THE IMPACT OF CLIMATE CHANGE ON THE WATER SECTOR IN THE CARIBBEAN

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Table of Contents

Executive Summary

In the Caribbean, many countries face constraints in obtaining high quality and adequate supplies of freshwater due to their small size and geo-climatic conditions. This is especially so for coral-based islands which have a limited ground water supply. The management of freshwater is further complicated by the threat of climate change, which could potentially have a significant effect on the hydrologic cycle and, hence, on key parameters such as rainfall and temperature, as global warming is generally expected to increase if current human emissions of greenhouse gases continue unabated.

This study econometrically analyses the projected impact of climate change on the water sector of nine Caribbean countries to 2100: Aruba, Barbados, Dominican Republic, Guyana, Montserrat, Jamaica, Netherlands Antilles, Saint Lucia, and Trinidad and Tobago. Overall, all countries, with the exception of Trinidad and Tobago, are expected to suffer aggregate losses as result of climate change in the early periods ca. 2020 under one or more scenarios. Over time, some countries experience declining negative impacts, as in the case of Guyana under the B2 scenario. Some countries, such as the Dominican Republic, is projected to suffer increasing losses under the B2 scenario and, for others, the impacts do not follow a defined trend. The A2 scenario offers the best outcome for all countries, except Jamaica (where BAU is most desirable), Montserrat (which performs most poorly under the A2 scenario), and the Netherlands Antilles, which does best under the B2 case.

Overall, relative to 2006, the total demand for water in the Caribbean is expected to fall by 2030 by 11.3% to approximately 12,967 million cubic meters. This is due to the expected fall in agricultural water demand by approximately 36% in that period. However, by 2050, total water demand for the Caribbean will again exceed the 2006 level by approximately 4% to 14,896.33 10^6 m^3. By 2100, water demand will increase almost fivefold to approximately 69,233.69 10^6 m^3.

Climate change is expected to affect all countries in the Caribbean. In some cases, there will be positive impacts that may continue to increase over time and, in other cases, the impact will be negative and worsen over time. Overall, the agricultural sector is expected to suffer the worst losses over any scenario, whilst growth in the industrial sectors is expected to be significant and contribute the most to increasing water demand over time.

I. INTRODUCTION

The management of freshwater is further complicated by the threat of climate change, which could potentially have a significant effect on the hydrologic cycle, and hence on key parameters, such as rainfall and temperature, as global warming is generally expected to increase if current human emission of greenhouse gases continues unabated. Furthermore, in low-lying States, a rise in sea level may also cause flooding of low-lying areas, which may contaminate freshwater bodies, or increase salt water intrusion (CARICOM 2003). Without adequate management, poor water quality or dwindling water supplies could set limits in the attainment of sustainable development.

In order to determine the impact of climate change on the water sector in the Caribbean, a baseline or reference climate parameter would first be established for the period 1970–2006. The Inter-government Panel on Climate Change (IPCC) Special Report on Emissions Scenarios (SRES) A2[1] and B2[2] scenarios would then be used as the projected future climate for the Caribbean, in addition to the Business As Usual (BAU), which represents a scenario in which greenhouse gas emissions continue unabated, and the socioeconomic parameters in the baseline period remain unchanged (IPCC 2000). Using Atmosphere-Ocean General Circulation and Earth System Models, the IPCC (2007) projects that global temperatures will rise. Under the A2 and B2 scenarios, it is expected that relative to temperatures during 1980-1992, temperatures will rise by 3.4°C and 2.4°C, respectively, with a likely range of 2.0 – 5.4 °C, and 1.4 – 3.8°C, respectively, by 2090-2099. Furthermore, sea levels are expected to rise by 0.23 – 0.51 m under the A2 scenario and between 0.2 – 0.43 m for the B2 scenario for the same period.

While climate projections have been made for a number of regions worldwide, the IPCC (1997) indicated that the potential change in many climate variables, including rainfall, for the Caribbean has had very little consistency among the Global Climate Models. From a small island perspective, one of the key concerns is the intensity, frequency and distribution of extreme events such as hurricanes, but model projections to date have not provided conclusive evidence of the patterns of these events that may occur in the future (IPCC 1997).

In the Caribbean, the tropical climate of most countries reflects an annual rainfall regime that is often characterized by pronounced wet and dry seasons. In the tropics and low-latitude regions of the Southern Hemisphere, the El Niño-Southern Oscillation (ENSO) phenomenon is a major factor in year-to-year climate variability, with a marked effect on rainfall patterns (IPCC 1997). Globally, there is high confidence that the negative impacts of climate change on freshwater systems will outweigh the benefits (Bates *et al* 2008). This study econometrically analyses the projected impact of climate change on the water sector of nine Caribbean countries to 2100: Aruba, Barbados, Dominican Republic, Guyana, Montserrat, Jamaica, Netherlands Antilles, Saint Lucia, and Trinidad and Tobago.

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[1] The A2 storyline and scenario family describes a very heterogeneous world. The underlying theme is self reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing populations. Economic development is primarily regionally oriented and per capita economic growth and technological change more fragmented and slower than other storylines.

[2] The B2 storyline and scenario family describes a world in which the emphasis is on local solutions to economic, social and environmental sustainability. It is a world with continuously increasing global population, at a rate lower than A2 and intermediate levels of economic development. While the scenario is also oriented towards environmental protection and social equity, it focuses on local and regional levels.

A. WATER DEMAND AND COSTS IN THE CARIBBEAN

Based on these observations, climate change is generally expected to result in a shortage of water in the Caribbean (Joslyn *et al* 2008). This shortage is expected to be caused by an increase in rainfall variability due to more periods of low rainfall, leading to droughts, lower streamflow and groundwater levels. There may also be a greater number and lengths of dry periods (Joslyn *et al* 2008).

Aruba: Aruba has an area of 180 km², with extremely limited freshwater resources. It therefore relies on a saltwater desalination plant which has a capacity of 42,000 metric tonnes per day (mtpd) (or 11 mil US gallons per day). On average, 36,000 mtpd (9.2 mil US gal per day) are consumed. Of this, WEB Aruba N.V, via personal communication, indicated that 1,000 mtpd is demanded by WEB Aruba N.V., 31,000 mtpd goes to Aruba, 2,600 mtpd goes to the Coastal Refinery and 1,400 mtpd is Unaccounted for Water (UFW). Between 1992 and 2007, water supply[3] doubled to 13,843 10^3 m^3 (Aruba Central Bureau of Statistics 2009a), and had an average price of 139.60 Aruban Florins in 2009, based on average household usage (Aruba Central Bureau of Statistics 2009b). For domestic water use, there is a tiered cost structure of 4.55 Aruban Guilders (AWG) for ≤ $3m^3$, 5.40 AWG for use of more than 3 m^3 and up to 6 m^3 and 7.55 AWG for use more than 6 m^3 up to 12 m^3 [4].

Barbados: Water quality pressures exist from agricultural activity, oil exploration, encroachment of industry, and leachate from landfill sites. Annual water withdrawal in the agriculture sector in 1996 was estimated at 19.01 million m^3 (not including golf course irrigation at 0.9 million m^3) whereas the domestic, municipal and industrial sector accounted for 25.85 million m^3. UFW was about 35 million m^3. Almost all of the potable water is pumped from 21 groundwater wells.

Ground water accounts for 79% of the water resources and 98.6% of the public water supply, due to the limestone soil that covers 86% of the island. All persons have access to improved water access, with a 94% connection rate. The island's potable water supply is used extensively by small farmers. In 1997, annual Internal Renewable Water Resources (IRWR) was estimated at 82 million m^3. Groundwater accounted for 73.9 million m^3; surface water 5.8 million m^3; springs 2.0 million m^3 and direct runoff to the sea 0.5 million m^3. Total IRWR per capita fell from 344.40 m^3/inhab/yr in 1962 to 273.10 in 2007. Total surface and groundwater withdrawal was estimated to triple from 0.03 10^9 m^3/yr between 1962 and 2002, and was 37.5% and 112.5%, respectively, of the total actual renewable water resources (FAO 2009). Between 1961 and 2006, water production increased by 168.4% and stood at 53,489 thousand litres in 2006.

Dominican Republic: On average, rainfall is 73 km^3/year (approximately 1,500 mm). Of this total volume, about 70% is lost by evapotranspiration. Annual average availability is therefore 22 km^3, which is split into 2.6 km^3/ year for aquifer recharge and 19.4 km^3/year for surface run-off. The total capacity of dams in the Dominican Republic is 2,144 million m^3. (FAO 2009).

Between 1994 and 2000, Total freshwater withdrawal fell from 8.34 to 3.39(10^9 m^3/yr). In 2005, of the 11,626.36 10^6 m^3 of total water demand, drinking water accounted for 72.2%, irrigation 7.6%, cattle 6%, ecological use 10.7%, industry 2.9% and tourism 0.5% (National Hydrological Diagnostic Plan, INDRHI 2007). No desalinated water was produced (FAO 2009). In 2005, total water availability in the Dominican Republic was 23,497.69 10^6 m^3. IRWR per capita fell from 5,862.47 m^3/inhab/yr in 1962 to 2,183.64 in 2007 (FAO 2009).

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[3] Excludes water supply to Coastal Aruba N.V. and vessels.

[4] Rates for higher use and other sectors are not available.

Of the 8.8 million persons in the Dominican Republic by 2002, 95% had access to a safe water source, and 78% had access to improved sanitation. Average tariffs are moderate at US$ 0.21 per cubic meter for water and US$ 0.07 per cubic meter for sewerage. Collection rates are extremely low at only 28% (Wikipedia 2009a).

Guyana: Sea level rise is very important for Guyana, as its coast is 6 ft below sea level, and 90% of the population resides there. The Atmosphere–Ocean Global Circulating Models predicted that the sea level rise for Guyana would be approximately 60 cm by 2100 if melt water is included. Sea level rise is expected to lead to inundation, salinization of groundwater and erosion, as well as a reduction in natural and artificial drainage, particularly in the East Demerara Water Conservancy (GUYSUCO 2009).

