WORKSHOP ON CLIMATE CHANGE ADAPTATION IN CARIBBEAN AGRICULTURE:
Enhancing Water Management

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### Acronyms and Abbreviations

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<th>Description</th>
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<tr>
<td>ADF</td>
<td>Agricultural Development Fund, Barbados</td>
</tr>
<tr>
<td>AMO</td>
<td>Atlantic Multi-decadal Oscillation</td>
</tr>
<tr>
<td>BADMC</td>
<td>Barbados Agricultural Development and Marketing Corporation</td>
</tr>
<tr>
<td>BAS</td>
<td>Barbados Agricultural Society</td>
</tr>
<tr>
<td>BSTA</td>
<td>Barbados Society of Technologists in Agriculture</td>
</tr>
<tr>
<td>BWA</td>
<td>Barbados Water Authority</td>
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<tr>
<td>CAMI</td>
<td>Caribbean Agrometeorological Initiative</td>
</tr>
<tr>
<td>CARDI</td>
<td>Caribbean Agricultural Research and Development Institute</td>
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<tr>
<td>CARICOM</td>
<td>Caribbean Community</td>
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<tr>
<td>CBRA</td>
<td>Community-Based Resource Assessment</td>
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<tr>
<td>CCCCCC</td>
<td>Caribbean Community Climate Change Centre</td>
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<tr>
<td>CDEMA</td>
<td>Caribbean Disaster Emergency Management Agency</td>
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<tr>
<td>CEHI</td>
<td>Caribbean Environmental Health Institute</td>
</tr>
<tr>
<td>CIMH</td>
<td>Caribbean Institute for Meteorology and Hydrology</td>
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<tr>
<td>CLAWRENET</td>
<td>Caribbean Land and Water Resources Network</td>
</tr>
<tr>
<td>COTED</td>
<td>Council of Trade and Economic Development</td>
</tr>
<tr>
<td>CPWC</td>
<td>Co-operative Programme on Water and Climate</td>
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<tr>
<td>CTA</td>
<td>Technical Centre for Agricultural and Rural Cooperation</td>
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<tr>
<td>CWWA</td>
<td>Caribbean Water and Wastewater Association</td>
</tr>
<tr>
<td>ENSO</td>
<td>El Niño Southern Oscillation</td>
</tr>
<tr>
<td>FAO</td>
<td>Food and Agriculture Organization of the United Nations</td>
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<tr>
<td>GCM</td>
<td>Global Climate Model</td>
</tr>
<tr>
<td>GHG</td>
<td>Green House Gas</td>
</tr>
<tr>
<td>GWP-C</td>
<td>Global Water Partnership, Caribbean</td>
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<tr>
<td>IPCC</td>
<td>Intergovernmental Panel on Climate Change</td>
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<tr>
<td>Acronym</td>
<td>Full Form</td>
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<tr>
<td>IUCN</td>
<td>International Union for Conservation of Nature</td>
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<tr>
<td>IWA</td>
<td>International Water Association</td>
</tr>
<tr>
<td>IWCAM</td>
<td>Integrating Watersheds and Coastal Areas Management</td>
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<tr>
<td>IWRM</td>
<td>Integrated Water Resources Management</td>
</tr>
<tr>
<td>LDPE</td>
<td>Low-density polyethylene</td>
</tr>
<tr>
<td>LWUU</td>
<td>Land and Water Use Unit, Barbados</td>
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<tr>
<td>MACC</td>
<td>Mainstreaming Adaptation to Climate Change</td>
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<tr>
<td>MEA</td>
<td>Multilateral environmental agreement</td>
</tr>
<tr>
<td>NAO</td>
<td>North Atlantic Oscillation</td>
</tr>
<tr>
<td>NGO</td>
<td>Nongovernmental organizations</td>
</tr>
<tr>
<td>NWC</td>
<td>National Water Commission, Jamaica</td>
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<tr>
<td>OFWM</td>
<td>On-farm water management</td>
</tr>
<tr>
<td>PRECIS</td>
<td>Providing Regional Climates for Impact Studies</td>
</tr>
<tr>
<td>RCM</td>
<td>Regional Climate Model</td>
</tr>
<tr>
<td>SIDS</td>
<td>Small Island Developing States</td>
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<tr>
<td>SLAFY</td>
<td>St. Lucia Agriculture Forum for Youth</td>
</tr>
<tr>
<td>SRES</td>
<td>Special Report on Emissions Scenarios</td>
</tr>
<tr>
<td>The Alliance</td>
<td>The Alliance for Sustainable Development of Agriculture and the Rural Milieu in the Wider Caribbean</td>
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<tr>
<td>TTABA</td>
<td>Trinidad and Tobago Agribusiness Association</td>
</tr>
<tr>
<td>USACE</td>
<td>United States Army Corps of Engineers</td>
</tr>
<tr>
<td>UWI</td>
<td>University of the West Indies</td>
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<tr>
<td>WASA</td>
<td>Water and Sewerage Authority, Trinidad and Tobago</td>
</tr>
<tr>
<td>WRMD</td>
<td>Water Resource Management Department, Barbados</td>
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Introduction

Climate change and climate variability with consequential increases in temperature, unpredictable rainfall and rises in sea level are of worldwide concern. In the Caribbean, the increasing unpredictability of rainfall is particularly worrying to the agricultural sector, since most of the food is produced using water sourced from rainfall—either directly or indirectly.

