precipitation are widely available, some associated variables, such as soil moisture, are poorly monitored or – like extreme wind speeds, and other low-frequency occurrences – not monitored with sufficient spatial resolution or temporal continuity.

(continues)

Textbox A1 (continued)

Extremes in a changing climate

An extreme event in the present climate may become more common, or rarer, under future climatic conditions. When the overall distribution of the climatic variable changes, what happens to mean climate may be different from what happens to the extremes at either end of the distribution.

For example, a warmer mean climate could result from fewer cold days, leading to a reduction in the variance of temperatures, or more hot days, leading to an expansion in the variance of the temperature distribution, or both. The issue of the scaling of changes in extreme events with respect to changes in mean temperatures is addressed further in the [IPCC SRES] report. In general, single extreme events cannot be simply and directly attributed to anthropogenic climate change, as there is always a possibility that the event in question might have occurred without this contribution. However, for certain classes of regional, long-duration extremes (of heat and rainfall), it has proved possible to argue from climate model outputs that the probability of such an extreme has changed due to anthropogenic climate forcing. Extremes sometimes result from the interactions between two unrelated geophysical phenomena, such as a moderate storm surge coinciding with an extreme spring tide, as in the most catastrophic United Kingdom storm surge flood of the past 500 years, in 1607.

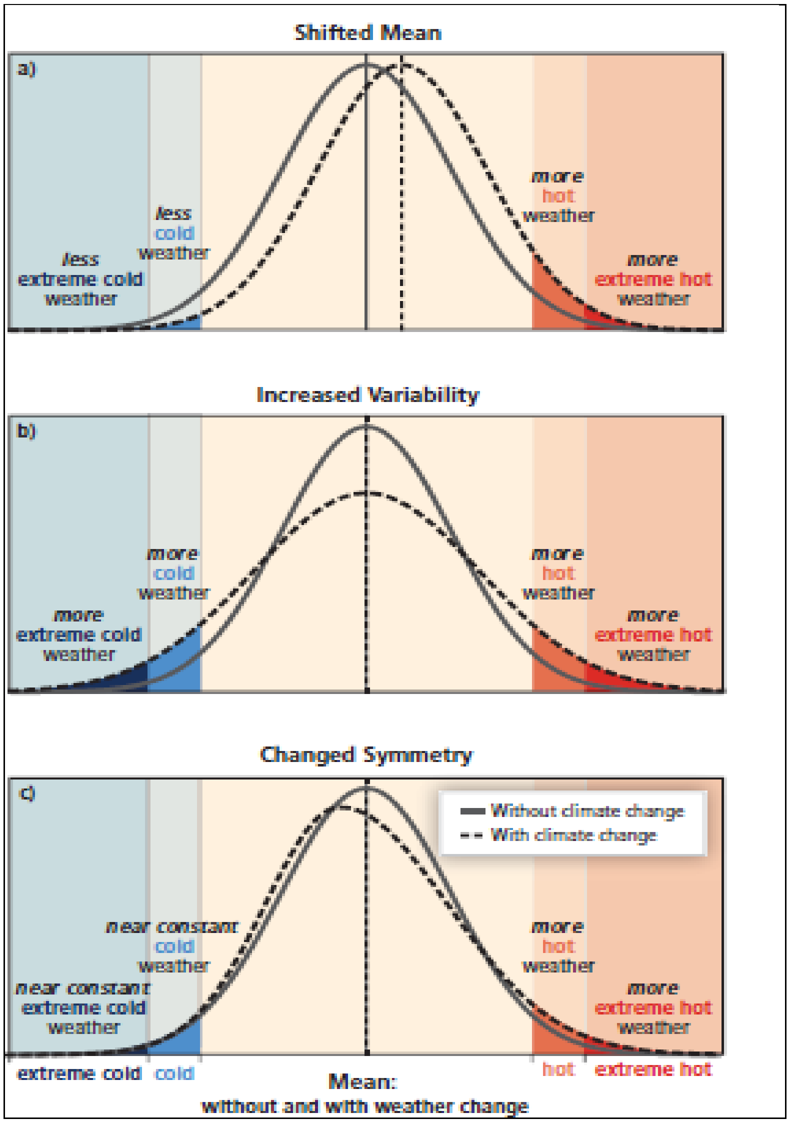
Climate change may alter both the frequency of extreme surges and cause gradual sea-level rise, compounding such future, extreme floods

Source: IPCC, 2009

Experts consider that there is evidence that increases in greenhouse gases have caused changes in extremes, but there is no simple response to the question of whether the climate has become more, or less, extreme, because extremes can be defined in different ways, and different characterization of observed changes are possible. It is also difficult to design a comprehensive scale that would characterize all aspects of extreme from the climate science perspective.