The 2000 Multiple Indicator Cluster Survey showed that 83% of persons had access to water (Wikipedia 2009b). Most of the domestic water supply comes from ground water resources, while most of the water supply for agriculture and industry comes from surface water. In 1992, a total of 1.46 km^3 was extracted in Guyana. Almost all (99%) was by the agricultural sector, 1% the domestic sector and less than 1%, the industrial sector (FAO 2009). Personal communication with Guyana Water Inc. indicated that water production increased steadily in Guyana by 67.4% between 2004 and 2008, when it stood at 117,274,360 m^3. Total IRWR per capita fell from 401,506.73 m^3/inhab/yr in 1962 to 326,087.69 in 2007. Total surface and groundwater withdrawal increased from 1.46 to 1.64 10^9 m^3/ yr between 1992 and 2002, and was 0.61% and 0.68%, respectively, of the total actual renewable water resources (FAO 2009).

In 2005, water rates varied from a low fixed rate of Guy$8,900 for rural and urban domestic unmetered customers to Guy$219,400 for large industrial customers. In the same period, for metered users, charges ranged from Guy$ 60.90/m^3 to Guy$96.60/$m^3$ for non-domestic users.

Jamaica: In Jamaica, the mean annual rainfall is 1980 mm, and approximately 56% of this is lost to evapotranspiration. IRWR is estimated at 9.4 km^3/year, of which 5.5 km^3/yr goes to surface water, and 3.9 km^3/year, to groundwater. However, only 44% of the IRWR is considered exploitable, of which 84% is groundwater and the rest, surface water. Annual withdrawal was estimated at 928 mil m^3. Almost all of the water used (92%) was obtained from groundwater sources.

Total IRWR per capita fell from 5,601.30 m^3/inhab/yr in 1962 to 3,484.77 in 2007. Total surface and groundwater withdrawal increased from 0.90 to 0.41 10^9 m^3/ yr between 1997 and 2002, and was 9.57% and 4.35%, respectively, of the total actual renewable water resources (FAO 2009). In 1987, total water production was 55.25 mil m^3, of which 65% was consumed. By 2006, preliminary estimates suggested that water production increased by 432.8% and water consumption by 162.9%. By 2005, total water demand was 1,311.6 mil m^3, of which agriculture accounted for 33.4%, domestic use 16.7%, commercial use 4.2%, hotels 0.3%, industry 6.6%, and environmental flows 38.8%[5] (Water Resources Authority 2009). In 2007, 34.6% of persons accessed pit latrines and 64.3% used water closets, which showed an improvement in access to improved sanitation over the previous decade. Most persons (70.2%) accessed piped water and 14.1% accessed rainwater in 2007.

Montserrat: In 1997, the Soufriere Hills volcano erupted, leading to the death of 19 people and to relocation of about two thirds of the population of 11,000 to the United Kingdom, the United States, other Eastern Caribbean nations, and to the northern half of the island (http://www.eird.org/wikien/index.php/Montserrat (20/08/2009)). In 2008, total water production was 918.59 mil m^3, of which 43.9% was metered consumption, with the balance as UFW. The Montserrat Utilities Limited indicated on its website that of the metered consumption, most was for domestic (80.2%)

[5] This is expected to represent Unaccounted for Water.

and commercial use (12.8%). Water customers are metered pay a standing charge plus a volume-related charge each month, ranging from EC$15 for less than 1,000 gal to EC$1170 for 30,000 gal[6].

Netherlands Antilles: This group is made up of Curaçao, Bonaire, St. Maarten, St. Eustatius and Saba. In 2008, 69.5% of the 19.6 mil m^3 water produced by the water authority was for Curaçao (Netherlands Antilles Central Bureau of Statistics 2009). In Curaçao[7], the main water source is desalinated seawater, produced by Aqualectra, with minor use of well water, as most of the groundwater is brackish (Aqualectra 2009). Total installed desalination capacity is: 57,000 m^3/day. Each person has a connection to the desalination water supply grid, so there is no unmet water demand. In 2007, a total of 13.718 mil m^3 water was produced. Of this, 28.6% was UFW, 4.7% for use by the water company, 46.5% for domestic use, 10.7% for business/industrial use and the rest for hotels, cruise ships, export and refineries. In 2007, everyone had access to safe drinking water. However, less than 20% of the population had access to central sewage treatment. In December 2008, the average domestic and commercial tariffs for water were: US$7.00/$m^3$, and US$7.20/m^3, respectively, and the total cost of water supplied was approximately US$9.4/$m^3$.

Saint Lucia: A rapidly increasing population and growing tourism sector have resulted in significant increases in water consumption. In 2006, water production was 19.78 mil m^3, which represented an increase of 137.8% from the 1982 level. Over the same period, water consumption doubled to 11.67 mil m^3, and the balance of water was UFW (Central Statistical Office of Saint Lucia 2000 and 2007).

WASA reports indicate that the amount of water supplied annually is about 12.53 mil m^3, with 100% of the urban and 90% of the rural population having access to potable water (FAO 2009). Also, 89% of the urban and rural populations have access to improved sanitation (Encyclopedia of Earth 2010). In 1987, 48.6% of water was demanded by the domestic/minor commercial sector, followed by hotels (9.6%), government (7.0%), industry (2.5%) and UFW (32.3%) (Springer 2010).

The current rates/1,000 gal for domestic users are EC$7.35 for less than 3,000 gal (EC$15, more than 3,000 gal); EC$20 for commercial users; EC$14 for government; EC$40 for ships and EC$22 for hotels.

Trinidad and Tobago: In 1998, available surface water was 3,600 mil m^3/year and 136 mil m^3/year for Trinidad and Tobago, respectively. Total groundwater was estimated at 107 mil m^3/year for both islands. A total of five surface water reservoirs are available with a combined capacity of 75 mill m^3. In 1997, total water withdrawal was 173 mil m^3/year, which represented approximately 5% of available surface water. Of this, withdrawal for domestic use was 68%, industrial 26% and agricultural 6% (FAO 2009). In 2006, total domestic demand for water was 175.52 mil m^3, while non-domestic demand was 58.47 mil m^3. UFW was 200.86 mil m^3. The total system demand of 434.86 mil m^3 was not met as supply was only 365.20 mil m^3 (Trinidad & Tobago WASA 2007).

Total internal renewable resources per capita fell from 4,418.89 in 1962 to 2,890.63 m^3/inhab/yr in 2007. Total water withdrawal per capita increased from 231.31 to 236.62 m^3/inhab/yr between 1997 and 2002, as total surface and groundwater withdrawal increased from 0.30 to 0.31 10^9 m^3/ yr over the same period represented 7.70% and 8.07%, respectively, of the total actual renewable water resources (FAO 2009).

[6] Domestic Tariff: Fixed Charge: 0.20% of the taxable value of the property. Special Cases: Metered consumption below 1000 gallons per month: $15.00 plus no fixed charge. Metered consumption over 30,000 gallons per month: $1170 plus $63.00 per 1000 gallons, plus fixed charge. Commercial and Industrial Tariff: Fixed Charge of 0.20% of the taxable value of the property plus $28.00 per 1000 gallons. Vacant Lots: 0.25% of the taxable value of the land.

[7] Information is provided in this paper about Curaçao, as data on the other islands were not available.

II. LITERATURE REVIEW

Several approaches have been used to estimate the demand for water. In some cases, discrete deterministic dynamic programming models are used to calculate the optimal growth in water supply (Gysi 1971; Power *et al* 1981), with known information about unit water prices, production costs and growth rates for individual sectors. More often, however, multivariate regression models are used (Hansen and Narayanan 1981) which model water demand in specific sectors, such as the municipal sector as a function of climate variables (temperature and rainfall), as well as water price and the day length. Time series and artificial neural network models have also been used to forecast water demand in the short term (Bougadis *et al* 2005). A seasonal index can also be composed (Hall 2003), which can be a function of temperature, sunshine variable and rainfall variables. In this case, temperature was mean temperature, but mean daily maximum values can be used. The sunshine variable used was the total hours of sunshine. The daily average total can also be used. For rainfall, total rainfall depth was used. Total number of rain-days is also appropriate. In composing the Summer Index, each of the variables was given weights, which were chosen so that the weighted standard deviations of the three variables were almost equal. Based on this, a water demand index was estimated using simple linear regression as a function of the Summer Index and a month in summer. This model used only hydrologic data for modeling.

Goodchild (2003) estimated the demand for residential water using daily water demand for Essex, United Kingdom. Stepwise and best subset linear regression analysis was used, where demand was estimated as a function of several climate variables including: evapotranspiration; soil water content; sunshine hours; solar radiation; maximum temperature; rain days since 2mm of rainfall; and rain. This model suggested that evapotranspiration, followed by 'days since rain" and temperature as the variables with the greatest impact on domestic water demand. In general, McKinney *et al* (1999) shows that the non-agricultural demand for water can be modeled as a function of the price of water and alternative sources, consumer's income, the general price of goods and services and other factors such as climate.

III. METHODOLOGY

For each country, water demand by sector was initially estimated using a double log specification in Eviews 5.0 under an Ordinary Least Squares (OLS) procedure[8]. As a result of poor performance, a Random Effects or Error Components Model was then used for each sector, as it was assumed that the countries selected are randomly chosen and taken to be representative of the larger number of countries in the Caribbean. These models provided estimates which are elasticities, leading to easy interpretation. In each case, GDP was measured in constant 1990 dollars of the national currency for each country, using IMF online databases. This model was also utilized as it was felt that given the outcomes of the single equation models, there may be some cross-country restrictions on the impact of the explanatory variables on each sector. However, the differences in the impact of climate change are shown since each country is allowed to have a different intercept parameter. A Random Effects model was estimated using the following specification for each of four sub-sectors:

Residential - $\ln Use_{it} = \beta_{1i} + \beta_2 \ln PCGDP_{2it} + \beta_3 \ln Temp_{3it} + \beta_4 \ln Rain_{4it} + e_{it}$

[8] This resulted in poor results. In each sector temperature was significant for about half of the countries, and rainfall was rarely significant. Estimates of these equations using squared climate variable terms produced even poorer results, and are not shown here.

