

Exploring A2 Futures: Combining modelling and scenarios to assess water availability and adaptation in the Small Island State of Carriacou

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1. Introduction

Climate change (CC) is projected to have a major impact on small island developing states (SIDS) across the globe. It is noted that SIDS will be impacted disproportionately more than other countries particularly by sea level rise (SLR), higher temperatures, increased occurrence of extreme weather events (hurricanes), prolonged drought events and unpredictable rainfall patterns¹. These threats along with other inherent vulnerabilities: small size (geographic and populace), high levels of debt, high exposure to external shocks, densely populated coastal communities², have urged SIDS representatives to lobby for greater action and accountability at the 2015 COP21 Paris meeting³. In November 2016 the Paris agreement was signed replacing the Kyoto Protocol, juxtaposing the fact that 2016 was the hottest year on record since 1880⁴. These events provide much impetus for more detailed research to better understand the impact on, not only the physical environment, but also the livelihood of persons living on these small islands.

Water availability refers to the ability of a water source to sustain additional water demand after considering current water uses and conditions (IPIECA 2014). It can be profoundly impacted by socioeconomic development since increases in population and growth in GDP can also cause an increase in the demand for water by various economic sectors. Issues arise when water demand exceeds the amount available and demand goes unmet. The small island of Carriacou in the Caribbean, like many other small islands, currently faces issues such as water scarcity and stress at certain time of the year. In recent times during prolonged periods of low rainfall have resulted in drought conditions causing bush fires which impacted

¹ Inter-American Development Bank, "Climate Change and IDB: Building Resilience and Reducing Emissions, Regional Study: LAC Small Island Development States," Regional Study (Inter-American Development Bank, 2014).

² Lino Briguglio, "Small Island Developing States and Their Economic Vulnerabilities," *World Development*, 1995, 1615–32.

³ Mazine Burkett, *Small Island States and the Paris Agreement* (Wilson Center, 2015).

⁴ National Aeronautics and Space Administration, "NASA, NOAA Data Show 2016 Warmest Year on Record Globally" 2017, <https://www.nasa.gov/press-release/nasa-noaa-data-show-2016-warmest-year-on-record-globally>.

agricultural crops and caused severe water shortages across the island⁵. In an effort to reduce current and future water shortages, climate projections and scenarios can be used to help improve the management of water resources. This could assist decision-makers in identify trends thus helping them plan more effectively for the future. This paper looks at the potential impact of changes in climate and socioeconomic factors on water availability in the future. The study analyzes the effect of 4 exploratory future foresight scenarios on water resources in Carriacou using the Water Evaluation and Planning (WEAP) software. In addition, the paper, by way of scenarios, outlines various plausible pathways that have implications for achieving the Sustainable Development Goals in 2030. The research seeks to contribute to the literature by presenting a case study of merging foresight scenarios and Water Evaluation and Planning (WEAP) modelling in the context of a water scarce small island state using downscaled climate data to outline adaptation options. Very few studies in the English speaking Caribbean have used foresight scenario methodology (see Agard, et al. 2007, and GEFCAF 2006), and even fewer have merged resource modelling to study the future. Therefore, one of the aims of this paper is to propel the mainstream use of scenarios in scientific research, particularly in environmental studies in the Caribbean to assess the impact of climate change. Our focus on water availability in the island of Carriacou presents a unique perspective on; (i) how climate change could impact scarce water resources in a small island state and (ii) present alternative future scenarios on how climatic changes could affect livelihoods on the island and in doing so, develop robust adaptation strategies that are applicable across a broad spectrum of scenarios. As a result this paper presents a case study of how global climate projections could be translated at the micro nation state level and we explore its impact on people in countries who may be forgotten in the international debate on climate change.

The rest of the paper is as follows; section 2 provides a country profile including socioeconomic, geographic and water resource contexts. Section 3 discusses the benefits of foresight scenarios in assessing climate change impacts, and section 4 outlines the foresight scenario and WEAP methodologies used. Section 5 presents the results, the implications of the results and proposed adaptation options are discussed in section 6 and section 7 concludes.

2. Background

2.1 Socioeconomic and Geographic profile of Carriacou

Carriacou is the largest of the Grenadine islands found in the southeast of the Caribbean, located 12 28'N & 61 28'W and is part of the tri-island State of Grenada. The total area of Carriacou is 34km² and the highest point on the island is High North Peak, at a height of 291m above sea level. The country has a tropical climate with an average temperature of 24° C/ 75° F. The island is characterized by a main upland topographic ridge along its center, which rises to a high point of 291.4m above sea level in the north. The geology of Carriacou is comprised of tertiary volcanic rocks, mostly comprised of agglomerates, tuffs and lavas^{6,7}.

The island faces many developmental challenges including: limited water resources, high energy and transportation cost, the absence of a sewage treatment facility and limited economic and employment opportunities⁸ Economic activity mainly comprises of fishing and

⁵ Everson Peters, "The 2009/2010 Caribbean Drought: A Case Study," *Disasters* 39, no. 4 (2015): 738–61.

⁶ Government of Grenada, "Road Map Toward Integrated Water Resources Management Planning for Grenada" (Government of Grenada, 2007).

⁷ Evanson Peters, "Desalination for Augmenting DRWH in the Grenadines Martinique" NA.