Although a change in climate may lead to changes in single extremes, these events are mainly caused by a combination of factors (like hurricanes). It could be possible to explore and attribute the occurrence of specific events to climate change when, in fact, the probability of a changed pattern of occurrence has already been well established. Annex 1 Figure 1 provides three different cases of changing extremes in which increased variability has proved more dangerous.

FIGURE A1
CHANGES IN EXTREME EVENTS



Source: Adapted from IPCC, 2009

Note: The vertical left axis shows the probability increase

Implications for Latin America and the Caribbean (LAC) are important. For that assessment, the LAC region was divided in five sub regions (1) Amazonia, (2) northeast Brazil, (3) southeast South America, (4) South America west coast and (5) Mexico and Central America. As may be seen from the next figure, the Caribbean has been omitted, generating greater uncertainty about results and lessons to be learned for adaptation. Thus, exploring trends in extreme events is an imperative for the Caribbean.

Understanding extremes is important to the assessment of water resources, not only because many relationships in the climatic system are changing, but also due to the high influence of droughts, heavy precipitation, hurricanes, and climate variability like ENSO on water availability, especially in the Caribbean.

The development of tools for the assessment of extreme events has been the focus of research over the last few decades. The framework developed for attributing individual extreme events takes into account the change in the probability of an extreme event under current conditions, and calculates and compares the result with the probability of the event if the effects of a particular external forcing, such as human influence, had been absent.

The method has been applied to the case of the probability of occurrence of seasonal mean temperatures as warm as those detected in Europe in 2003, and came to the conclusion that the probability had very likely at least doubled as a result of human influence (Stott and others, 2004). Reports have concluded that attributing human footprints to changes in the frequency and intensity of hurricanes remains very controversial—not because the link may not exist, but because the link cannot be demonstrated yet through scientific research and the available data. The importance of anthropogenic influence on increases in sea surface temperatures and in the cyclogenesis of past and future changes in hurricane activity is still poorly understood.

Annex 2
Modelling results

The model estimated the water availability and demand for the residential, industrial, tourism and agricultural sectors. For this purpose, lack of data has proved to be an important shortcoming. Nevertheless, the model used panel data in an attempt to capture heterogeneous perspectives from 15 Caribbean countries, and to amplify the number of observations. In some cases, non-linear specifications were used, due the complexity of economic and climate variables, in an effort to obtain more relevant estimates, given the limited data available. Once water availability and demand estimates had been forecast, water balances could be obtained for selected countries based on the Caribbean Sea Ecosystem Assessment (CARSEA, 2007) Quality over Quantity (Q&Q)[34] and the Intergovernmental Panel on Climate Change A2 and B2 climate scenarios.

TABLE A1
REGRESSION OUTPUT

	105	R^2	0.998	
F test (18, 86)	3568.54	Adjust R^2	0.99	
Prob> F	0.000			
lwaterperc	Coef	StdErr	T	P> t
Lgdpperc	-0.0592	0.344	-1.72	0.089***
Ltemp	-448.86	133.6	3.36	0.001*
ltemp2	68.73	20.578	3.34	0.001*
Lrain	0.408	0.867	4.71	0.000*
Cons	731.82	217.04	3.37	0.001*
Country effects				
Haiti	-0.961	0.8878	-10.83	0.000*
The Dominican Republic	-0.639	0.1438	-4.45	0.289
Jamaica	-0.4506	0.422	-1.07	0.000*
Barbados	-2.634	0.1215	-21.69	0.000*
The Bahamas	-4.144	0.1254	-33.04	0.000*
Belize	2.872	0.0596	48.18	0.801
Dominica	-0.1314	0.518	-0.25	0.000*
Grenada	-1.518	0.1855	-8.18	0.000*
Guyana	4.202	0.1364	30.8	0.000*
Saint Lucia	-3.625	0.079	-45.96	0.000*

(continues)

[34] Four Caribbean Sea Ecosystem Assessment (CARSEA, 2007) scenarios were developed to the year 2050: Neo-plantation Economy, Quality over Quantity, Diversify Together, and Growing Asymmetries.