Industrial - $\ln GDP_{it} = \beta_{1i} + \beta_2 \ln PCGDP_{2it} + \beta_3 \ln Pop_{3it} + \beta_4 \ln Temp_{4it} + \beta_5 \ln Rain_{5it} + e_{it}$

Tourism - $\ln Exp_{it} = \beta_{1i} + \beta_2 \ln Arr_{2it} + \beta_3 \ln Temp_{3it} + \beta_4 \ln Rain_{4it} + e_{it}$

Agricultural - $\ln AgGDP_{it} = \beta_{1i} + \beta_2 \ln Ag\ Land_{2it} + \beta_3 \ln Temp_{3it} + \beta_4 \ln Rain_{4it} + e_{it}$

Where

Use = Pop * Water use (m^3/h/yr).

PCGDP = real per-capita GDP

Temp = mean annual temperature

Rain = mean monthly rainfall

GDP = real GDP

Pop – total population

Exp = Total tourist expenditure (excluding same day tourists)

Arr = Total tourist arrivals.

AgGDP = real agricultural GDP (a proxy of farm income)

AgLand = total acreage of agricultural land

and β_{1i} is assumed o be random as: $\beta_{1i} = \overline{\beta}_1 + \mu_i$, $i = 1,\ldots,9$ (countries under consideration).

Water Use (Use) was estimated at 132.352 m^3/head/yr for all countries based on the water demand for internal unmetered domestic demand in Trinidad and Tobago in 2007 of 376 l/h/day (WASA 2007). Data on land area were obtained from FAOStat online database, and for climate variables in the base period, from the University of Delaware's online water balance data archive. For tourism, data were obtained from the Caribbean Tourism Organization via personal communication, and it was assumed that changes in expenditure per tourist were captured in total tourist expenditure, and that increased visitor expenditure translates to a greater demand for goods and services which utilize water.

IV. RESULTS

Besides the climate variables, two of the most important economic variables expected to impact on water demand are GDP and population growth. From 1980 to 2008, the study countries had an upward trend in their population levels, but from the early 1990s, the population growth rate has been fairly steady at about 1.0% annual growth. During the same period, each country experienced variations in the annual growth rate of GDP, with some countries like Guyana suffering significant negative impacts on GDP as a result of extreme weather events. Overall, however, the region (study countries) had an upward trend in its GDP annual growth rate, which is expected to have a positive impact on water demand, unless the per-capita demand for water falls to counteract this effect.

A. Base Scenario - Temperature and Rainfall

The base scenario is for 1970 to 2006. The average monthly temperature and rainfall for each country are shown in table 1, with trends for the Caribbean shown in figure 1. Each of the individual countries (not shown here) had an increasing trend in average annual temperatures, except Barbados and Trinidad and Tobago. All of these trends, when evaluated in Eviews, were significant at the 5% level, except for Guyana and Saint Lucia. For the Caribbean, the trend indicated that the average annual temperature increased by 0.01 °C, which was significant at the 5% level.

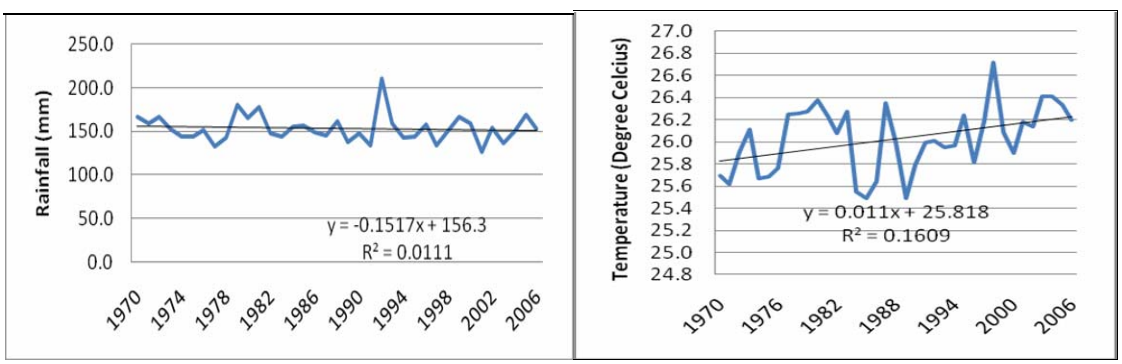
Table 1: Mean Temperature and Rainfall (1970 – 2006)

	Aru	Bar	DR	Guy	Ja	Mon	NA	SL	TT	Car
Temp (°C)	27.2	26.5	25.0	27.6	22.5	26.6	26.5	26.5	25.8	26.0
Rain (mm)	38.7	247.1	161.5	258.1	128.8	114.8	75.6	202.4	153.7	153.4

Source: INSMET, Cuba

For all countries (not shown here), rainfall had a downward trend, except for Aruba, Guyana and the Netherlands Antilles. The Caribbean had a small downward trend, however, for each country and for the region, time had no statistically significant impact on the level of rainfall, either at the 5% or 10% level.

Figure 1: Regional Rainfall and Temperature in the Base Scenario



Source: Prepared by author.

B. Water Demand Estimates

This section shows the Random Effects model estimates for the subsectors. The cross random effects, in general, shows the differences in the intercept (μ_i) for each country, relative to the mean regional intercept (C), and therefore indicates differences in country behaviour.

Residential Sector: Estimates of the impact of per capita GDP, temperature and rainfall on residential water use are shown in table 2.

Table 2: Random Effects Model Estimates for the Residential Sector

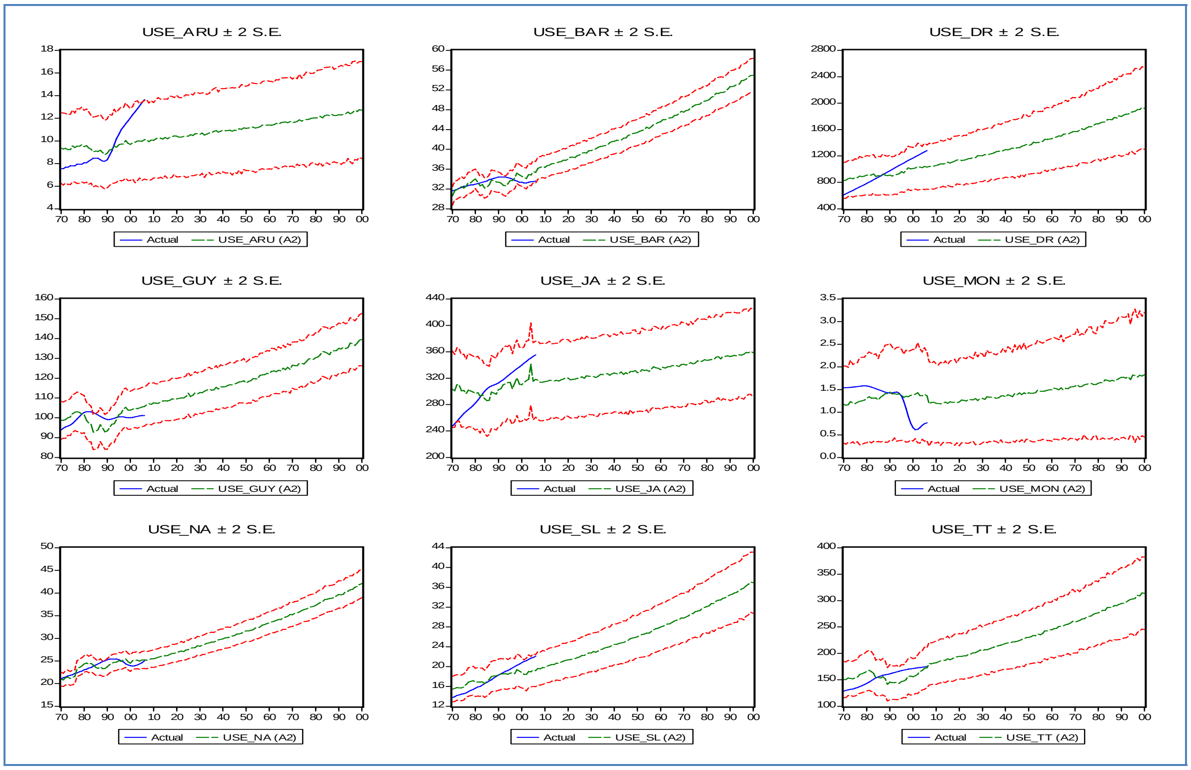
Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-0.908909	1.547523	-0.587332	0.5574
LOG(PCGDP)	0.193631	0.039557	4.894958	0.0000
LOG(AVETEMP)	0.853962	0.459053	1.860267	0.0637
LOG(RAIN)	0.012348	0.047930	0.257631	0.7969
Random Effects (Cross)				
ARU--C	-1.705188			
BAR--C	-0.277719			
DR--C	3.105733			
GUY--C	0.628403			
JA--C	2.072366			
MON--C	-3.536918			
NA--C	-0.674998			
SL--C	-0.789550			
TT--C	1.177872			

Source: Prepared by author.

Per capita GDP and temperature were found to be significant at the 5% and 10% level, respectively. A 1% increase in per capita GDP, temperature and rainfall is expected to raise residential water use by 0.19%, 0.85% and 0.01%, respectively, for all countries. However, rainfall was not shown to have any statistically significant impact. Overall, the model fit in the base period was poor, and did not show any consistent trend across countries. Furthermore, there were sometimes big gaps in the actual and fitted values in more recent years. This is highlighted further in Figure 2, as in most cases the standard deviations of the projections were fairly wide, which indicates a low confidence in estimating precisely the path of residential water use in the future.