In the recent past, significant flooding and drought events have severely affected regional crop and livestock production, leading to an unpredictable supply of locally produced food. The situation is projected to get worse and the International Water Management Institute (IWMI) has predicted that most countries in the Region will be economically water scarce by 2025.

Although it is clear that action must be taken, there is a paucity of the necessary supporting systems. Current policies in the Caribbean do not adequately support sustainable land use and water management as a result, access to water for agriculture is unpredictable and mostly unregulated. Additionally, the region has limited technical capacity to predict future water scenarios through modelling, which is critical to food and nutrition security. It is therefore imperative that regional policies address these deficiencies.

Caribbean Initiatives

The Consortium of Caribbean Community (CARICOM) Institutions on Water Management was established in 2008 to assist Member States with developing and implementing their Integrated Water Resource Management (IWRM) Plans. This contributed to CARICOM’s effort to establish effective mechanisms leading to the adoption of a harmonized approach to securing, managing and protecting its water resources in the region.

CARDI and the Caribbean Community Climate Change Centre, as members of the Consortium, have been mandated to lead the development of water management policies for the agricultural sector. To this end, CARDI has collaborated with other institutions on a Caribbean Agro-Meteorology Initiative (CAMI) project aimed at increasing and sustaining agricultural productivity in the Caribbean through improved dissemination and application of weather and climate information. CARDI is also implementing a World Bank supported project on ‘Agricultural Practices to Mitigate Risks in Smallholder Agricultural Production in the Caribbean Region’.

The Technical Centre for Agricultural and Rural Co-operation (CTA) has identified climate change as one of the priority thematic areas of their 2011–2015 Strategic Plan. In 2011, the CTA joined CARDI in hosting a workshop on ‘Climate Change and Agriculture in the Caribbean: Protected Agriculture – An Adaptation Option’. The main area of focus was the impact of climate change on the agricultural sector and adaptation and mitigation strategies that show potential to reduce the impact of climate change on

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1 The other institutions are the Caribbean Institute of Meteorology and Hydrology (CIMH), the World Meteorological Organization (WMO) and National Meteorological and Hydrological Services (NMHSs) of Caribbean Member States
agricultural productivity. Protected agriculture was highlighted as a technological option to assist in achieving food and nutrition security.

The workshop took place during the Ninth Caribbean Week of Agriculture (CWA). The CWA is an annual event, which brings together agriculture policy makers and all the key regional agricultural institutions. It aims to place agriculture and rural life at the forefront of regional integration activities. The CWA is convened under the aegis of the Alliance for Sustainable Development of Agriculture and the Rural Milieu (The Alliance). The main collaborating agencies are IICA, the CARICOM Secretariat, the Food and Agriculture Organization of the United Nations (FAO), CARDI and the CTA.

In 2011, the Tenth CWA was held in Dominica. The theme for the Week was ‘Caribbean Food and Nutrition Security in a Changing Climate – The Nature Island Experience’. In keeping with the theme, CARDI and CTA launched the Week of activities with a workshop titled, ‘Climate Change Adaptation in Caribbean Agriculture – Enhancing Water Resources Management’.

**Climate Change Workshop Structure**

The inclusive (multi-stakeholder, multi-sectoral and multi-disciplinary) CARDI/CTA workshop took place from 9–11 October 2011 and consisted of presentations on an e-consultation, synthesis papers, case studies, plenary and working group sessions and a field visit. The workshop was divided into four technical sessions, which provided guidelines for an e-consultation that preceded the workshop.

**e-Consultation**

The e-consultation was held from August and September 2011. Its objective was to ‘virtually’ solicit and distil the views, opinions, and experiences of stakeholders in the agricultural and water sectors in the Caribbean who were unable to participate in person at the workshop. This enabled everyone with an interest in water use to contribute to the workshop activity of formulating operational and policy guidelines to ensure adequate supplies of, what has been termed by CTA, “the water we eat”.

A consultant developed e-questions on the workshop themes, initiated an e-forum to elicit answers to these questions and presented summary reports at each session of the workshop.

There were four questions posed, one per nine to ten day period. Each question started a new thread and each was supplemented by ‘thread builder’ questions that assisted in guiding or broadening the discussion.