⁸ United Nations Economic and Social Affairs, "Road Map on Building a Green Economy for Sustainable Development in Carriacou and Petite Martinique, Grenada," Project Report (United Nations Department of Economic and Social Affairs, 2012).

agriculture (including livestock-rearing). At present, except for the lime industry which has been ad hoc, only a few farmers grow small crops for subsistence consumption. Carriacou is also renowned for its boat building industry, especially in the village of Windward. Traditional methods of boatbuilding are still practiced and can be seen in the many local schooners that ply between the islands of Grenada and Carriacou⁹. In 2004 and 2005 the island was impacted by Hurricane Ivan and Emily respectively and the loss to economic activity was even more severe than that of Grenada. Carriacou also engages in tourism activities where many of the tourists who visit the island are a spillover from those visiting the mainland of Grenada¹⁰.

Carriacou is administered through the Ministry of Carriacou and Petite Martinique Affairs led by the Cabinet Minister and is financed through the central government of Grenada. In 2000 it was estimated that 50% of the population had migrated which consequently has resulted in high levels of remittances which is assumed to represent about 30% of GDP. Despite having high levels of unemployment, particularly among the youth, there is a low level of poverty due to remittances (United Nations Department of Economic and Social Affairs 2012).

2.2 Carriacou's Water Resources

The island of Carriacou comprises of 17 watersheds (Figure 1) however, there is no permanent surface streamflow and very limited groundwater found in narrow strips along the coast (E. J. Peters 2011). As such, the primary source of freshwater comes from rainwater harvesting. The island is considered to be water scarce since it is significantly drier than mainland Grenada and has an average annual rainfall of 1000 mm (Grenada 2007). Most households collect runoff from their roofs and store them in cisterns or PVC tanks and during extended dry periods, the water supply is augmented by communal cisterns which can be found in public buildings such as schools, clinics and churches. The capacity of these cisterns however is usually not enough to meet the island's water requirements when water shortages occur. In addition, many of the communal cisterns are in disrepair and need refurbishing rendering them unusable for potable water consumption.

⁹ Government of Grenada, "The Official Website of the Government of Grenada" 2009, http://www.gov.gd/carriacou_petite_martinique.html.

¹⁰ United Nations Economic and Affairs, "Road Map on Building a Green Economy for Sustainable Development in Carriacou and Petite Martinique, Grenada."

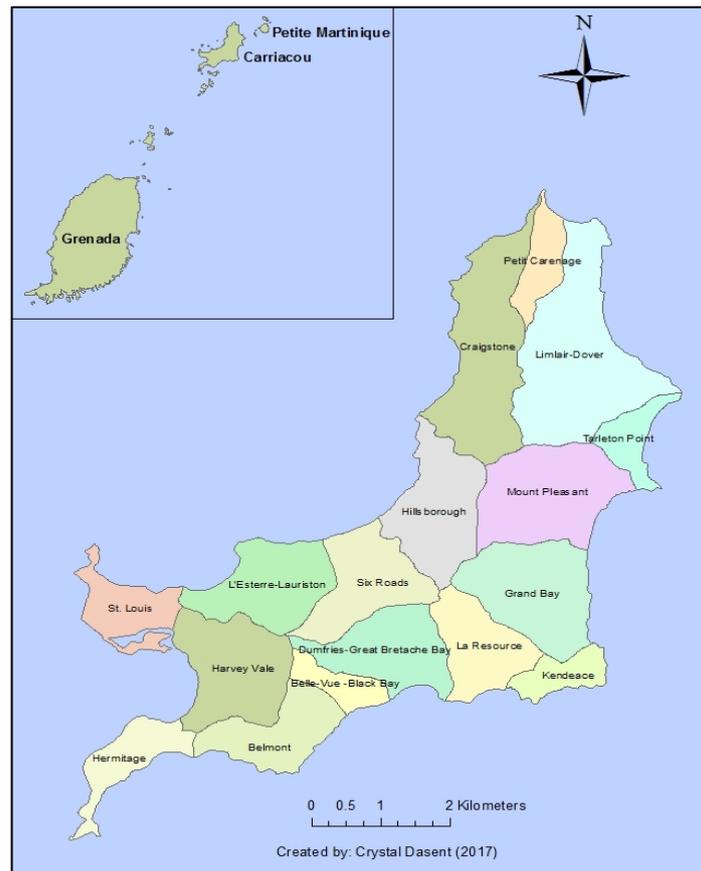


Figure 1: Watershed map of Carriacou (Inset: Tri-Island state of Grenada, Carriacou and Petite Martinique)

3. Why use scenarios to assess climatic changes in SIDS

To fully understand the challenges, and possible opportunities SIDS face in the future due to a changing climate, climatic projections should not be assessed in isolation. To enhance the understanding of complex systems and interactions of ecosystems, climate and anthropogenic changes, futurists, foresight strategists and others has developed and popularized the use of scenarios¹¹. Scenarios are defined as plausible descriptions of how the future may unfold base on a set of internally consistent and coherent assumptions about key drivers and their interdependent relationships¹². Other definitions and descriptions exist for the term ‘scenario’^{13,14,15} however, all comprise of the underlying context that scenarios are plausible, coherent storylines about the future. Scenarios from a methodological perspective are a tool and product used widely throughout foresight and futures study¹⁶ and it is within this context

¹¹ Richard Moss et al., “The next Generation of Scenarios for Climate Change Research and Assessment,” *Nature* 463 (2011): 747–56.

¹² Intergovernmental Panel of Climate Change, *Summary for Policymakers Emissions Report. Special Report.* (Geneva: IPCC, 2000).

¹³ Michael Godet and Fabrice Roubelat, “Creating the Future: The Use and Misuse of Scenarios,” *Long Range Planning* 29, no. 2 (1996): 164–71.