Industrial Sector: Estimates of the Random Effects model for the industrial sector are shown in table 3. Per capita GDP and population were found to be extremely significant at the 5% level. A 1% increase in per capita GDP and in population is expected to raise industrial GDP by 0.96% and 1.30% respectively, for all countries. However, both temperature and rainfall were not shown to have any statistically significant impacts on industrial GDP. Overall, the fit of the model in the Base period was good, especially for the Dominican Republic, Saint Lucia and Trinidad and Tobago. This is highlighted further in figure 3, as in most cases the standard deviations of the projections were fairly narrow, which indicates a high confidence in estimating precisely the path of industrial GDP in the future.

Figure 2: Mean +- 2 Standard Deviations for Fitted Residential Water Use, 1970–2100, under the A2 Scenario



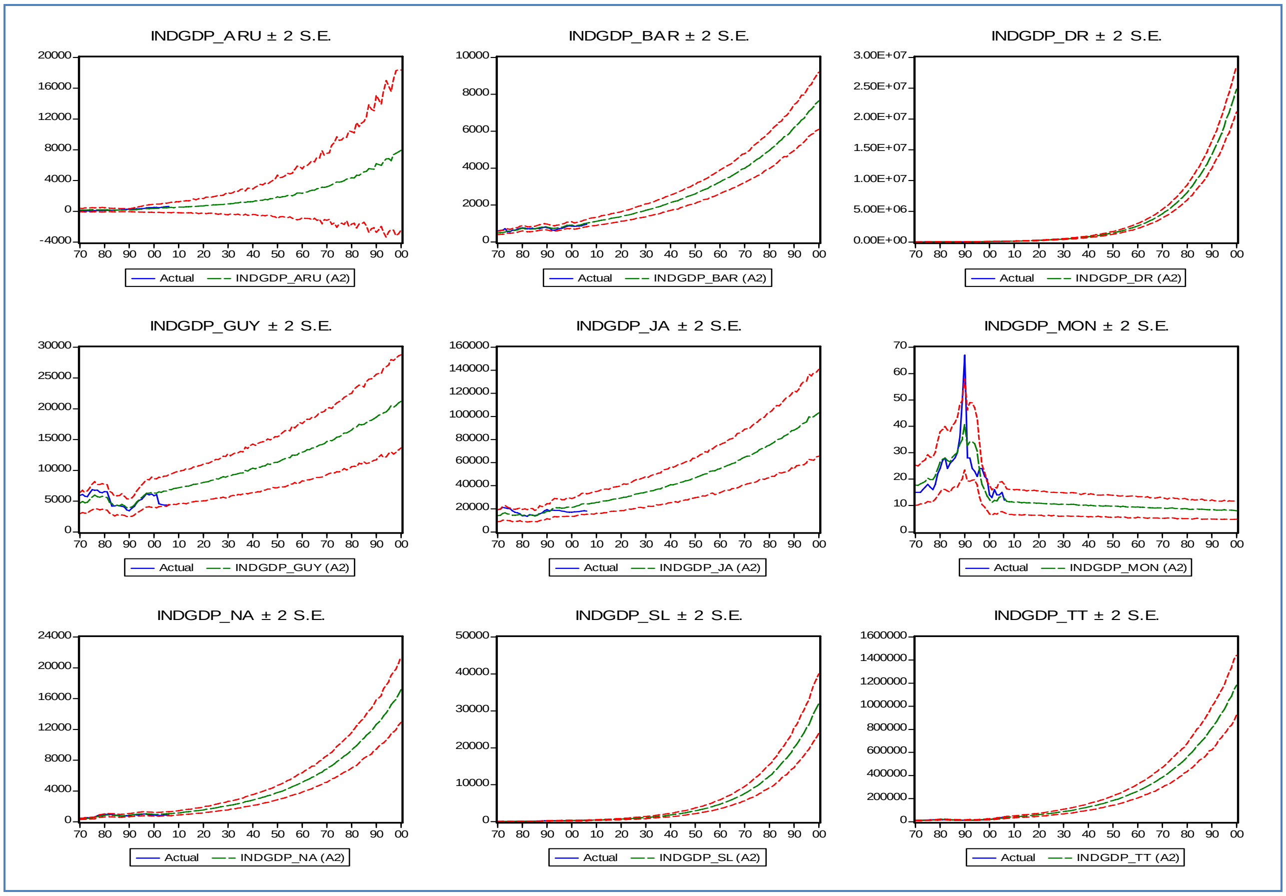
Source: Prepared by author.

Table 3: Random Effects Model Estimates for the Industrial Sector

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-3.135208	2.301378	-1.362318	0.1740
LOG(PCGDP)	0.964951	0.064834	14.88336	0.0000
LOG(POP)	1.296409	0.060655	21.37345	0.0000
LOG(AVETEMP)	0.639250	0.720582	0.887130	0.3757
LOG(RAIN)	0.092939	0.074994	1.239280	0.2161
Random Effects (Cross)				
ARU--C	-0.545239			
BAR--C	-0.178102			
DR--C	-0.123391			
GUY--C	-0.468415			
JA--C	0.223215			
MON--C	0.753380			
NA--C	0.052602			
SL--C	-0.165815			
_TT--C	0.451764			

Source: Prepared by author.

Figure 3: Mean +- 2 Standard Deviations for Fitted Industrial GDP, 1970 – 2100, under the A2 Scenario



Source: Prepared by author.

Tourism Sector: Table 4 shows Estimates of the Random Effects model for the tourism sector

Table 4: Random Effects Model Estimates for the Tourism Sector

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-11.75379	3.613341	-3.252887	0.0014
LOG(ARR)	0.838682	0.049083	17.08701	0.0000
LOG(AVETEMP)	3.641742	1.081764	3.366484	0.0010
LOG(RAIN)	0.134163	0.093475	1.435283	0.1532
Random Effects (Cross)				
ARU--C	0.171057			
BAR--C	0.371695			
DR--C	0.369963			
GUY--C	-0.735102			
JA--C	0.773820			
MON--C	-0.737314			
NA--C	0.167816			

SL--C	0.044371
_TT--C	-0.426306

Source: Prepared by author.

In this case, tourist arrivals and temperature were found to be extremely significant at the 5% level. A 1% increase in tourist arrivals and temperature is expected to raise tourism expenditure by 0.84% and by 3.64% for all countries. Similar to the residential and industrial sectors, rainfall was not estimated to have any statistically significant impact on tourism expenditure. Overall, the fit of the model in the base period was fair (not shown), and performed well especially for Montserrat and Saint Lucia. In most cases the standard deviations of the projections were fairly narrow.

Agricultural sector: Estimates of the Random Effects model for the agricultural sector are shown in table 5. In this case, all the explanatory variables were found to have a statistically significant effect on agricultural GDP. As is expected, the quantity of agricultural land had a positive impact on agricultural GDP, as a 1% increase in land is expected to raise agricultural GDP by 1.0% for all countries. Rainfall and temperature are also estimated to have positive effects on agricultural GDP. While the elasticity measure for rainfall was 0.23, the expected impact of temperature was much larger, with an elasticity of 3.11. Overall, the fit of the model in the base period was poor (not shown), with fairly wide standard deviations of the projections in most cases.

Table 5: Random Effects Model Estimates for the Agricultural Sector

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-9.883903	3.742274	-2.641149	0.0087
LOG(AREA)	0.995264	0.067702	14.70073	0.0000
LOG(AVETEMP)	3.106265	1.122037	2.768415	0.0060
LOG(RAIN)	0.227997	0.124114	1.836996	0.0671
Random Effects (Cross)				
ARU--C	-0.340867			
BAR--C	0.551116			
DR--C	0.155158			
GUY--C	0.050223			
JA--C	0.607766			
MON--C	-1.099335			
NA--C	-0.362930			
SL--C	-0.062358			
_TT--C	0.501227			

Source: Prepared by author.

C. Costs and Benefits of Climate Change

In order to determine the impact of climate change on the water sector, projections have to be made about water use under a scenario of no climate change. This scenario was determined in this study, and it was assumed that the mean monthly temperature and rainfall of the baseline period existed for all years from 2007 to 2099. Then, the projected water uses under the A2, B2 and BAU scenarios were calculated. The temperature and rainfall projections for the A2 scenario to 2100 were obtained from the University of Oxford, Department of Geography. The temperature and rainfall projections for the B2 scenario to 2099 were obtained from the Institute of Meteorology in Cuba (INSMET). The A2 scenario represents a future where $C0_2$ emissions are in the medium to medium-high range, and the B2 scenario, is a possible future where the $C0_2$ emissions are in the low to medium range. The BAU scenario was determined by using the mean of the A2 and B2 temperature and rainfall projections[9].

For all scenarios, forecasts were made within this study for all non-climate variables, as these projections were not available. Tourist arrivals were also forecasted to increase by the average annual increase in the base period, for each country. Agricultural land was forecasted to decrease by 0.05% per year, from the 2006 level. This figure was randomly chosen to represent a nominal decline in agricultural land, as there is severe competition for land in the Caribbean, even though some countries had positive projections for agricultural land area in the base period, which usually did not reflect more recent country experiences. Further, population and per capita GDP were forecasted to increase at the average growth rate for each country in the base period. The income impact of climate change was then determined as *the difference* in forecasted industrial GDP, agricultural GDP and tourism expenditure under the A2, B2 and BAU scenarios, relative to these outcomes where no climate change exists. These impacts are shown in table 6. Some countries, such as Aruba, Jamaica, and the Netherlands Antilles are expected to benefit from climate change in terms of total income under all three scenarios. On the contrary, no country was made worse off in terms of total income under these possible futures. Where countries suffered a loss of income, this occurred mostly under the B2 scenario, and in 5 cases, the B2 scenario resulted in the smallest gains or largest losses. By 2099, the Dominican Republic was estimated to have the largest gain in total income of US$456,870.36 million under the A2 scenario. Overall, no scenario consistently resulted in the least costs to all countries. With no action (BAU), Montserrat will suffer a loss of income for the greatest length of time.