There were 120 invitees drawn from water authorities, environmental agencies, nongovernmental organizations (NGOs), farmer organizations and regional organizations; as well as individual technocrats, farmers and activists. However, anyone with an interest in water use was welcome to join the discussion.

**Synthesis studies** on water availability and management for agriculture in the Caribbean under a changing climate presented science-based evidence for the formation of regional agricultural water management based on past and current research, studies and initiatives.
Case studies on innovative on-farm water management, one in Jamaica and one in Barbados, presented practice-based evidence for the formation of regional agricultural water management. They illustrated innovative on-farm water management techniques, identifying success factors and constraints and the main lessons learnt.

Parallel Working Group Discussions focused on Climate Change and Agriculture from the ‘Why’, ‘How’ and ‘What’ perspectives. ‘Why’ issues revolved around meteorological and other evidence of increasing variability and climate change. The ‘How’ group looked at the policy agenda that would adequately address the impacts of Climate Change, whilst the ‘What’ group documented the on-farm technologies, practices and approaches that would mitigate them.

The Alliance

The main recommendations from the workshop were presented at the annual meeting of The Alliance, which took place on 12 October 2011. The endorsement of the main recommendations by The Alliance will pave the way for further engagement with policy makers, including members of the Council of Trade and Economic Development (COTED) a decision-making organ of CARICOM, Ministers of related areas, members of Parliament, the CARICOM Secretariat and Heads of Government.

In addition, the outcomes of all the workshop activities will be used to develop materials (briefing papers, media articles) to inform engagement with policy-makers.
Workshop programme

DAY 1

Technical Session I: Climate Variability and Change and Water Availability in the Caribbean

Chairperson – Mr. Mark Bynoe, (Caribbean Community Climate Change Centre, CCCCC)

Synthesis paper: “Climate variability and change and water availability in the Caribbean” – Dr Michael Taylor (The University of the West Indies)

Summarized report on the e-discussions - Coordinator

Panel discussion: Technical session I

Technical Session II: Managing water resources under a changing climate

Chairperson – Mr Adrian Trotman (Caribbean Institute for Meteorology and Hydrology, CIMH)

Synthesis paper: “Managing water resources in the Caribbean under a changing climate” – Ms Judi Clarke (Consultant)

Summarized report on the e-discussions - Coordinator

Panel Discussion: Technical session II

DAY 2

Technical Session III: Soil water management systems for a drier Caribbean

Chairperson – Dr Leslie A. Simpson (Natural Resources Management Specialist, CARDI)

Synthesis paper: Soil water management systems for a drier Caribbean – Prof. Nazeer Ahmad (Professor Emeritus, Soil Science, University of the West Indies)

Summarized report on the e-discussions - Coordinator

Case study 1 – Mr Stanley Rampair

Case study 2 – Mr Gregg Marshall

Panel Discussion: Technical session III

Technical Session IV: Adaptation strategy for agriculture in the Caribbean in relation to declining water resources as a result of climate change - Facilitator: Mr Steve Maximay
Working Groups (Parallel)

- Water resources adaptation practices
- Soil water management adaptation practices
- Policy measures required to facilitate adaptation practices

Presentations on the findings by the Working Groups

Plenary Discussion: Synthesizing the recommendations that emerged from the presentations

Closing Ceremony

- Synopsis of the workshop activities in relation to the expected outcomes (Facilitator)
- Feedback from participants (3 selected participants)
- Follow-up actions
- Closing statements in relation Climate Change and agriculture in the Region (CTA, CARDI, CCCCC)

DAY 3

Field Trip: Water resources management and irrigation facilities in Dominica
TECHNICAL SESSION I
Synthesis Paper: Climate Variability and Change and Water Availability in the Caribbean

MICHAEL A. TAYLOR, KIMBERLY A. STEPHENSON AND DALE R. RANKINE

Climate Studies Group, Department of Physics, Mona Campus, University of the West Indies

About this Paper

This paper seeks to zoom in on regional issues relating to climate variability and change and water availability in the Caribbean. The countries of the Caribbean, like other small island developing states, face a number of challenges in respect of both water availability and climate change. Water availability varies significantly within and between the region’s states and reliance on surface and groundwater is significant. Moreover, there is already an inherent vulnerability to climate change due to small physical size (in most cases), location in the hurricane belt, and limited physical and financial resources. Collectively, these increase the concerns for future water availability and the need for shrewd management and improved adaptation planning. A number of studies have examined the effect of climate change on water availability in the Caribbean (see for example Farrell et al. 2007, Durant et al. 2008, and Cashman et al. 2010). This paper seeks to synthesize the findings of these and other works while making special highlight of challenges that are unique to the region.