Table A1 (continued

Suriname	3.682	0.1074	34.29	0.000*
Trinidad and Tobago	-0.297	0.1303	-2.28	0.025**
Antigua and Barbuda	-1.8026	0.1145	-15.74	0.000*
Saint Vincent and Grenadines	-1.813	0.1592	-11.39	0.000*

Source: Compiled by Author
Note: * 99% significance level
** 95% significance level
*** 90% significance level

TABLE A2
ECONOMETRIC PANEL DATA MODELS: SUMMARY

	Model 1 FE		Model 2 RE		Model 3 RE		Model 4 RE		Model 5 FE	
	Coeff	P>[Z]	Coeff	P>[Z]	Coeff	P>[Z]	Coeff	P>[Z]	Coeff	P>[Z]
lgdpperc	0.72	0.070	0.958	0.000	0.806	0.038	0.3404	0.085		
lexchrate	0.06	0.592	0.132	0.078	0.073	0.578				
lfuel	0.141	0.473	-0.201	0.170						
lindex					-0.012	0.945				
lt	27.46	0.312	-8.434		15.237	0.549	2161.4	0.021	2179.1	0.023
lt2							-328	0.024	-330.1	0.025
lrainfall	-1.46	0.076	-3.068	0.000	-1.877	0.019	-2.473	0.000	-2.73	0.000
C	-78.597	0.383	47.1	0.000	-36.730	0.666	-3539	0.02	-3569	0.021
R2	0.807		0.899		0.761		0.82		0.815	
Haiti	0.421	0.645	0.34	0.69	0.288	0.753	0.337	0.69	-0.165	0.79
The Dominican Republic	2.278	0.089	3.33	0.001	1.743	0.168	3.329	0.001	3.443	0.001
Jamaica	-2.887	0.31	0.5	0.862	-1.612	0.547	0.522	0.862	0.125	0.04
Barbados	-1.368	0.218	-1.215	0.835	-0.930	0.395	-0.215	0.835	0.241	0.787
The Bahamas	1.447	0.205	2.8	0.006	1.065	0.325	2.764	0.006	3.384	0.000
Belize	-1.481	0.75	0.4	0.395	-0.100	0.83	0.381	0.395	0.479	0.272
Dominica	3.029	0.327	10.2	0.003	1.852	0.528	10.152	0.003	10.756	0.002
Grenada	-2.932	0.061	-1.8	0.174	-2.183	0.138	-1.801	0.174	-1.766	0.187
Guyana	-1.707	0.146	-1.2	0.202	-1.149	0.301	-1.183	0.202	-1.454	0.099
St Lucia	-0.3	0.653	0.3	0.625	-0.020	0.976	0.292	0.625	0.429	0.458
Suriname	-1.491	0.148	-1.5	0.074	-0.992	0.312	-1.52	0.074	-1.256	0.117
Trinidad and Tobago	-1.666	0.137	-0.7	0.49	-1.176	0.278	-0.694	0.49	-0.453	0.64
Antigua and Barbuda	-2.044	0.044	-1.2	0.156	-1.582	0.104	-1.243	0.156	-1.061	0.215

Source: Compiled by Author

TABLE A3
GROSS DOMESTIC PRODUCT PURCHASING POWER PARITY PER CAPITA ESTIMATES

	Base year	CARSEA	SRES	
	2009	Q&Q	A2	B2
Cuba	576	4 780	2 264	1 776
Haiti	324	1 099	461	498
The Dominican Republic	516	4 466	625	675
Jamaica	464	1 828	50	397
Barbados	687	4 928	6 487	2 496
The Bahamas	620	1 878	811	794
Belize	728	4 192	32 105	25 691
Dominica	1 561	10 728	2 366	1 894
Grenada	536	9 265	3 343	2 675
Guyana	677	785	161	129
Suriname	606	1 834	3 199	2 560
Trinidad &Tobago	48	147	2 396	1 917
Antigua & Barbuda	938	2 841	517	414

Source: Author's calculations

TABLE A4
OUTPUT OF THE MODEL

lagro	coef	P>t
lpermperc	0.6217	0.001
lt	15.468	0.071
lt2	-0.0564	0.160
lp	0.7898	0.160
c	-44.056	0.165
Haiti	-0.4427	0.100
The Dominican Republic	-0.4218	0.326
Jamaica	-2.787	0.003
Barbados	1.207	0.039
Belize	-0.876	0.049
Dominica	1.249	0.000
Grenada	-1.894	0.243
Guyana	-0.9074	0.000
Suriname	-3.344	0.011
Trinidad & Tobago	-2.693	0.000
Antigua & Barbuda	0.384	0.312