¹⁴ Dana Mietzner and Guido Reger, “Advantages and Disadvantages of Scenario Approaches for Strategic Foresight,” *International Journal of Technology Intelligence and Planning* 1, no. 2 (2005): 220–39.

¹⁵ Luke Georghiou et al., *The Handbook of Technology Foresight* (Cheltenham: Edward Elgar Publishing Limited, 2008).

¹⁶ *Ibid.*

we develop our national level scenarios. Due to their ability to merge creativity and analytics¹⁷ scenarios provide a medium where dynamic processes can be constructed, and modelled in some instances, in order to enhance our understanding of not just outcomes, but how actors, actions, reactions, events and uncertainty interplay within a given system¹⁸. Scenarios are beneficial tools in assessing climate impact as it prompts participants and end-users to discover and explore unexpected developments that would otherwise remain hidden¹⁹, as well as help identify new areas of needed research²⁰ or action plans. Moreover, by merging rigorous techniques of mental mapping, with identified future driving forces and critical uncertainties, scenarios can systematically “unpack” the complexity, uncertainty and long time horizons associated with climate change impacts²¹. Given the peculiarities and vulnerabilities of island states foresight scenarios can prove an effective tool to be used in anticipatory planning in relation to climate change.

Following similar studies^{22,23,24} we seek to use scenarios to provide context for climatic changes and its impact on water resource availability across various alternative socioeconomic conditions in order to inform adaptations options. Our aim therefore mirrors Schwartz’s²⁵ goal of scenarios, that is, to create scenarios to better understand the uncertainty of the future to reach decisions that are robust across a wide range of possible futures.

4. Methodology

4.1 Scenario Development

To develop exploratory socioeconomic scenarios for Carriacou in the year 2050 we build on the multi-scale methodology and results discussed by Drakes, et al.²⁶. The authors provide a detailed case study of how to develop scenarios for SIDS using a multi-scale, iterative process that starts from the regional level and are “up-linked” to incorporate global pathways. We add to the work by downscaling those Caribbean scenarios to the national level of Carriacou with country specific storylines under the SRES A2 climate scenario.

¹⁷ Joost Vervoot et al., “Combining Analytic and Experiential Communication in Participatory Scenario Development,” *Landscape and Urban Planning* 107 (2012): 203–13.

¹⁸ Peter Hofman, Frank Geels, and Boelie Elzan, “Sociotechnical Scenarios as a New Policy Tool to Explore System Innovations: Co-Evolution of Technology and Society in The Netherland’s Electricity Domain,” *Innovation: Management, Policy & Practice* 6 (2004): 344–360.

¹⁹ Vanessa Schweizer and Elmar Kriegler, “Improving Environmental Change Research with Systematic Techniques for Qualitative Scenarios,” *Environmental Research Letters* 7 (2012): 1–14.

²⁰ Jonathan R. Thompson et al., “Scenario Studies as a Synthetic and Integrative Research Activity for Long-Term Ecological Research,” *Bioscience* 62 (2012): 367–76.

²¹ Ruth Kelly, Lorcan Sirr, and John Ratcliffe, “Futures Thinking to Achieve Sustainable Development at the Local Level in Ireland,” *Foresight* 6, no. 2 (2004): 80–90.

²² Abeer Shakweer Reham M. Youssef, “Futures Studies in Egypt: Water Foresight 2025,” *Foresight* 9, no. 4 (2007): 22–32.

²³ Tom van der Voorn, Claudia Pahl-Wostl, and Jaco Quist, “Combining Backcasting and Adaptive Management for Climate Adaptation in Coastal Regions: A Methodology and a South African Case Study,” *Futures* 44, no. 4 (2012): 346–64.

²⁴ Congli Dong, Gerrit Schoups, and Nick van de Giesen, “Scenario Development for Water Resource Planning and Management: A Review,” *Technological Forecasting & Social Change* 80, no. 4 (2012): 749–61.

²⁵ Peter Schwartz, *Art of the Long View: Planning for the Future in an Uncertain World* (New York: Doubleday, 1996).

²⁶ Crystal Drakes et al., “Caribbean Scenarios 2050: GoLoCarSce Report,” Technical Report (Centre for Resources Management and Environmental Studies, 2016).

A participatory approach was taken in downscaling the global/regional scenarios. This approach was taken due to the pedagogical advantages of the scenario process itself²⁷, the rich tacit knowledge participants can bring to the process and to foster “ownership” of the scenarios to increase the likelihood of successful post-scenario activities such as action plans and policy development. A one day stakeholder workshop was conducted and was attended by 10 local persons who worked in the areas of agriculture, agro-processing, tourism and construction. The objectives of the workshop were for the participants to:

- 1) Conduct an assessment of the existing global/regional scenarios
- 2) Develop an understanding of how the scenarios are or are not applicable in the Carriacou context
- 3) Assess how the each scenario could impact the livelihoods of those living on the island

In order to meet the above objectives the following steps were taken:

Step 1- A video presentation²⁸ of four Caribbean scenarios, 3 exploratory²⁹ and 1 wild card³⁰, was made and participants ranked the video based on three criteria; plausibility, consistency and coherence³¹. A weighted average was then calculated using the criteria, plausibility was assigned the highest weight of 5 and consistency and coherence carried a weight of 3. Plausibility was given a heavier weighting to consistency and coherence as it was agreed that plausibility was a prerequisite criteria of the scenario for the other two. Each principle was ranked between 1 and 5, with 1 being the lowest score and 5 the highest score. During this exercise a rich discussion was also had on the general premise of each scenario and its elements.

Step 2- Based on the rankings and elicited discussions each person then identified if Carriacou could “fit” into each scenario space and what that future would look like. Participants gave detailed descriptions of island specific factors (driving forces) that would shape Carriacou under these future conditions.