Methodology

The paper begins by describing the importance of both water and rainfall to Caribbean development and also examines the role of precipitation in determining water availability in the Caribbean (Section 1). It then presents a detailed examination of the primary drivers of rainfall variability on short and long-term timescales, and how they in turn impact water availability via their impact on Caribbean rainfall (Section 2). The paper also examines, in detail, climate change and its manifestations as observed and projected for the region (section 3). The paper closes by summarizing some key points while drawing ten observations from the information presented in the previous sections (Section 4).

Major Points

Some of the final observations made include (i) the need for climate monitoring as a critical element of water management; (ii) the role of climate change in impacting water availability via changes in temperature, rainfall, intensity of storms and sea levels; and (iii) the identification of possible ‘at risk’ Caribbean territories. This paper does not attempt to provide options for managing deficiencies in water availability or offer water sector adaptation strategies to climate change in light of the results presented in Sections 2 and 3. Those, it is contended, are in themselves subjects worthy of their own comprehensive analysis.
Setting the Context

Water as Key

The Hydrologic Cycle

Water is indispensable for all forms of life. It is needed in almost all human activities and is regarded as a *sin qua non* for development and sustainable development in particular. The access to safe freshwater is now regarded as a universal human right (United Nations Committee on Economic, Social and Cultural Rights, 2003) and, not surprisingly, water as an issue has gained increasing recognition in the international context (e.g. Agenda 21, World Water Fora, the Millennium Ecosystem Assessment and the World Water Development Report). Sustainable management of freshwater resources has gained importance at global and regional scales, as has the recognition that surfeits can seriously challenge the livelihood, well being and economic development of individuals, countries and regions.

Water is a naturally circulating resource that is constantly recharged (Oki et al. 2006). Its abundance in any form is governed by the hydrologic cycle (Figure 1), which defines the cycling of water in the oceans, atmosphere and biosphere. As much as 97% of the world’s water is contained in the ocean, compared to only 0.001% in the atmosphere (Chahine 1992, Peixoto et al. 1992). The rest is locked up in glaciers, ice caps, snow and underground sources (Chahine 1992).

Water for input into the atmosphere is evaporated from water bodies including oceans, rivers, and streams and transpired from vegetation. The resulting water vapour condenses and produces precipitation. Most of the precipitation occurs as rain, with the total annual amount being about 505,000 km$^3$/year. Of this amount, nearly 80% falls over the ocean. Over the oceans evaporation exceeds precipitation and the difference contributes to precipitation over land (Chahine 1992). Thirty-five per cent of the rainfall over land comes from marine evaporation driven by winds while 65% comes from evaporation from the land. Since precipitation exceeds evaporation over land, the excess must return to the ocean as runoff (see again Figure 1).

The atmosphere recycles its entire water contents about 33 times per year giving water vapour a mean residence time of about 10 days. This is in sharp contrast to the ocean residence time, which varies considerably with depth (Chahine 1992). Surface ocean water has a short residence time of a few days to weeks, but deep ocean level water has a time of up to centuries; so that the mean residence time of ocean
water is about 3000 years (Chahine 1992). This emphasizes the importance of surface flow like rivers and streams from which a significant portion of freshwater is obtained. The amount of water stored in all the rivers in the world is only 2000 km$^3$, much less than the annual water withdrawal of 3800 km$^3$/year (Oki et al. 2006). The water demand is satisfied by the annual discharge of 45,500 km$^3$, which flows mainly through rivers from continents to the sea (Oki et al. 2006).

**Links to climate and climate change**

It is not hard to see that climate and water resources are intimately connected through the hydrologic cycle. On the one hand, the hydrological cycle is intimately linked with changes in atmospheric temperature and the radiation balance. Temperature influences water availability as it is a determinant of the amount of water that is lost via evapotranspiration from the earth’s surface and returned to the atmosphere. This in turn impacts precipitation, which has already been noted to be a key component of the earth’s hydrologic cycle. Changes in precipitation greatly influence the amount of water flowing through the water cycle and, as a consequence, water availability.

It is the linkages between climate and the hydrological cycle, particularly the links with temperature and rainfall, that make climate change an important issue for water availability. Climate change is characterized by an unequivocal warming of the climate system, which in recent decades has been evident in observations of increased global average air and ocean temperatures, widespread melting of snow and ice, and rising global sea level (IPCC, 2007). The warming is expected to continue into the future at increased rates, since much of it is due to increased anthropogenic emissions of greenhouse gases, which are closely linked to development pathways of the world. Future climate change is projected to have significant effects on the hydrological cycle (IPCC 2008). Rising surface temperatures will intensify the hydrological cycle by causing more evaporation and consequently more precipitation (IPCC, 2008). Unfortunately, the extra precipitation will not be equally distributed, and some parts of the world will also see significant reductions in precipitation, or major alterations in the timing of wet and dry seasons (Arnell 1999).