Source: Author's calculations

TABLE A5
SUMMARY OF ASSUMPTIONS

	SRES IPCC				CARSEA (Q&Q)	
	Temperature 2050		Rainfall 2050		1960-1990	
	A 2	B 2	A 2	B 2	Temperature	Rainfall
Caribbean	28.47	28.13	1689.8	1735.6	26.825	1879.8
Cuba	28.1	27.7	1247	1232	24.9	1326
Haiti	26.4	26.4	1142	1260	24.8	1469

(continues)

Table A5 (continued)

	SRES IPCC				CARSEA (Q&Q)	
	Temperature 2050		Rainfall 2050		1960-1990	
	A 2	B 2	A 2	B 2	Temperature	Rainfall
The Dominican Republic	26.4	26.4	1142	1260	24.8	1469
Jamaica	30	29.5	1516	1602	28.3	1868
Belize	28.5	28.1	1761	1740	27.1	2368
Lesser Antilles	28.5	28.1	2272	2292	27.1	2368
Dominica	28.5	28.1	2272	2292	27.1	2368
Grenada	28.5	28.1	2272	2292	27.1	2368
Guyana	28.5	28.1	2272	2292	27.1	2368
Saint Lucia	28.5	28.1	2272	2292	27.1	2368
Suriname	28.5	28.1	2272	2292	27.1	2368
Trinidad and Tobago	28.5	28.1	2272	2292	27.1	2368
Antigua and Barbuda	28.5	28.1	2272	2292	27.1	2368
Saint Vincent and the Grenadines	28.5	28.1	2272	2292	27.1	2368

Source: Author's calculations

TABLE A6
TOTAL CARIBBEAN DOMESTIC RENEWABLE WATER RESOURCE ESTIMATES
(Millions of cubic metres per year)

COUNTRY	Base year	CARSEA	SRES IPCC	
	2009	Q&Q	A2	B2
Cuba	38 120	91 488	51 045	44 884
Haiti	14 030	33 672	22 791	23 767
The Dominican Republic	21 000	46 231	17 950	18 680
Jamaica	9 404	17 831	7 632	8065
Barbados	81	1 253	132	115
The Bahamas	22	158	36	32
Belize	18 550	44 520	32 661	27983
Dominica	793	326	422	365
Grenada	94	455	147	127
Guyana	239 380	375 200	371 429	320872
Saint Lucia	17	801	32	27
Suriname	92 207	20 840	12 323	10645
Trinidad &Tobago	3 981	6 194	6 821	5888
Antigua & Barbuda	55	431	105	91
St. Vincent & the Grenadines	58	515	124	108

Source: Author's calculations

TABLE A7

CARIBBEAN RENEWABLE WATER RESOURCES ESTIMATES

(Thousands of cubic metres per inhabitant per year)

	Base year	CARSEA	SRES IPCC	
	2009	Q&Q	A2	B2
Cuba	3.39	4.05	4.64	4.08
Haiti	1.40	4.98	1.40	1.46
The Dominican Republic	2.12	4.43	1.72	1.79
Jamaica	3.43	6.03	8.29	6.32
Barbados	0.29	4.46	0.47	0.41
The Bahamas	0.06	4.39	0.10	0.09
Belize	59.46	4.83	113.8	97.5
Dominica	11.33	4.65	6.03	5.21
Grenada	0.97	4.69	1.52	1.31
Guyana	319.6	5.01	495.9	428.4
Saint Lucia	0.10	4.74	0.19	0.16
Suriname	211.0	4.77	282.0	243.6
Trinidad &Tobago	2.86	4.45	4.90	4.23
Antigua & Barbuda	0.58	4.54	1.11	0.96
Saint Vincent & the Grenadines	0.53	4.68	1.13	0.98

Source: Author's calculations

TABLE A8

WATER DEMAND (PER CAPITA LOG) FOR THE CARIBBEAN RESIDENTIAL SECTOR

	Coef	P>t
lgdp (log GDP ppp per capita)	4.572	0.000
lgdp2 (log GDP ppp per capita over squared)	-0.259	0.001
lt (log temperature)	-1254.5	0.034
lt2 (log temperature over squared)	191.9	0.035
lp (log rainfall)	13.6	0.013
lp2 (log of rainfall over squared)	-0.954	0.011
Haiti	-1.855	0.000
The Dominican Republic	-0.941	0.119
Jamaica	-1.911	0.255
Barbados	-0.622	0.268
The Bahamas	-2.402	0.000
Belize	-1.606	0.000
Dominica	-10.990	0.000
Grenada	-5.470	0.000

(continues)

Table A9 (continued)