Toba (2007) estimated that sea-level would rise by 0.35m for CARICOM countries, based on an assumption of a 2°C temperature rise between 1980 and 2099. As a result, he determined that this would lead to an 8% loss of land over the period, and an associated loss of water connection and sanitation infrastructure. Relative to the mean temperature in the Baseline of 26°C, temperature was expected to rise by 2.3°C, 3.4°C and 2.9°C, respectively, under the A2, B2 and BAU scenarios.

Table 6: Change in Total Income[10] Relative to the Scenario of No Climate Change (1990 US$ million)

	A2	B2	BAU	A2	B2	BAU	A2	B2	BAU
	Aruba	Aruba	Aruba	Guyana	Guyana	Guyana	NA	NA	NA
2020	34.41	-3.19	15.53	14.86	-45.61	-9.65	34.93	-137.13	35.19
2030	65.83	101.34	84.18	26.90	-27.36	5.01	50.82	70.37	89.12
2040	136.10	108.33	122.98	31.87	-40.07	1.61	83.45	249.69	101.28

[9] This was done based on the advice of INSMET, as the BAU case would simulate a possible future with intermediate $C0_2$ emissions, between the relatively high-emission A2 case and the relatively low-emission B2 case.
[10] Total Income refers to the sum of Agricultural GDP, Industrial GDP and Tourism Expenditure.

2050	314.65	246.23	280.39	36.17	-55.19	3.48	145.40	578.88	153.06
2060	485.25	527.94	512.13	53.87	-44.86	13.80	182.65	1,204.79	217.05
2070	713.97	916.89	831.63	72.43	-27.87	30.99	222.57	2,289.10	281.02
2080	1,428.54	1,135.38	1,284.13	87.89	-19.10	41.29	353.37	3,696.26	315.76
2090	2,888.86	2,390.74	2,639.80	116.77	-24.16	55.98	589.23	6,047.65	533.71
2099	4,374.40	3,592.75	4,053.25	142.85	-5.12	76.04	761.53	9,754.22	754.66
	Bdos	Bdos	Bdos	Jamaica	Jamaica	Jamaica	St. Lucia	St. Lucia	St. Lucia
2020	49.73	-136.67	-5.95	68.26	-125.52	321.29	19.35	-37.09	-0.16
2030	71.67	-109.71	32.84	163.86	425.30	510.25	37.36	-10.29	21.94
2040	111.10	-230.34	19.98	290.16	104.10	741.71	84.06	-45.77	31.24
2050	148.21	-235.32	66.55	478.08	1,363.34	1,228.65	162.54	-90.90	84.72
2060	220.41	-252.66	96.79	711.16	1,629.47	1,783.64	304.89	-57.13	163.78
2070	271.93	-174.77	167.75	1,599.80	3,641.38	3,170.64	508.74	156.05	357.99
2080	375.15	-346.43	193.92	2,565.92	5,257.76	4,891.60	961.79	402.60	657.58
2090	565.88	-285.54	344.80	4,946.93	10,544.67	8,796.56	1,907.62	672.45	1,306.16
2099	703.35	-229.33	438.62	7,959.84	10,652.91	13,108.90	3,209.97	1,688.42	2,260.07
	DR	DR	DR	Mont-serrat	Mont-serrat	Mont-serrat	T& T	T& T	T& T
2020	1,092.01	-10,441.23	-2,393.41	-1.32	-0.11	-0.70	227.49	215.75	233.59
2030	2,120.21	-12,080.91	-2,464.58	-1.04	0.25	-0.42	396.50	687.40	590.74
2040	4,854.03	-31,102.20	-5,356.23	-0.87	0.11	-0.38	769.92	387.06	715.87
2050	10,681.98	-42,221.87	-3,522.05	-0.77	0.14	-0.30	1,542.82	-871.86	897.80
2060	24,699.44	-66,410.66	-705.21	-0.61	0.18	-0.21	2,436.62	-230.16	1,755.93
2070	59,114.55	-92,537.09	15,765.40	-0.58	0.31	-0.14	3,808.11	1,374.88	3,527.40
2080	112,857.47	-198,492.38	24,268.40	-0.47	0.03	-0.18	6,766.37	3,513.73	6,462.81
2090	253,403.89	-257,036.93	111,103.47	-0.36	0.25	-0.03	12,555.97	2,869.26	10,303.57
2099	456,870.36	-457,956.76	163,154.37	-0.30	0.33	0.01	19,590.31	8,932.89	17,516.91

Source: Prepared by author

Therefore, the rate of land loss was adjusted to be 9.2%, 13.6% and 11.6% under the three scenarios. Based on this, the cost of sea-level rise to these infrastructures was calculated (table 7). Using investment costs of US$400 and US$700 for water and sanitation connections per household, respectively, projected populations (with 4.1 persons per household) (Toba 2007) were used to determine costs[11].

Table 7: Costs Due to Loss in Water Connection and Sanitation Infrastructure (2007 US $ million)

	A2	B2	BAU	A2	B2	BAU	A2	B2	BAU
	Aruba	Aruba	Aruba	Guyana	Guyana	Guyana	NA	NA	NA
2020	0.0019	0.0029	0.0024	0.0117	0.0173	0.0148	0.0030	0.0044	0.0038
2030	0.0037	0.0055	0.0047	0.0194	0.0288	0.0246	0.0051	0.0076	0.0065
2040	0.0071	0.0106	0.0090	0.0323	0.0479	0.0409	0.0088	0.0130	0.0111
2050	0.0137	0.0203	0.0174	0.0538	0.0796	0.0680	0.0150	0.0222	0.0190
2060	0.0264	0.0391	0.0334	0.0895	0.1325	0.1132	0.0257	0.0380	0.0325
2070	0.0507	0.0751	0.0642	0.1488	0.2203	0.1882	0.0439	0.0650	0.0555
2080	0.0975	0.1444	0.1234	0.2475	0.3664	0.3131	0.0750	0.1111	0.0949
2090	0.1875	0.2776	0.2372	0.4117	0.6095	0.5207	0.1282	0.1899	0.1622
2099	0.3378	0.5000	0.4272	0.6508	0.9635	0.8231	0.2078	0.3076	0.2628
	Barbados	Barbados	Barbados	Jamaica	Jamaica	Jamaica	St. Lucia	St. Lucia	St. Lucia
2020	0.0039	0.0057	0.0049	0.0459	0.0679	0.0580	0.0030	0.0044	0.0038
2030	0.0064	0.0095	0.0081	0.0827	0.1224	0.1045	0.0055	0.0082	0.0070
2040	0.0106	0.0157	0.0134	0.1489	0.2204	0.1883	0.0103	0.0152	0.0130
2050	0.0176	0.0260	0.0222	0.2681	0.3969	0.3391	0.0191	0.0283	0.0242
2060	0.0291	0.0431	0.0368	0.4829	0.7149	0.6107	0.0356	0.0526	0.0450
2070	0.0483	0.0714	0.0610	0.8698	1.2876	1.1000	0.0661	0.0978	0.0836
2080	0.0799	0.1184	0.1011	1.5665	2.3191	1.9812	0.1228	0.1818	0.1553
2090	0.1325	0.1961	0.1675	2.8215	4.1769	3.5683	0.2281	0.3377	0.2885
2099	0.2087	0.3089	0.2639	4.7913	7.0930	6.0596	0.3984	0.5898	0.5039
	D R	D R	D R	Montserrat	Montserrat	Montserrat	T&T	T&T	T&T
2020	0.1920	0.2843	0.2428	0.0001	0.0001	0.0001	0.0222	0.0328	0.0280
2030	0.3846	0.5694	0.4864	0.0001	0.0001	0.0001	0.0394	0.0583	0.0498
2040	0.7704	1.1405	0.9743	0.0001	0.0002	0.0002	0.0699	0.1035	0.0884
2050	1.5431	2.2844	1.9515	0.0002	0.0003	0.0002	0.1241	0.1837	0.1569

[11] Toba (2007) also assumed a 5% real interest rate and a 30-year life of water and sanitation connections, therefore the value of the infrastructure was set to increase by 5% each year, and the investment cost was used on an annual basis, over a 30-year life span.

2060	3.0908	4.5756	3.9090	0.0002	0.0003	0.0003	0.2202	0.3260	0.2785
2070	6.1910	9.1651	7.8298	0.0003	0.0005	0.0004	0.3910	0.5788	0.4945
2080	12.4006	18.3578	15.6832	0.0004	0.0006	0.0005	0.6941	1.0275	0.8778
2090	24.8387	36.7710	31.4137	0.0006	0.0009	0.0007	1.2322	1.8241	1.5583
2099	46.4136	68.7104	58.6996	0.0008	0.0012	0.0010	2.0654	3.0576	2.6121

Source: Prepared by author.

All countries bore the most costs under the B2 scenario, which represented the highest sea-level rise of 0.595 m[12]. Countries with the biggest populations: Dominican Republic, Jamaica and Trinidad and Tobago had the largest costs. In general, costs were highest in the B2 scenario, followed by BAU and then A2. When these costs were combined with the changes in total income as a result of climate change, the aggregate costs are shown in table 8.