**Table 1** List of some observed or possible impacts of climate change on water availability

<table>
<thead>
<tr>
<th>Observed Effect</th>
<th>Observed/ Possible Impacts</th>
</tr>
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</table>
| Increase in Atmospheric temperature | • Reduction in water availability in basins fed by glaciers that are shrinking, as observed in some cities along the Andes in South America (Ames, 1998; Kaser and Osmaston, 2002)  
• Increased evaporation of surface water | |
| Increase in surface water temperature | • Reductions in dissolved oxygen content, mixing patterns and self purification capacity  
• Increase in algal blooms | |
| Sea level rise                    | • Salinization of coastal aquifers                                                      | |
| Shifts in precipitation patterns  | • Changes in water availability due to changes in precipitation and other related phenomena (e.g. groundwater, recharge, evapotranspiration) | |
From the supply side, climate change will affect the water cycle directly and through it, the quantity and quality of water resources available to meet the needs of societies and ecosystems. Table 1 above summarizes some of the observed or potential impacts on water availability due to climate change. If the changing climate results in increased intensity in precipitation, it will likely cause greater peak runoffs but less groundwater recharge. If the changing climate results in receding glaciers, melting permafrost and changes in precipitation from snow to rain, then seasonal flows will likely be impacted. If the changing climate causes sea levels to rise, then coastal freshwater aquifers may be impacted by saline intrusion thereby reducing freshwater supplies. If the changing climate produces longer dry periods in some places, then reductions in groundwater recharge are possible as are lower minimum flows in rivers. Increased intensity in rainfall, melting glacial ice, sea level rise and longer dry periods are already being observed in varying locations over the globe, along with their impacts on water availability (IPCC 2007). One of the aims of this document is to try to capture what is known about how climate change will manifest itself in the Caribbean and its likely impact on water availability in the region.

The Caribbean Context

Rainfall, Rainfall, Rainfall

Several islands in the Caribbean are defined as water scarce with respect to natural freshwater resources. The United Nations defines a water scarce country as one having an annual freshwater availability of below 1000 m³ per person. According to Farrell et al. (2010) Caribbean territories falling into this category include, but are not limited to, Barbados, Antigua and Barbuda, St Kitts and Nevis and The Bahamas. They also note, however, that in larger islands where water scarcity may not presently exist at the national level, regional disparities with respect to the amount of rainfall received in a given location and/or physical conditions can result in water scarcity at the local level.

In the region, it is unmistakable that rainfall is a key determinant of water resources in the Caribbean. This is borne out by the fact that all CARICOM Member States rely primarily on groundwater, surface water or rainwater harvesting or various combinations of all three for their potable, industrial, sewerage and agricultural water supply. These sources are recharged by rainfall during the course of the year. Table 2 provides water profiles for a number of Caribbean countries. Some countries, such as Barbados, rely almost exclusively on groundwater resources for their potable water supply, while other countries such as Dominica rely exclusively on surface water sources. Jamaica and Guyana utilize both surface water and groundwater sources for their potable water supply, while countries such as Antigua and Barbuda, The
Bahamas and the Cayman Islands obtain significant portions of their potable water supplies from reverse osmosis plants, which augment groundwater and/or surface water sources. Sources may also vary both within and between islands. For example, there is an abundance of surface water in rivers and streams on mainland St Vincent, while the Grenadines experience severe shortages due to the limited supply of surface or groundwater (Durrant 2008).

A strong reliance on rainfall for freshwater, however, means that water availability in the Caribbean possesses a very strong sensitivity to variations in rainfall on any timescale (short to long-term). The timing and magnitude of the impact of more or less rainfall on the various sources of water will, however, vary. For example, surface water resources are generally the first to show the impacts of a deficit in rainfall given that they are primarily fed by rainfall runoff, with contributions from groundwater occurring in the lower portions of watersheds (Farrell et al. 2010). Surface water impoundments are also particularly vulnerable to high rates of evaporation due to elevated temperatures and drier than normal air masses. In comparison, the impacts of drought on groundwater systems tend to be delayed due to the slow nature of the infiltration/recharge process. Farrell et al. (2010) note that in the latter instance many groundwater managers may misinterpret the initial lack of a decline in water levels as a lack of impact and, if not careful, may resort to increased groundwater mining (pumping more than the volume of recharging volume). This may in turn trigger aquifer salinization due to seawater intrusion or increased pollutant concentrations due to reduced groundwater mixing volumes. Both processes could result in a further reduction in potable groundwater. With respect to rainwater harvesting, the volume stored can be highly variable in periods of prolonged drought conditions.