	Coef	P>t
Guyana	-0.627	0.242
Saint Lucia	-0.699	0.025
Suriname	-1.130	0.016
Trinidad & Tobago	0.194	0.718
Antigua & Barbuda	-0.751	0.117
Saint Vincent & the Grenadines	-1.118	0.07
_cons	1986.570	0.038
R2	0.956	
Prob>F	0.000	

Source: Author's calculations

TABLE A9
WATER DEMAND, CARIBBEAN RESIDENTIAL SECTOR
(Millions of cubic metres per year)

	Base year	CARSEA	Scenario SRES	
	2009	Q&Q	A2 2050	B2 2050
Cuba	1 159.5	2 814.0	1 806.0	2 189.0
Haiti	233.0	602.32	314.18	315.81
The Dominican Republic	1 481.0	1 304.50	1 359.0	1 362.0
Jamaica	275.0	645.0	330.0	349.0
Barbados	20.37	5.62	16.41	7.50
The Bahamas	5.17	2.01	1.90	1.62
Belize	115.0	227.0	111.0	112.0
Dominica	0.01	0.03	0.00	0.00
Grenada	0.06	5.24	0.08	0.05
Guyana	60.89	54.90	135.19	89.51
St Lucia	9.80	3.52	18.74	12.40
Suriname	23.47	56.37	33.69	22.29
Trinidad & Tobago	180.26	74.75	136.69	90.48
Antigua & Barbuda	5.66	2.57	5.31	3.52
Saint Vincent & the Grenadines	5.90	4.25	6.85	4.53

Source: Author's calculations

TABLE A10
WATER DEMAND, CARIBBEAN AGRICULTURAL SECTOR
(Millions of cubic metres per year)

	Base year	CARSEA	SRES	
	2009	Q&Q	A2	B2
Cuba	5 664.0	13 594.0	11 776.0	15 012.0
Haiti	961.0	16 792.0	4 003.1	3 705.7
The Dominican Republic	2 241.0	5 778.0	1 742.0	1 922.0
Jamaica	200.0	503.0	258.0	272.0
Barbados	145.8	203.0	15.4	40.1
The Bahamas	3.6	12.0	2.7	2.8
Belize	160.1	278.0	36.0	45.0
Dominica	93.9	137.0	62.0	77.4
Grenada	130.1	75.0	20.9	26.1
Guyana	187.1	161.3	786.6	981.7
Suriname	38.2	12.6	7.2	9.0
Trinidad &Tobago	68.2	22.3	1.4	1.7
Antigua & Barbuda	4.5	15.0	8.1	10.2

Source: Author’s calculations

TABLE A11
WATER DEMAND, CARIBBEAN INDUSTRIAL SECTOR
(Millions of cubic metres per year)

	Base year	CARSEA	SRES IPCC	
	2009	Q&Q	A2	B2
Barbados	146.2	156.4	87.6	23.9
Belize	297.2	407.0	324.0	312.2
Cuba	751.0	1534.0	1266.0	1403.0
Grenada	1.0	0.5	0.3	0.1
Guyana	10.9	13.1	7.3	2.0
Haiti	46.0	70.5	36.0	40.0
Jamaica	138.0	322.0	275.0	174.0
The Dominican Republic	80.0	123.0	67.9	65.2
Suriname	656.0	1924.3	1539.4	420.4
Trinidad & Tobago	12.7	9.7	5.4	1.5

Source: Author’s calculations

TABLE A12
WATER DEMAND, CARIBBEAN TOURISM SECTOR
(Millions of cubic metres per year)

	Base year	Q&Q CARSEA	SRES Scenario	
	2009	2050	2050 A2	2050 B2
Cuba	759.2	1 620.6	1 080.4	1 481.3
Haiti	168.0	358.7	1 219.5	956.1
The Dominican Republic	1 288.8	2 175.5	1 631.2	1 279.1
Jamaica	600.5	1 281.9	727.4	2 052.4
Barbados	177.4	378.7	172.8	263.4
The Bahamas	1 130.0	2 412.3	1 925.6	2 967.2
Belize	161.2	344.0	214.3	326.8
Dominica	64.9	138.4	422.1	643.6
Grenada	83.6	178.4	28.4	39.7
Guyana	32.6	69.7	48.1	80.3
Saint Lucia	202.3	431.8	216.2	329.6
Suriname	63.7	136.2	33.7	51.6
Trinidad and Tobago	144.3	308.1	110.3	168.1
Antigua and Barbuda	58.9	125.6	50.3	76.5
Saint Vincent and the Grenadines	23.6	50.3	26.9	40.6
Caribbean (15)	4 958.9	10 010.3	7 907.2	10 756.4

Source: Author’s calculations