Step 3- Participants were then asked to assign “values” (e.g. increasing, unchanged, decreasing) to how each scenario would affect their livelihood. Livelihoods were based on the indicator of net wages/salaries and were also discussed with respect to the factors that would directly impact them e.g. market structure, pricing, government policy etc.

Once the workshop was completed the scenario team, through an iterative process using the SRES A2 scenario storylines and the WEAP modelling (discussed next in section 4.2) framed the Carriacou national scenarios for the year 2050 and key stakeholders were sent the storylines to review before the final national storylines were developed.

4.2 WEAP Model Development

The Carriacou Water Availability Model (C-WAM) was built using the Water Evaluation and Planning (WEAP) software in order to assess the current water use and availability on the island. WEAP is modelling software that uses an integrated approach to water resources planning and considers both demand and supply. This model was chosen since it is not data intensive and the level of detail can be customized to suit the available data.

²⁷ Abdul Khakee, “Participatory Scenarios for Sustainable Development,” *Foresight* 1, no. 3 (1999): 229–40.

²⁸ <https://vimeo.com/188425016?ref=em-share>

²⁹ Cool Runnings, *Island in the Sun, Harder they Come*

³⁰ *Pirates of the Caribbean*

³¹ Intergovernmental Panel of Climate Change, *Summary for Policymakers Emissions Report. Special Report.*

WEAP provides five (5) different ways of modelling a catchment, the Rainfall Runoff (Simplified Coefficient Method) was selected for this study since it most accurately represents how water moves across the island. This method helps to determine crop requirement and the water that is not used for evapotranspiration is simulated as runoff. The required hydrological and demand data was collected from the relevant agencies such as the Grenada Statistical Office and the Grenada Tourism Authority and inputted into the model. A monthly time step was used beginning from January of the Current Accounts Year 2001. The Current Accounts Year in WEAP is the first year of the analysis period and provides a basic definition of the existing water system³². The Business As Usual (BAU) or Reference scenario was then created spanning from 2002 to 2011 and was inherited from the Current Accounts year. The reference scenario represents the system in the absence of any climatic or socioeconomic changes. To simulate demand, the main water users in Carriacou were aggregated into three sectors; Domestic, Tourism and Agriculture. Domestic demand was further disaggregated to distinguish between those who use cisterns from those who used PVC tanks for water storage. On the ground, rainwater harvesting (RWH) systems are spatially distributed however for the purpose of this study they were lumped and represented as a single reservoir node labeled 'Total RWH' in the model (Figure 2).

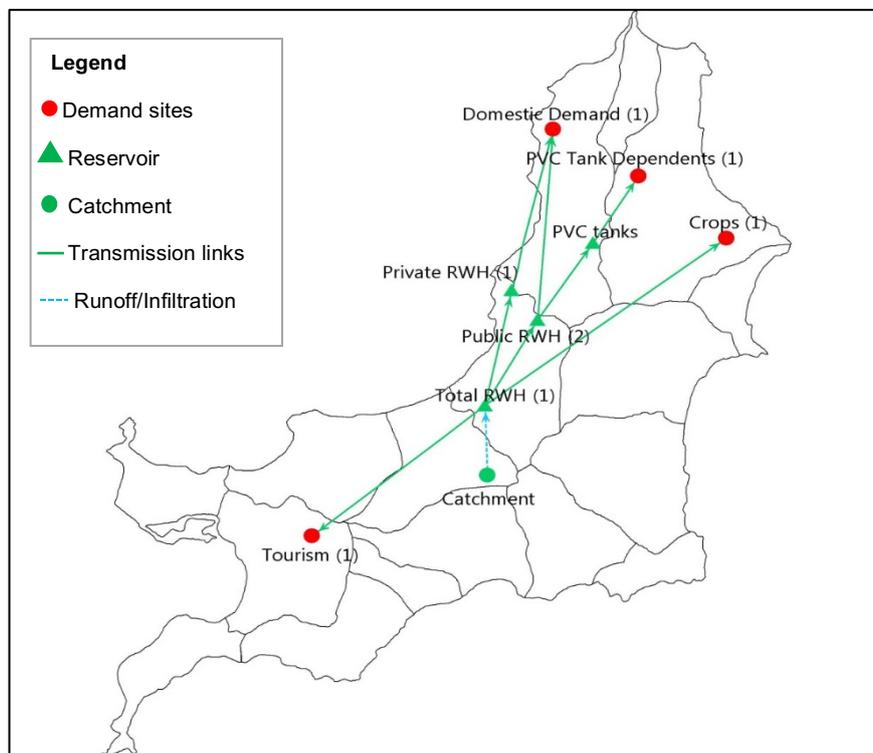


Figure 2: Schematic representation of Carriacou Water Availability Model (C-WAM) in WEAP

Once the model framework was established, a climate only scenario for the Near Term (2040-2050) was built based on the IPCC A2 SRES climate projections or 'worst case' scenario for the island. Precipitation data for this scenario was obtained through downscaling of the Hadley Centre Providing Climates for Impact Studies (PRECIS) regional climate model using the Direct Areal Downscaling (DAD) Model. Four (4) scenarios were then created based on the socioeconomic projections derived from the foresight analysis. These scenarios inherited the climate data from the Near Term scenario with the demand data altered between scenarios.

³² Jack Sieber and David Purkey, *WEAP: Water Evaluation and Planning System* (Massachusetts: User Guide. Stockholm Environment Institute, 2015).