The importance of Summer Rainfall

Geographically the wider Caribbean region sits between the North American coast of Florida and the South American mainland, and spreads out as an arc of islands varying in size and topography. Though there is wide variation in rainfall due to the influence of topography and size of landmass, there are some commonalities including a distinct dry period occurring somewhere between December to April and a rainfall season which coincides with the hurricane season of June to November (Taylor and Alfaro 2002). A plot of the mean monthly distribution of Caribbean rainfall is shown in Figure 2. Table 3 documents the mean rainfall season for selected Caribbean states and the percentage of total rainfall receive during the wet season. The seasonal distribution of rain is further elaborated on in Section 2.1.

Both Table 3 and Figure 2 highlight the fact that it is largely summer rainfall that is relied upon for recharging the regional water resources (groundwater, surface water or rainwater harvesting) during the year. Figure 2 shows that the period between May and November is the chief rainy period in the Caribbean during which up to 70% of total annual rainfall generally occurs. In the examination of water availability to follow, an emphasis will be placed on examining how rainfall in these summer months vary on both short and long-term scales and due to climate change.
## Table 2  Water profiles for selected Caribbean states

<table>
<thead>
<tr>
<th>Country</th>
<th>Water source</th>
<th>Agriculture - usage</th>
<th>Climate Change vulnerability</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jamaica</td>
<td>Groundwater resources (84%) primarily from limestone aquifers, Surface water (16%) 92% to (agriculture, tourism, domestic, industrial)</td>
<td>Irrigation (75% - 2000)</td>
<td>Drought, Saline intrusion (coastal aquifers) – storms and sea level rise</td>
<td>Meteorological Service of Jamaica (2000); USACE* (2001); Simpson et al. (2009); Chase (2008)</td>
</tr>
<tr>
<td>Dominica</td>
<td>Surface water (rivers)</td>
<td>Rain fed (very little irrigation)</td>
<td>Turbidity – storms, drought</td>
<td>USACE (2004a); Simpson et al. (2009)</td>
</tr>
<tr>
<td>Antigua</td>
<td>Desalination (75% dry season vs 60% wet season), Groundwater, (20% dry season vs 15% wet season), Surface water (5% dry season vs 25% wet season)</td>
<td>Irrigation from surface water (20% of withdrawals)</td>
<td>Sea levels (water table high)</td>
<td>USACE (2004a); Simpson et al. (2009)</td>
</tr>
<tr>
<td>Barbuda</td>
<td>Groundwater, surface water</td>
<td></td>
<td>Sea levels (water table high), drought</td>
<td>USACE (2004a); Simpson et al. (2009)</td>
</tr>
<tr>
<td>St Kitts &amp; Nevis</td>
<td>Groundwater (primary), Surface water</td>
<td>Rain fed (85%), Irrigated (15%)</td>
<td>Sea level rise, High temperatures (high evaporation rates), Drought</td>
<td>USACE (2004a); Simpson et al. (2009)</td>
</tr>
<tr>
<td>Barbados</td>
<td>Groundwater (79%) desalination</td>
<td>Irrigated (11%)</td>
<td>Drought</td>
<td>Government of Barbados (2001); Chase (2008)</td>
</tr>
<tr>
<td>Trinidad &amp; Tobago</td>
<td>Surface water (52%), Groundwater (32%), Desalination (12%)</td>
<td>Irrigated agriculture (3-6% of usage)</td>
<td>Drought, sea level rise for coastal aquifers</td>
<td>Government of Trinidad &amp; Tobago (2010)</td>
</tr>
<tr>
<td>Grenada</td>
<td>Surface water</td>
<td></td>
<td>Drought, High temperatures</td>
<td>Simpson et al. (2009); Department of Economic Affairs (2001)</td>
</tr>
<tr>
<td>Bahamas</td>
<td>Groundwater, Desalination</td>
<td></td>
<td>Salt-water intrusion, storms, sea level rise, drought</td>
<td>USACE (2004b), Simpson et al. (2009); Chase (2008)</td>
</tr>
<tr>
<td>Belize</td>
<td>Groundwater (95% rural areas), Surface water (90%)</td>
<td></td>
<td>Drought</td>
<td>Simpson et al. (2009)</td>
</tr>
<tr>
<td>St Lucia</td>
<td>Surface water (100%)</td>
<td></td>
<td>Drought</td>
<td>Chase (2008)</td>
</tr>
<tr>
<td>British Virgin Islands</td>
<td>Desalination (60%), Groundwater (40%)</td>
<td></td>
<td>Drought</td>
<td>Chase (2008)</td>
</tr>
</tbody>
</table>

* USACE: United States Army Corps of Engineers
Table 3  Rainfall Season of selected Caribbean states