Table 8: Change in Income Combined with Loss in Water Connection and Sanitation Infrastructure (US$ million)

	A2	**B2**	**BAU**	**A2**	**B2**	**BAU**	**A2**	**B2**	**BAU**
	Aruba	Aruba	Aruba	Guyana	Guyana	Guyana	NA	NA	NA
2020	34.41	-3.19	15.53	14.88	-45.59	-9.63	34.93	-137.12	35.19
2030	65.84	101.34	84.18	26.92	-27.33	5.04	50.83	70.38	89.13
2040	136.11	108.35	122.99	31.91	-40.02	1.65	83.46	249.70	101.29
2050	314.66	246.25	280.41	36.22	-55.11	3.54	145.42	578.91	153.08
2060	485.28	527.98	512.17	53.96	-44.73	13.91	182.67	1,204.82	217.08
2070	714.02	916.96	831.69	72.58	-27.65	31.18	222.61	2,289.16	281.08
2080	1,428.64	1,135.52	1,284.25	88.13	-18.73	41.60	353.45	3,696.37	315.85
2090	2,889.05	2,391.02	2,640.04	117.19	-23.55	56.50	589.36	6,047.84	533.87
2099	4,374.74	3,593.25	4,053.68	143.50	-4.15	76.87	761.73	9,754.53	754.93
	Barbados	Barbados	Barbados	Jamaica	Jamaica	Jamaica	St. Lucia	St. Lucia	St. Lucia
2020	49.73	-136.66	-5.94	68.31	-125.46	321.35	19.36	-37.08	-0.15
2030	71.67	-109.70	32.85	163.94	425.42	510.36	37.37	-10.28	21.94
2040	111.11	-230.32	19.99	290.31	104.32	741.90	84.07	-45.76	31.25
2050	148.23	-235.29	66.57	478.35	1,363.74	1,228.99	162.56	-90.88	84.75
2060	220.44	-252.62	96.82	711.64	1,630.19	1,784.25	304.93	-57.08	163.83
2070	271.97	-174.70	167.81	1,600.67	3,642.67	3,171.74	508.81	156.15	358.07
2080	375.23	-346.31	194.02	2,567.49	5,260.08	4,893.58	961.91	402.79	657.73
2090	566.01	-285.34	344.97	4,949.75	10,548.84	8,800.13	1,907.85	672.78	1,306.45
2099	703.56	-229.02	438.89	7,964.63	10,660.00	13,114.96	3,210.37	1,689.01	2,260.57
	DR	DR	DR	Montserrat	Montserrat	Montserrat	T&T	T&T	T&T
2020	1,092.20	-10,440.95	-2,393.16	-1.32	-0.11	-0.70	227.51	215.78	233.62
2030	2,120.59	-12,080.34	-2,464.09	-1.04	0.25	-0.42	396.54	687.46	590.79
2040	4,854.80	-31,101.06	-5,355.26	-0.86	0.11	-0.38	769.99	387.17	715.95
2050	10,683.52	-42,219.59	-3,520.10	-0.77	0.14	-0.30	1,542.95	-871.67	897.96

[12] Sea-level rise under the A2 and BAU scenarios was calculated as 0.4025 and 0.5075 m, respectively.

2060	24,702.53	-66,406.09	-701.30	-0.61	0.18	-0.21	2,436.84	-229.83	1,756.20
2070	59,120.74	-92,527.93	15,773.23	-0.58	0.31	-0.14	3,808.50	1,375.46	3,527.90
2080	112,869.87	-198,474.02	24,284.08	-0.46	0.03	-0.18	6,767.07	3,514.76	6,463.69
2090	253,428.73	-257,000.16	111,134.88	-0.35	0.26	-0.03	12,557.20	2,871.09	10,305.13
2099	456,916.77	-457,888.05	163,213.07	-0.30	0.33	0.02	19,592.38	8,935.95	17,519.52

Source: Prepared by author

Overall, all countries, with the exception of Trinidad and Tobago, are expected to suffer aggregate losses as result of climate change, in the early periods ca. 2020 under one or more scenarios. Over time, some countries experience declining negative impacts, as in the case of Guyana under the B2 scenario. Some countries, such as the Dominican Republic, is projected to suffer increasing losses under the B2 scenario, and for others, the impacts do not follow a defined trend. The A2 scenario offers the best outcome for all countries, except Jamaica (where BAU is most desirable), Montserrat (which performs most poorly under the A2 scenario), and the Netherlands Antilles, which does best under the B2 case. The discounted aggregate costs of climate change between 2010 and 2099 using discount rates of 0.5%, 2% and 4% were calculated and are shown for each country and for the Caribbean, under each scenario, in table 9 below.

Table 9: Net Present Value of Changes in Total Income and Loss of Infrastructure – A2 (US$ million)

A2	**Aru**	**Bar**	**DR**	**Guy**	**Ja**	**Mon**	**NA**	**SL**	**TT**	**Car**
(.05%)	96,699	31,397	15,951,980	171,107	683,256	-163	25,698	98,456	1,086,155	18,144,585
(2%)	34,931	13,377	5,335,563	77,727	246,710	-111	10,620	34,745	399,218	6,152,779
(4%)	10,492	5,336	1,382,707	34,165	74,685	-77	4,051	10,022	124,452	1,645,832
B2	**Aru**	**Bar**	**DR**	**Guy**	**Ja**	**Mon**	**NA**	**SL**	**TT**	**Car**
(.05%)	84,857	-31,767	-22,295,455	-122,940	1,250,613	19	221,005	23,842	278,384	-20,591,441
(2%)	30,977	-17,235	-8,550,952	-77,574	445,006	7	75,628	5,801	106,527	-7,981,815
(4%)	9,317	-9,537	-2,887,405	-49,462	125,330	2	18,638	-183	36,669	-2,756,632
BAU	**Aru**	**Bar**	**DR**	**Guy**	**Ja**	**Mon**	**NA**	**SL**	**TT**	**Car**
(.05%)	91,757	15,707	4,599,962	50,577	1,294,031	-70	26,993	63,943	921,625	7,064,524
(2%)	33,308	5,892	1,267,700	14,760	496,587	-51	11,573	21,989	341,867	2,193,625
(4%)	10,015	1,738	153,581	539	169,467	-37	4,652	5,883	108,095	453,933

Source: Prepared by author.

Under the A2 scenario, all countries are expected to gain from climate change in the water sector, based on costs to loss of infrastructure and income, except for Montserrat, which will only gain under B2. The costs due to flooding under extreme events were not included here as estimates of this on water supply alone could not be disaggregated from existing data. The gains in the Caribbean under the A2 scenario is largely accounted for by the expected performance gains of the Dominican Republic, which by comparison, dwarf the gains in other countries. The Caribbean will suffer negative impacts overall under the B2 scenario, but Aruba, Jamaica, Montserrat, the Netherlands Antilles and Trinidad and Tobago will gain here. Here again, most of the losses occur in the Dominican Republic. If there is no change (BAU), the Caribbean will still gain overall as a result of climate change, with the Jamaica accounting for approximately 40% of the gains, followed by the Dominican Republic (33% of gains) and Trinidad and Tobago (24% of gains), with a discount rate of 4%.

Forecasts of the socio-economic variables for 2030, 2050, 2070 and 2099 relative to 2006 actual values are shown in tables 10– 2 below. Forecasts for the climate variables relative to the base period are shown in the annex.

Table 10: Projected Levels and Percentage Change in Industrial GDP Relative to 2006 – A2 Scenario

obs	ARU	BAR	DR	GUY	JA	MON	NA	SL	TT
2006	397.67	1,016.06	126,502.90	6,713.78	23,420.73	12.51	1,030.16	352.52	34,885.09
2030	784.26	1,705.55	485,601.60	8,896.87	33,870.77	10.21	2,064.68	1115.45	86,892.38
% Δ	*97.21*	*67.86*	*283.87*	*32.52*	*44.62*	*-18.36*	*100.42*	*216.43*	*149.08*
2050	1,446.01	2,610.31	1,486,326.00	11,224.92	46,200.96	9.43	3,774.56	2,912.01	18,3029.50
% Δ	*263.62*	*156.91*	*1,074.93*	*67.19*	*97.27*	*-24.60*	*266.40*	*726.06*	*424.66*
2070	2,583.11	3,987.62	4,589,505.00	14,393.05	63,391.88	8.76	6,789.87	7,540.83	381,718.70
% Δ	*549.56*	*292.46*	*3,527.98*	*114.38*	*170.67*	*-29.98*	*559.11*	*2,039.14*	*994.22*
2100	6,603.21	7,603.29	24,731,650.00	20,820.71	101,395.80	7.90	16,970.61	31,839.32	1,175,322.00
% Δ	*1,560.48*	*648.31*	*19,450.26*	*210.12*	*332.93*	*-36.86*	*1,547.37*	*8,932.02*	*3269.12*

Source: Prepared by author.

Table 11: Projected Levels and Percentage Change in Tourism Expenditure Relative to 2006 – A2 Scenario

obs	ARU	BAR	DR	GUY	JA	MON	NA	SL	TT
2006	717.71	953.40	3,792.20	86.60	1,888.00	7.75	1,018.62	293.95	260.30
2030	1,609.22	1,060.25	11,195.76	202.81	4,429.67	0.74	841.10	921.05	759.10
% Δ	*124.22*	*11.21*	*195.23*	*134.19*	*134.62*	*-90.40*	*-17.43*	*213.33*	*191.63*
2050	3,663.82	1,397.26	34,168.44	433.89	11,314.21	0.20	1,024.93	2,289.12	1,991.63
% Δ	*410.49*	*46.56*	*801.02*	*401.02*	*499.27*	*-97.37*	*0.62*	*678.74*	*665.13*
2070	7,816.77	1,856.56	110,394.90	1,041.65	30,641.09	0.06	1,196.17	5,585.05	5,047.66
% Δ	*989.13*	*94.73*	*2,811.10*	*1,102.83*	*1,522.94*	*-99.24*	*17.43*	*1,799.99*	*1,839.17*
2100	28,118.15	2,945.97	611,073.00	3,735.41	133,789.40	0.01	1,661.68	22,462.50	22,031.67

% Δ	*3,817.76*	*209.00*	*16,013.94*	*4,213.40*	*6,986.30*	*-99.88*	*63.13*	*7541.55*	*8,363.95*

Source: Prepared by author.

Table 12: Projected Levels and Percentage Change in Agricultural GDP Relative to 2006 – A2 Scenario

obs	ARU	BAR	DR	GUY	JA	MON	NA	SL	TT
2006	10.00	133.00	15,640.00	13,707.00	2,458.00	1.00	26.00	46.00	565.00
2030	4.43	148.40	9,597.94	9,206.26	2,160.22	2.26	18.80	48.10	332.97
% Δ	*-55.73*	*11.58*	*-38.63*	*-32.84*	*-12.11*	*125.69*	*-27.68*	*4.56*	*-41.07*
2050	4.29	141.34	9,101.31	8,647.34	2,065.50	2.12	18.34	46.45	325.99
% Δ	*-57.09*	*6.27*	*-41.81*	*-36.91*	*-15.97*	*111.73*	*-29.45*	*0.97*	*-42.30*
2070	3.81	134.84	9,042.31	8,902.08	2,061.21	2.06	17.01	43.80	307.93
% Δ	*-61.93*	*1.38*	*-42.18*	*-35.05*	*-16.14*	*106.35*	*-34.59*	*-4.78*	*-45.50*
2100	3.86	130.26	8,617.07	9,052.46	2,015.18	2.01	16.99	42.25	306.40
% Δ	*-61.42*	*-2.06*	*-44.90*	*-33.96*	*-18.02*	*101.16*	*-34.65*	*-8.15*	*-45.77*

Source: Prepared by author.