Limitations

One of the major challenges associated with this research was the availability of data. In addition, due to the limited time available with stakeholders on the island the foresight scenarios only represent a snapshot of the year 2050 rather than a continuum of events leading up to 2050. A snapshot in time results in discrete representation of variables which limits the analysis. Quantitative scenarios should not only assign values discretely based on the main qualitative scenario themes, but also for a multitude of intermediate situations³³.

5. Results

5.1 Scenario Workshop

The regional Caribbean scenarios were given the following scores and weighted averages based on the scoring of the scenario principles; plausibility, coherence and consistency.

Table 1: Scenario Weighted Average Ranking

Scenario	Plausibility Weight=5	Consistency Weight=3	Coherence Weight=3	Weighted Average
Cool Runnings	44 (220)	46 (138)	43 (129)	60.87
Island in the Sun	48 (240)	45 (135)	47 (141)	64.50
Harder they Come	47 (235)	45 (135)	48 (144)	64.25
Pirates of the Caribbean	45 (225)	47 (141)	45 (135)	62.62

Source: Authors' Calculations

Based on Table 1 all of the scenarios presented to the participants were “believable” futures based on a criteria of $(WA > 41)$ ³⁴, where Island in the Sun scenario which is a renewable energy driven future ranked highest, it also received the highest score for plausibility. This could be due to the current close relationship of everyday life to nature on the island and this type of future could be seen to participants as an easy transition. Cool Runnings gained the lowest weighted average of 60.87, where this could be due to the mismatch of this business-driven type of scenario against historical and current norms and values of the people of Carriacou. Based on these results all four scenarios were downscaled to the national level.

³³ Dong, Schoups, and Giesen, “Scenario Development for Water Resource Planning and Management: A Review.”

³⁴ If all scores were the median $n=3$, $WA=41$. The authors selected the weighted average as the indicator of $WA > 41$ as “believable” and $WA < 41$ as “not believable” for each scenario.

Table 2: Scenario Context and Local Drivers

Scenario	Global Context	Regional Context	Local Drivers
Cool Runnings	Globalization, Income inequality, trade between blocs, energy mix	Private-public partnerships providing social services, small governments, strong regional integration, increasing GDP growth, increasing export for niche products, large middle class, moderate crime levels	Economic activity (tourism, agriculture) Migration Remittances Land use and management Political and social cohesion Water Access
Island in the Sun	Moderate globalization, central global goal of renewable energy, high GDP growth in some regions	Strong governance, community oriented, Moderate GDP growth, income equality with small pockets of vulnerable communities, minimal crime, declining population growth rate	
Harder they Come	Regional rivalry, political mistrust, protectionist policies, slow trade, uneven growth	Stable governance ad hoc corruption scandals, strained regional integration, stagnant growth, high debt levels, large middle class, widening of the income gap between the “haves” and the “have nots”	
Pirates of the Caribbean (wild card)	Economic collapse of US economy, economic depression, bio-chemical and cyber-attacks, dissolution of international organizations	Weak growth, corrupt governance, large underground economy (drugs, weaponries, human trafficking), increasing poverty, limited import supplies, informal community governance groups, prevalence of organized gangs	

Source: Authors' Compilation

Table 2 outlines the main global and regional context associated with each scenario. The table also lists the local drivers that were identified in discussions during step 2 of the scenario workshop; these drivers were highlighted to be very important to the way of life in Carriacou and are expected to have a high impact on the future of the island. The national level scenario storylines were developed based on the “value” trend of each driver in a scenario, and how each driver interacted within that scenario with other drivers. Each scenario is discussed in further detail in section 5.3.

5.2 WEAP results

Unmet Demand

For this paper we focus on the WEAP output of Unmet Demand which is defined as the amount of water requirement that is not met by the existing water supply³⁵ and provides a snapshot of the magnitude of shortages. The following graphs illustrate the unmet demand for the island of Carriacou leading up to the target year 2050 using the water availability model.

³⁵ Sieber and Purkey, *WEAP: Water Evaluation and Planning System*.