<table>
<thead>
<tr>
<th>Island</th>
<th>Rainy Season, Annual Rainfall mean (or range)</th>
<th>Percentage of Rain Occurring in Summer Rainy Season</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antigua and Barbuda</td>
<td>May–November</td>
<td>50%</td>
</tr>
<tr>
<td>Barbados</td>
<td>June–November</td>
<td></td>
</tr>
<tr>
<td>Belize</td>
<td>May–November (1500-3800 mm/year depending on location. The south is wetter)</td>
<td>60%</td>
</tr>
<tr>
<td>Dominica</td>
<td>June–November</td>
<td></td>
</tr>
<tr>
<td>Jamaica</td>
<td>May–November (1270-5080mm/annum – Northeast and northwest are the wettest. Southern coastal fringes are driest)</td>
<td>Up to 70%</td>
</tr>
<tr>
<td>Grenada</td>
<td>June–December (750-1400mm/year)</td>
<td>About 75%</td>
</tr>
<tr>
<td>Guyana</td>
<td>Two wet season and two dry seasons. Wet 1: April–July, Wet 2: November–January</td>
<td></td>
</tr>
<tr>
<td>St Kitts &amp; Nevis</td>
<td>May-September (890-3800mm/year)</td>
<td></td>
</tr>
<tr>
<td>St Lucia</td>
<td>June–November (1265-3420 mm/year increases from flat coastal areas to hilly interior)</td>
<td>70%</td>
</tr>
<tr>
<td>St Vincent &amp; Grenadines</td>
<td>June–November (about 2190mm)</td>
<td>70%</td>
</tr>
<tr>
<td>Trinidad &amp; Tobago</td>
<td>June–December</td>
<td></td>
</tr>
</tbody>
</table>
The Importance of Rainfall for Caribbean Agriculture

Finally, in the specific context of the regional agricultural sector, the near synonymy between rainfall and water availability becomes even more obvious. Table 2 also suggests that agriculture in the Caribbean is predominantly rain fed. Even in the case of countries like Jamaica (75% irrigated), the reliance on groundwater and surface water to supply agricultural water demand makes the sector still dependent on rainfall. The fact that the cropping system in the Caribbean is largely made up of characteristic smallholdings and open field farming and that a significant number of farms are totally rain fed with no supplemental irrigation system emphasizes the great dependence of the region’s agriculture sector on (reliable) rainfall for water.

Variability in rainfall events can therefore increase the volatility of rain fed production at local and regional levels (FAO 2008). Table 4 gives examples of some recent drought impacts on agricultural production in selected Caribbean islands. The impact is often extensive and costly to the agricultural sector, with both the timing and severity of droughts affecting crop production (Gamble et al. 2010). This is especially so if there are no supplementary irrigation systems. In general, as droughts intensify the need for irrigation increases, as most crops cannot survive drought conditions, particularly during the early stages of growth.

Table 4  Recent Drought impacts in selected Caribbean States

<table>
<thead>
<tr>
<th>Country</th>
<th>Date</th>
<th>Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Guyana</td>
<td>2009/2010</td>
<td>Up to 35% of rice fields left uncultivated. US$1.3 million spent to operate irrigation pumps (US$16,000/day). About 150 acres irrigated with salt water in desperation. In 2010 alone over 100,000 acres experienced water stress prompting government investment of over US$30 million</td>
</tr>
<tr>
<td>Trinidad</td>
<td>Jan–May 1987</td>
<td>Over 10,000 acres of natural forest burned resulting in severe crop losses at a mean of US$500,000/year</td>
</tr>
<tr>
<td>Dominica</td>
<td>2010</td>
<td>Banana export fell 43% below normal</td>
</tr>
<tr>
<td>St Vincent &amp; Grenadines</td>
<td>2010</td>
<td>Crop production reduced to 20% of normal</td>
</tr>
<tr>
<td>Antigua and Barbuda</td>
<td>2010</td>
<td>Loss of 25% of onion crop, 30% of tomato crop estimated at 250,000 kg</td>
</tr>
<tr>
<td>Jamaica</td>
<td>1996 and 1998</td>
<td>Severe loss of sugar crop, caused government US$100 million in compensation</td>
</tr>
</tbody>
</table>
Quick Summary

One notes then the following from the preceding discussion:

- Access to water is essential for sustainable development.
- In the hydrological cycle, rainfall and temperatures impact the available water at a given location.
- In the Caribbean, there is a high dependence on rainfall for accessing water.
- Tracking variations in rainfall (short and long-term) will provide good insight into water availability in the Caribbean.
- Upwards of 70% of Caribbean rainfall falls between May and November.
- Tracking variations in summer rainfall will provide good insight into water availability in the Caribbean.
- Agriculture in the Caribbean is heavily dependent on rain with many crop seasons mirroring the rainfall climatology.
- Tracking variations in rainfall (short and long-term) will provide good insight into water availability for the Caribbean agricultural sector.
- Aspects of the hydrological cycle will also be impacted by temperature variations.
- Accessible water may be impacted by intensity of the rainfall and saline intrusion, which can be linked to sea level rise.
- Climate change has, and will continue to alter rainfall intensities, temperatures and sea levels.
- Knowledge of changes in temperature, rainfall intensity and sea level rise are useful for also determining available water under climate change.