Changes in actual water demand were determined using the expected changes in the proxy variables over time, and using actual water demand, by sector, for each country. Actual residential water demand was available for all countries, and this case is presented below in tables 13 and 14. As anticipated, residential demand rises for all countries with no climate change. Climate change is expected to raise residential water demand the most, to 218.4 million m^3 by 2099 under the B2 scenario, with the smallest increase under the A2 scenario. Countries should expect an increase in residential water demand as population pressures dominate water demand, if per-capita use does not decline. However, these estimates exclude the population effects, as it captures the change in water demand under the various scenarios.

Table 13: Water Demand in the Residential Sector with No Climate Change (10^6 m^3)

obs	ARU	BAR	DR	GUY	JA	MON	NA	SL	TT	Caribbean
2006	8.309	11.457	679.860	1.003	219.100	0.339	6.281	6.689	175.523	
2030	6.220064	13.21131	618.2947	1.082298	193.2926	0.608415	6.93391	6.700149	198.0878	1,044.4312
2050	6.435142	14.23164	693.6777	1.119722	194.7395	0.655954	7.609564	7.563777	219.2629	1,145.2959
2070	6.657662	15.33078	778.2515	1.158441	196.1972	0.707208	8.35106	8.538725	242.7016	1,257.8942
2099	6.994051	17.07705	919.5277	1.216972	198.3304	0.788722	9.556417	10.17986	281.2083	1,444.8795

Source: Prepared by author.

Table 14: Change in Residential Water Demand Relative to No Climate Change (10^6 m^3)

A2	ARU	BAR	DR	GUY	JA	MON	NA	SL	TT	Caribbean
2006	8.309	11.457	679.860	1.003	219.100	338.714	6.281	6.689	175.523	
2030	0.0933	0.3793	11.2226	0.0397	4.3933	-0.1259	0.1642	0.1531	6.3395	22.6591
2050	0.2063	0.6907	23.6887	0.0540	6.8790	-0.1341	0.4023	0.3449	14.0391	46.1709
2070	0.2825	1.1576	54.8799	0.1105	12.2586	-0.1238	0.6447	0.5991	22.5239	92.3331
2099	0.5499	2.4222	118.5572	0.1948	20.3025	-0.0855	1.4516	1.4663	49.5930	194.4519
B2										
2006	8.309	11.457	679.860	1.003	219.100	338.714	6.281	6.689	175.523	
2030	0.1098	0.5248	17.3594	0.0287	30.2679	0.0543	0.3841	0.2381	20.6312	69.5983
2050	0.1757	0.6367	37.8573	0.0287	34.6478	0.0788	0.5759	0.2902	24.8034	99.0944
2070	0.2806	1.2047	70.6446	0.0622	38.9373	0.1184	0.8922	0.6324	38.8062	151.5787
2099	0.4009	1.9981	107.1771	0.1000	43.6225	0.1709	1.3761	1.2364	62.3006	218.3825
BAU										
2006	8.309	11.457	679.860	1.003	219.100	338.714	6.281	6.689	175.523	
2030	0.1018	0.5211	15.7552	0.0357	18.3083	-0.0347	0.2743	0.2269	13.5844	48.7731
2050	0.1910	0.7932	33.8866	0.0455	21.7670	-0.0258	0.4905	0.3816	19.8705	77.4001
2070	0.2832	1.2961	66.2257	0.0892	26.6793	-0.0013	0.7686	0.6802	30.9243	126.9454
2099	0.4781	2.3591	117.7579	0.1500	34.4749	0.0441	1.4139	1.4331	56.1729	214.2841

Source: Prepared by author.

When the relative changes by sector for each country are applied to actual water demand in 2006, the total change in water demand is shown in table 15. Overall, relative to 2006, the total demand for water in the Caribbean is expected to fall by 2030 by 11.3% to approximately 12,967 million cubic meters. This is due to the expected fall in agricultural water demand by approximately 36% in that period. However, by 2050, total water demand for the Caribbean will again exceed the 2006 level by approximately 4% to 14,896.33 10^6 m^3. By 2100, water demand will increase almost fivefold to approximately 69,233.69 10^6 m^3.

Table 15: Change in Water Use by Sector for the Caribbean, Relative to 2006 – A2 Scenario

Water (10^6 m^3)		Agric	Ind	Resid	Tour	UFW	Total
	2006	7,519.23	518.84	1,108.56	53.65	5,075.03	14,275.31
	2030	4,734.33	1,402.51	1,068.09	149.87	5,075.03	12,429.83
% Δ		*-37.04*	*170.32*	*-3.65*	110.20		
	2050	4,491.95	3,698.52	1,188.93	441.90	5,075.03	14,896.33
% Δ		*-40.26*	*612.85*	*7.25*	*723.62*		
	2070	4,466.11	10,518.55	1,338.02	1,387.59	5,075.03	22,785.29
% Δ		*-40.60*	*1,927.32*	*20.70*	*2,486.18*		
	2100	4,269.57	50,795.08	1,590.24	7,503.78	5,075.03	69,233.69
% Δ		*-43.22*	*9,690.15*	*43.45*	*13,885.50*		

Source: Prepared by author.

D. MITIGATION AND ADAPTATION

Mitigation in the water sector is not well documented, as the main focus of mitigation is the energy sector, which accounts for a large part of the emission of green house gases which lead to global warming, and climate change. Despite this, drinking water companies are often "electricity guzzlers", therefore, the water utilities can focus on changing their energy usage in a bid to reduce the impact of the water sector on climate change. Therefore, the main mitigation measures proposed are to reduce the climate footprint of water agencies (in drinking water supply, sewerage and wastewater treatment), to switch to green electricity throughout the water chain. However, several challenges in supplying water exist. The main challenges are:

- Poor maintenance of water distribution systems, which has resulted in significant leakages
- Large proportion of water supplied unaccounted for in some countries
- Many users un-metered (e.g. residential sector in Trinidad and Tobago)
- Inefficient water fees in some countries (e.g. flat fee system)
- Stiff competition among sectors (especially in the dry season where there is often rationing of water)
- Illegal and/or unmonitored pumping of ground water (e.g. Barbados)
- Incidence of extreme weather events (which affects both water quality and quality)
- Pollution at intake for desalinization
- Contamination of the water supply by overuse of fertilizers and pesticides (e.g. in Trinidad and Tobago)
- Increased salinization due to sea level rise and over-pumping (e.g. in Guyana).

In order to meet the increased need for water in the future, the Caribbean will have to focus on water saving activities in the sectors that utilize the most water for each country. There will also be a need for water utilities to adapt (see table 16). In order to change consumer behaviour, however, pricing water to reflect its true societal value and increasing scarcity (particularly from year to year) utilizes the market mechanism, and can potentially lead to maximized efficiency in water use. The flat fee system which is common in many Caribbean countries, under prices water resources and essentially indicates that after the first unit of water is obtained, additional water is free.

E. ADAPTATIONS ALONG THE WATER CHAIN

Some of the main adaptation strategies proposed are:

- Increased water distribution efficiency. Sometimes >50% of water produced is UFW as a result of leaks, non-metered users and illegal withdrawals
- Increased incentives for all users to reduce demand. This includes the use of universal metering, a change from flat fee systems to increasing block pricing systems, and monetary incentives to use water conservation devices
- Adjustment of fees for all users to reflect increasing scarcity
- Water harvesting techniques, including water collection from rooftops
- Increased treatment and reuse of wastewater in all sectors
- New water treatment technologies by utilities which are energy saving e.g. water softening

Table 16: Potential Effects of Climate Change on Water Utilities

Climate Change Physical Effect	Effect on Water Utilities	Adaptation Measure(s)
Drinking Water		
Higher temperatures	Poorer influent quality/ increased concentration of microbes, other temp-dependent pollutants	Increased treatment costs to maintain same quality
Sea level rise	Salt water intrusion (primarily ground water systems)	Hydrologic barriers, desalinization, alternative sources
Higher proportion of precipitation in more intense events ("lumpier" hydrology)	High flows: more runoff creates higher concentrations of non-point source pollutants Low flows: More frequent droughts, so if system does not have ample supply, could exacerbate problems	Generally higher treatment costs during high-flow periods; Potential need for alternate supplies during droughts
Wastewater		
Higher temperatures	If effluent limits are based on ambient water quality, dissolved oxygen standard will be slightly harder to meet	Discharge less BOD, increase treatment costs
Higher proportion of precipitation in more intense events ("lumpier" hydrology)	If effluent limits are based on ambient water quality under specific low-flow conditions, receiving stream will have lower flows for a given recurrence interval	Tighter effluent limits on all pollutants will require higher treatment costs
Stormwater		
Higher proportion of precipitation in more intense events ("lumpier" hydrology)	For combined sewer systems, if standards are expressed in terms of hydrologic design conditions (e.g., no more than 4 overflows per year), it will be harder to meet the standard Design flows will be exceeded more frequently	Increase margin of safety in design specifications (implies higher hydraulic capacity, higher costs)

Source: ICF International (2007), Table 2

In the agriculture sector, the proposed adaptation measures by the IPCC (Development Policy and Management Consultants 2009) include: improved infrastructure to ensure irrigation in the dry season; increased water management to prevent saline intrusion; improved sea and river defences protection; land use change; improved drainage capacity; more storage in conservancies; and the use of more water pumps.