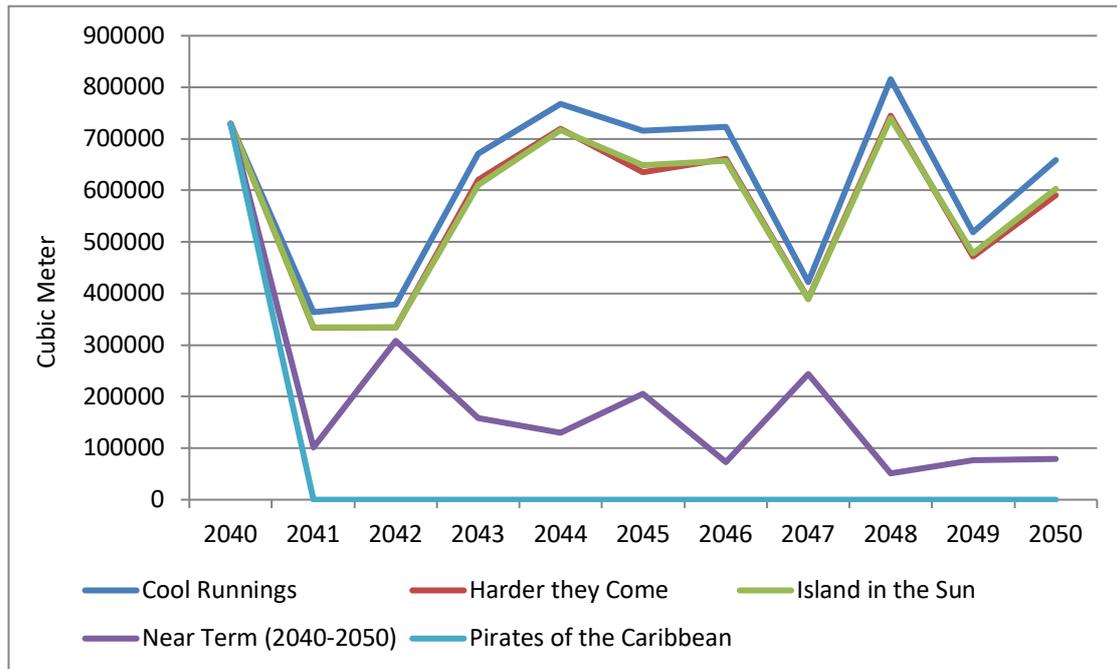


Figure 3: Annual unmet demand for climate and socioeconomic scenarios (2035-2045)

Of the four foresight scenarios ‘Cool Runnings’, ‘Island in the Sun’ and ‘Harder they Come’ all have unmet demand which exceeds that of the climate-based Near Term scenario. Cool Runnings has the highest unmet demand and under this scenario annual shortages could be as great as 800,000 m³. The ‘Pirates of the Caribbean’ projection has the lowest unmet demand and shows that demand could be met for all years within the time period. This suggests that overall there is a sufficient quantity of water under this scenario to meet Carriacou’s water needs. Given “Pirates of the Caribbean” is a wild card scenario, socioeconomic conditions affect how persons access water and also the quality of the available water.

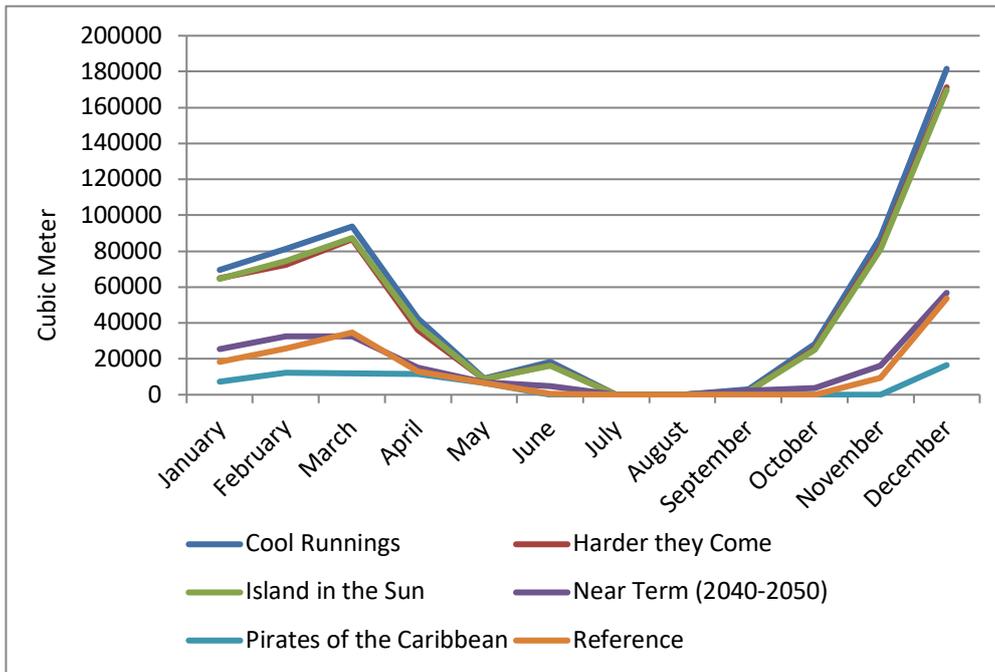


Figure 4: Monthly Average unmet demand for Reference, climate and socioeconomic scenarios

Figure 5 shows the average monthly unmet demand for all scenarios including the Reference scenario where no adjustments were made to climate or socioeconomic conditions. Under the Reference scenario demand is met for four months of the year. For the other scenarios, with the exception of 'Pirates of the Caribbean', demand is only met completely for two months of the year which coincides with the start of the rainy season in July. This suggests that the frequency of shortages is likely to increase in the near future under those socioeconomic conditions as more months of the year experience unmet demand. The 'Pirates of the Caribbean' scenario is an exception as it once has the lowest volume of unmet demand and shows demand being met for five months of the year. This indicates a reduction in water shortages however this is largely influenced by the decline in water demand across all sectors. Across all scenarios the month of December has the highest unmet demand and this is possibly due to the increase in domestic demand during the Christmas season since many nationals living abroad return to Carriacou at this time.

5.3 Carriacou Scenarios 2050

Combining the global/regional scenarios, the national level drivers and the WEAP model results the following scenarios were developed for the island of Carriacou in 2050.