Furthermore, agriculture is a significant user of water in the Caribbean, and adaptation should seek to increase efficiency in water use via: drip irrigation; water retention during high rainfall events for irrigation; and water harvesting. However, cost estimates for these proposed solutions were not available.

Based on Kirshen (2007), under the A1b scenario, by 2030, the cost of providing 0.19 km^3/yr of water in response to climate change will cost Guyana US$4.3 10^7, and for the Dominican Republic, additional reservoir storage is expected to cost US$1.81 10^8 under the same scenario. Other Caribbean countries were not examined in this study. Box 1 shows the estimated costs of providing additional groundwater, surface water and desalination facilities.

Box 1: Operational Costs of Groundwater, Surface Water and Desalination

The capital costs (all 2000 USA dollars) of providing the incremental amounts of production facilities were estimated. US **groundwater** capital costs were taken from Kirshen et al (2005)and are, assuming an average depth of ~ 20m, $100,000 for 1000 m3/day, or $2.74 x 10^8 per km3/year.

Total costs for **surface water storage** were taken from Kirshen et al (2005) for China, which over all terrains was estimated to be approximately $300,000/MCM of storage. Based upon the Engineering News-Record index, Chinese costs were estimated to be 70 percent of US costs; thus the USA cost is $450,000/MCM or $450,000,000 /km3. Since this is for dead storage, the active storage estimates determined above were increased by 10 percent.

Costs for **desalination** were taken from US Bureau of Reclamation (2002) for a planning study in California USA. The reported capital cost of Reverse Osmosis (RO) technology was approximately $ 600/m3/day. This compares well with the reported cost of the Ashkelon Desalination Plant in Israel of $780/m3/day (Water-Technology Net, 2007). $600/m3/day is equivalent to $1.64 x 10^9/km3/day.

Source: Kirshen (2007)

Possible adaptation costs utilize the residential sector. For the additional water demand under the various scenarios, it is assumed that Aruba and the Netherlands Antilles can meet their water needs, based on the existing capacity of their desalination plants. For the other countries, it is assumed that the additional demand can be met if countries implement high-cost options (Option A) such as desalination, or lower-cost options (Option B) such as reservoirs for surface water storage. Under Option A, it is assumed that desalination is used by the Dominican Republic, Jamaica and Trinidad and Tobago to satisfy additional water demands in the residential sector due to climate change. Groundwater wells are utilized for Barbados, as its surface water supply is limited, and surface water storage is used for the other countries. Under Option B, all eligible countries use surface water storage, except Barbados, where groundwater wells are used. These estimates are shown in table 17.

Table 17: Costs of Adapting to Climate Change in the Residential Sector – A2 (US$ 2000)

Option A - Desalination/Surface/Groundwater

obs	ARU	BAR	DR	GUY	JA	MON	NA	SL	TT	Caribbean
2030	0	103,927	18,405,131	17,843	7,205,019	-56,650	0	68,882	10,396,844	36,140,996
2050	0	189,265	38,849,451	24,301	11,281,554	-60,351	0	155,192	23,024,084	73,463,495
2070	0	317,194	90,003,060	49,716	20,104,078	-55,731	0	269,617	36,939,195	147,627,129
2099	0	663,676	194,433,822	87,671	33,296,027	-38,486	0	659,839	81,332,573	310,435,122

Option B - Surface and Groundwater Costs

obs	ARU	BAR	DR	GUY	JA	MON	NA	SL	TT	Caribbean
2030	0	103,927	5,050,188	17,843	1,976,987	-56,650	0	68,882	2,852,793	10,013,970
2050	0	189,265	10,659,910	24,301	3,095,548	-60,351	0	155,192	6,317,584	20,381,449
2070	0	317,194	24,695,962	49,716	5,516,363	-55,731	0	269,617	10,135,755	40,928,875
2099	0	663,676	53,350,744	87,671	9,136,105	-38,486	0	659,839	22,316,865	86,176,413

Source: Prepared by author.

Adaptation costs are expected to rise significantly, regardless of the choice of infrastructure, but grow at a slower rate when desalination is used.

A lack of continuous climate variables in the Caribbean resulted in the use of geographical data which approximated the spatial location of study countries, and in some cases could not represent a true mean, given the size or of the country and/or the proximity to the sea. Further, unavailable data on production costs for water supply in time series form makes it impossible to model water demand and supply from the true perspective of the supplier and consumer. The use of proxies therefore leads to a second-best outcome, which results in some uncertainty about the robustness of the outcomes and projections.

V. CONCLUSION

Climate change is expected to affect all countries in the Caribbean. In some cases, there will be positive impacts that may continue to increase over time and, in other cases, the impact will be negative and worsen over time. Overall, the agricultural sector is expected to suffer the worst losses over any scenario, whilst growth in the industrial sectors are expected to be significant, and contribute the most to increasing water demand over time.

Annex

CHANGES IN TEMPERATURE AND RAINFALL UNDER A2 AND B2 SCENARIOS

Table A-1: Levels and Percentage Change in Rainfall Relative to 2006 – A2 Scenario

obs	ARU	BAR	DR	GUY	JA	MON	NA	SL	TT
2006	55.38	246.72	150.44	271.18	109.12	117.03	81.68	196.08	147.78
2030	33.93	242.51	156.49	252.61	122.97	112.27	70.76	195.52	148.88
% Δ	*-38.73*	*-1.70*	*4.02*	*-6.85*	*12.69*	*-4.07*	*-13.37*	*-0.28*	*0.75*
2050	32.71	243.97	155.45	259.26	126.86	110.21	69.54	198.80	147.66
% Δ	*-40.93*	*-1.11*	*3.33*	*-4.39*	*16.26*	*-5.83*	*-14.87*	*1.39*	*-0.08*
2070	23.56	234.07	151.74	250.97	122.85	102.56	60.39	188.49	138.51
% Δ	*-57.45*	*-5.13*	*0.86*	*-7.45*	*12.58*	*-12.37*	*-26.07*	*-3.87*	*-6.27*
2100	26.80	231.62	149.62	248.58	115.05	102.60	63.63	183.50	141.75
% Δ	*-51.60*	*-6.12*	*-0.55*	*-8.33*	*5.44*	*-12.33*	*-22.10*	*-6.41*	*-4.08*

Source: Prepared by author.

Table A-2: Levels and Percentage Change in Temperature Relative to 2006 – A2 Scenario

obs	ARU	BAR	DR	GUY	JA	MON	NA	SL	TT
2006	27.66	26.37	25.19	27.83	23.18	26.78	27.10	26.48	25.18
2030	27.89	27.28	25.60	28.71	23.20	23.06	27.19	27.22	26.67
Δ	*0.23*	*0.91*	*0.41*	*0.88*	*0.02*	*-3.73*	*0.09*	*0.74*	*1.50*
2050	28.59	27.72	26.00	29.00	23.56	23.36	27.89	27.76	27.37
Δ	*0.93*	*1.36*	*0.81*	*1.17*	*0.38*	*-3.43*	*0.79*	*1.28*	*2.20*
2070	29.10	28.28	26.84	30.30	24.37	24.05	28.40	28.24	27.88
Δ	*1.44*	*1.92*	*1.65*	*2.47*	*1.19*	*-2.74*	*1.30*	*1.76*	*2.71*
2100	30.38	29.37	27.76	31.99	25.51	25.03	29.68	29.35	29.16
Δ	*2.72*	*3.01*	*2.57*	*4.16*	*2.33*	*-1.76*	*2.58*	*2.87*	*3.99*

Source: Prepared by author.

Table A-3: Levels and Percentage Change in Rainfall Relative to the Baseline – B2 Scenario

obs	ARU	BAR	DR	GUY	JA	MON	NA	SL	TT
1961-1990	38.30	30.30	32.03	91.86	17.44	60.09	58.83	30.30	91.86
2030	35.50	41.79	42.62	99.53	22.50	78.29	67.48	41.79	99.53
% Δ	*-7.31*	*37.91*	*33.06*	*8.35*	*28.98*	*30.29*	*14.69*	*37.91*	*8.35*
2050	29.88	23.90	28.35	56.88	24.73	63.28	52.37	23.90	56.88
% Δ	*-21.98*	*-21.12*	*-11.51*	*-38.08*	*41.76*	*5.30*	*-10.98*	*-21.12*	*-38.08*
2070	39.59	32.87	31.55	75.52	19.36	72.34	59.63	32.87	75.52
% Δ	*3.37*	*8.48*	*-1.50*	*-17.79*	*10.97*	*20.39*	*1.36*	*8.48*	*-17.79*

2100	31.21	30.58	29.97	83.79	6.13	72.06	62.70	30.58	83.79
% Δ	*-18.52*	*0.94*	*-6.44*	*-8.78*	*-64.86*	*19.91*	*6.57*	*0.94*	*-8.78*

Source: Prepared by author.

Table A-4: Levels and Percentage Change in Temperature Relative to the Baseline – B2 Scenario

obs	**ARU**	**BAR**	**DR**	**GUY**	**JA**	**MON**	**NA**	**SL**	**TT**
1961-1990	26.58	26.69	25.09	27.14	26.64	26.91	26.76	26.69	27.14
2030	27.92	28.29	26.41	28.79	27.93	28.31	28.11	28.29	28.79
Δ	*1.34*	*1.6*	1.32	1.65	1.29	1.4	1.35	1.6	1.65
2050	28.41	28.57	27.25	28.97	28.54	28.79	28.6	28.57	28.97
Δ	*1.83*	*1.88*	2.16	1.83	1.9	1.88	1.84	1.88	1.83
2070	28.91	29.17	27.99	29.63	29.18	29.31	29.11	29.17	29.63
Δ	*2.33*	*2.48*	2.9	2.49	2.54	2.4	2.35	2.48	2.49
2100	29.36	29.84	28.22	30.29	30.33	29.72	29.54	29.84	30.29
Δ	*2.78*	*3.15*	3.13	3.15	3.69	2.81	2.78	3.15	3.15

Source: Prepared by author.

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