Cool Runnings

Globally, economic growth and development is uneven in line with historical patterns of winners and losers of a capitalist system. Income inequality also persists within and between countries placing pressure on the attainment of global development goals³⁶. Increased free trade will force CARICOM member states to eliminate almost all barriers to regional trade. Countries specialize in high-end luxury tourism, specialty crops and products and micro technology assembly projects funded by Chinese and African investors. By 2050 the region, through Private Public Partnerships (PPPs), is focused on providing universal primary level

³⁶ Brian O'Neill et al., "The Roads Ahead; Narratives for Shared Socioeconomic Pathways Describing World Futures in the 21st Century," *Global Environmental Change* 42 (2015): 169–80.

education and basic health care services. Global goals related to poverty, gender equality, education and economic growth have been achieved to varying degrees. Carriacou's main focus of economic activity is in commercial agriculture and agro-processing. The free movement of persons allow for specialists (botanist, horticulturalist) to work with investors and the mainland university to create indigenous products for export³⁷. A diversified set of foods is produced and promoted through the island's farmer's cooperative. Land management is guided by formal contracts to increase farming efficiency and return on investments. High profit margins are made through strategic marketing and high end target markets and customers. Tourism is another large revenue earner for the island with two newly constructed luxury marina villages. Government plays a small but influential role in society as political alliances are strong. The increasing wealth throughout the region benefits the development of the mainland St Georges University. Improvements in IT infrastructure and technology allow more citizens of Carriacou to engage in remote learning. This leads to improvements in agricultural techniques and productivity but also facilitates migration of skilled persons off the island in search of better employment opportunities. Regional organizations assist in the provision of social services for citizens such as pension schemes. Population growth on the island remains stable, and the movement of persons results in a regional identity emerging with island specific norms being lost.

Unmet Water Demand - 658,306 m³

The demand for water is highest for all sectors under the 'Cool Runnings' scenario compared to the other foresight projections driven by economic activity. Cooperative commercial agriculture places the highest level of strain on the water supply competing with the demand from luxury villas and hotels. Domestic supply through the island's desalination network is ad hoc and unreliable with most homes relying on water catchments (cisterns and personal tanks). The water availability model therefore shows that an increase in socioeconomic activity would likely result in increased volumes of water shortages in Carriacou if adaptation measures are not put in place.

Island in the Sun

The over industrialization and mass levels of pollution from the major economies (USA & China) accelerates warming of the earth and causes a drastic shift aimed at reclaiming the earth's natural state. This revolution sparks a rapid investment in renewable energy and the promotion of eco-friendly lifestyles. The Caribbean is politically integrated and the economies are driven mainly by renewable energy sources, with economic activity and job opportunities mainly coming from health and wellness tourism and recycling and reuse sector. Regional cooperation is most effective in areas of energy, agriculture and health management. The shift in livelihood ideology facilitates the fast movement towards SDGs related to poverty, health and well-being, the environment and functional partnerships by 2050^{38,39}. The island of Carriacou is driven by growth in infrastructure and innovation to promote eco-friendly living and business and artisanal organic farming. Health and eco-tourism are the island's main economic drivers, driven mainly by "bed and breakfast" style accommodation with many local produce such as fish and vegetables being consumed primarily by those in the tourism sector. The country still maintains a large diaspora and remittances still play an important role in

³⁷ Drakes et al., "Caribbean Scenarios 2050: GoLoCarSce Report."

³⁸ O'Neill et al., "The Roads Ahead; Narratives for Shared Socioeconomic Pathways Describing World Futures in the 21st Century."

³⁹ Drakes et al., "Caribbean Scenarios 2050: GoLoCarSce Report."

economic activity. Many organic spices, fruits and vegetables are cultivated for medicinal uses. Most of the island's facilities are powered by solar energy with some fuel needs being met by biogas particularly on farms and for small engine transportation. Sustainable fishing techniques is also popular on the island. Investment to the island is targeted towards tourism projects and the maintenance of renewable energy infrastructure. The shift towards green lifestyles leads to a low rate of unemployment as many persons become self-sufficient. There is strong cohesion between various civil society organizations and this helps to promote a zero-waste economy. Women play a significant role in local governance and family centered activities are engrained within societal norms. Formal communal arrangements guide land use management.

Unmet Water Demand - 603,073 m³

In this scenario there is growth in the tourism, domestic and agricultural water demand. These sectors are driven by communal use and activities where renewable energy and sustainable development play a major role. Despite the strong social cohesion and conservation efforts of resources, given the projected demand the island still does not have the required water supply and there is a large volume of unmet demand.

Harder they Come

At the global level regional rivalry is prevalent, compounded by weak coordination among global institutions. Protectionist policies become more widely used at the regional and national level with a focus on security and food imports. Due to the slowdown in globalization economic growth slows and income inequality between countries grows^{40,41}. In 2050 there is little focus on global goals as international organizations are weakly coordinated and very few countries attained the SDGs particularly those related to health, education and climate in 2030. The Carriacou economy remains relatively unchanged. When compared to the past, traditional tourism growth remains flat while there are increases in subsistence agriculture across the island. Remittances from family members living abroad becomes the sole source of income for many families on the island. To spur economic activity, the government offers citizenship to high net worth individuals accompanied by land packages. These high net worth individuals live in isolated communities and share utility facilities such as electricity and water amongst themselves. The economic disparity between locals and citizens by investment increases the conflict over land use and rights. Conflicts arise over access to water storage and the trespassing of livestock on private property. Due to increasing pressures from economic hardship, there is a weakened social network and strong political divide on the island.

Unmet Water Demand- 590,169 m³

Under this scenario, although growth in tourism is stagnant, tourism numbers are still greater than that of the baseline scenario. There is also a small increase in agriculture due to the increase in subsistence farming while domestic demand declines. Though there is not much overall socioeconomic growth under this scenario, demand still goes unmet due to the high tourism water requirement likely driven by the introduction of citizens by investment and the large amounts of non-revenue water (leakages) because of deteriorating infrastructure.

Pirates of the Caribbean

⁴⁰ O'Neill et al., "The Roads Ahead; Narratives for Shared Socioeconomic Pathways Describing World Futures in the 21st Century."

⁴¹ Drakes et al., "Caribbean Scenarios 2050: GoLoCarSce Report."

The collapse of the US economy and devaluation of the US dollar in the early 2040s pushed most of the Western world into an economic depression. The economic downturn heightens tensions between the US and Arab extremist countries with many bio-chemical and cyber-attacks occurring. Some progress was being made to attain SDGs associated with poverty, education, water and climate however, any progress that was made was quickly eroded after the collapse⁴². The worsening economic performance of the rest of the world negatively impacts the Caribbean economies. The absence of global cooperation results in the abandonment of global objectives. In the Caribbean reduced investment and limited job opportunities force many persons into poverty. Increased trafficking of drugs and arms create unstable societies where crime is the main concern for many and regional organizations weaken in capacity. After the collapse, the government of Grenada orders an evacuation of Carriacou due to supply shortages in food, and other essential supplies such as medicine and to secure all coastal areas. In 2050 2,500 persons remain on the island where economic activity is solely driven by subsistence and a barter system is the main mechanism for trade on the island. Subsistence farming causes issues such as deforestation, soil erosion and water run-off. Most of the illegal activity occurs by way of transshipment of narcotics and coastal areas are hotspots for violence. The absence of formal governance systems leads to deserted lands and properties being used and occupied by those living on the island without permission. Due to such a small number of persons living on the island a communal governance system is set up where designated individuals manage security, food rationing and other day to day activities.

Unmet Water Demand- 0 m³

For the Pirates of the Caribbean scenario the model projects that there is sufficient water available to meet all of the demand. This is mainly due the significant reduction in population as well as there being no tourism and very little agriculture. The societal conditions do not guarantee those living on the island have access to clean water. Demand may still go unmet due to water contamination issues and lack of access and persons being unable to reach water sources because of high levels of crime, also the lack of the economic means to acquire facilities such as PVC tanks could affect water storage.

6. Adaptation Strategies

The research presents a case study of how global trends can be used to better understand the vulnerability of SIDS. The socioeconomic scenarios coupled with the water availability projections underscore the dynamic nature of understanding and interpreting the future beyond generic terminology for adaptation. The application of WEAP to assess water availability in a small island such as Carriacou helps to identify trends in water shortages thereby allowing for more informed decision-making when applying adaptation strategies. Due to the flexibility of the data needs within the software it can be very useful in SIDS where data is limited or unavailable. It also helps water managers identify how water is currently being used by different sectors and how that may change in the future by incorporating socioeconomic projections. The following water availability adaptation options for Carriacou were identified based on the results. Each option was assessed on robustness and applicability across the different future scenarios and unmet water projections.

Second desalination plant and expansion of pipe distribution network

⁴² Ibid.

By introducing a second desalination plant to the island this allows an opportunity for all sectors, particularly tourism, to be connected to a reliable supply of water. This method is somewhat “climate” proof as it does not rely on harvesting which is heavily dependent on rainfall. The management of the plant would have to be adapted within each future in order to effectively supply water to consumers. Under the Cool Running Scenario a private public partnership ownership arrangement may be more effective to ensure vulnerable groups in society can access and afford water and whereas in Island in the Sun there may need to be designated committee under the local government system who manages the maintenance and operations of the desalination plants to ensure all communities have access to water. Due to the level of investment, technical skills and access to spare parts required for maintaining of a reverse osmosis plant this adaptation strategy may not be applicable under the Pirates of the Caribbean scenario.

Check dams

The island of Carriacou has a network of ephemeral streams cause by runoff after heavy rainfall. Check dams can be used to capture this runoff and are an effective way to utilize an otherwise wasted resource. The dams could vary in size and cost and can be used as either a temporary or permanent means of mitigating water shortages. Due to the flexibility of this approach it can be used under all the foresight scenarios particularly for irrigation of agricultural land. Concrete dams require construction skills and a greater level of investment which makes it suitable under the ‘Cool Runnings’ and ‘Island in the Sun’ scenarios. Since the society is highly fragmented under the ‘Harder they Come’ and ‘Pirates of the Caribbean’ scenarios individual farmers could construct dams using inexpensive materials such as clay. There is also the added benefit of reducing erosion during high intensity rainfall events.

Rehabilitation of community cisterns, wells and ponds

Over the years some cleaning and repairing of cisterns has been conducted by both community members and the Ministry of Works, however, many are still unfit for use. The restoration of these sources would increase storage and subsequently reduce the volume of unmet demand. Under the ‘Pirates of the Caribbean’ and ‘Harder they Come’ scenarios communities would have to self-organize and bear the responsibility and cost of improving the condition of the wells, cisterns and ponds in the absence of other institutions to take the lead. With the strong social cohesion present in the other two socioeconomic scenarios, a systematic approach to the use and management of the island’s public cisterns, wells and ponds can be established with both government and community sharing the responsibilities. This mechanism can be potentially useful in supplying unmet demand in the domestic and agricultural segments of society.

7. Conclusion

This paper sought to combine foresight scenarios and WEAP modelling to assess the impact of climate and socioeconomic change on water availability in the island of Carriacou using downscaled climate data. The study utilized a participatory approach to scenario development and a WEAP water demand model which resulted in four exploratory scenarios with unmet water demand projections for 2050. Three of the four scenarios did not have adequate water available and the wild card scenario highlighted that although water may be available in the future, socioeconomic conditions could hinder water access and quality. The findings demonstrate the uncertain, dynamic and complex nature of climate change and how scenarios and modelling can integrate creative, exploratory techniques with quantitative models to identify robust adaptation options. To build on this work it is proposed that future work

investigate assigning continuous rather than discrete values for quantitative indicators to give an indication of intermediate time horizons. The findings of the research could act as an input into the public policy process to evaluate the robustness of current policies and to inform new ones.

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