Because of the significance of rainfall to Caribbean water availability, the remaining sections of this document examine how Caribbean rainfall is altered on short and longer-term time scales and how rainfall in the region will likely be altered by climate change. Some discussion on how temperatures, rainfall intensities and extreme weather (hurricanes) and sea level rise will vary under climate change is also offered, given the role each of these also play in determining water availability.
Climate Variability

Seasonal Variation

The amount of available water is strongly modulated by the regional climatology of rain. As noted previously, the Caribbean generally possesses a dry, winter-warm, summer climatology with the exception of the Dutch Caribbean island where the pattern is reversed. Consequently, there is a dry period from December through April and a wet season that runs from May through November. This pattern is further modulated by the orography of each territory, as well as by their orientation and location in the basin. It is the rain of the wet season on which the Caribbean is largely dependent for most of its freshwater. Upwards of 70% of total annual rainfall occurs within this period.

A unique feature of the wet season is its interruption by a brief dry period in July/August, which is often referred to as the ‘midsummer drought’ (Magaña et al. 1999, Chen and Taylor 2002, Ashby et al. 2005, Taylor and Alfaro 2005; Curtis and Gamble 2008, Gamble et al. 2008) (see again Figure 2). Curtis and Gamble (2008) and Gamble et al. (2008) suggest that there is some spatial variation in the onset of the midsummer drying, as it generally begins in May–June in the eastern Caribbean and June–July in the northwest Caribbean. The greatest decrease in summer precipitation occurs over Jamaica and the western Caribbean. The decrease in rainfall can be significant, by as much as 40% in late July and early August compared to June and September (Hastenrath 1976). Beckford and Barker (2007) note that such variability offers a challenge to rain-fed agriculture and water supply across the region, particularly on small carbonate islands.

The midsummer drying also gives rise to the bimodal precipitation pattern, which is characteristic of many of the countries of the region (see again Figure 2). There is, as a result, a rainfall maxima in May-June and September–October separated by the brief dry period. Giannini et al. (2000) suggest that the bimodal pattern accounts for 66% of the total variance of the annual cycle of Caribbean rainfall and it facilitates references to an early (May through July) and late (August through November) Caribbean rainfall season.

An understanding of the drivers of the seasonal pattern of variability is necessary to understand the reasons for variations from this pattern. There are a number of synoptic modulators of Caribbean rainfall that span both the Pacific and Atlantic Oceans. The start of the Caribbean rainy season is coincident with the northward movement of the north Atlantic subtropical high, which results in a weaker surface pressure gradient at its southern edge and weaker northeasterly trades. The weaker trades converge on the eastern edge of the Caribbean (Hastenrath 1966 and 1967). At the same time, the Pacific Inter-tropical Convergence Zone (ITCZ) is north of the equator (with maximum northern displacement in August/September - Giannini et al. 2000), thereby allowing for convergence of winds and moisture towards the Caribbean from both east and west. As the rainy season progresses, vertical shear due to opposing wind flow near the surface and in the upper atmosphere is also reduced, giving rise to a generally more favourable atmospheric regime for rainfall over the regime.

Very warm Caribbean and tropical Atlantic sea surface temperatures also enhance the region’s favourability to rain, by contributing to an unstable boundary layer, increased evaporation from the ocean’s surface and an abundance of moisture in the lower atmosphere. Warm waters first appear in the
Gulf of Mexico by early summer, and spread southwards and eastwards into the Caribbean, eventually engulfing the entire region by October (Wang and Enfield 2003, Taylor et al. 2002). It is no coincidence that the peak of the Caribbean rainfall and hurricane seasons occurs in October, when warm surface waters spread across the entire Caribbean and tropical Atlantic. By the time easterly waves begin to traverse the Caribbean region in May /June, they encounter increasingly favourable conditions, i.e. warm oceans, increased moisture in the troposphere, large-scale convergence and low vertical shear, which enhance their potential for development in tropical depressions, storms and hurricanes. Landsea (1993) attributes 58% of all tropical storms and 83% of all major hurricanes to easterly waves, while Frank (1977) attributes 40% of all tropical Atlantic depressions to them.

The rainy season ends in November when the north Atlantic high retreats southward yielding both stronger trades and increased vertical shear. A brief southward retrogression of the subtropical high in late July/early August that is also partially responsible for the midsummer drying (Gamble and Curtis 2008).

Rainfall in the dry months is generally as a result of the passage of north American frontal systems. For this reason, it is generally the northern Caribbean which sees the most rain in this period.

Interannual Variability

ENSO

Within the above context, variability in Caribbean rainfall, and by extension water availability, is often driven by global climatic variations that alter the seasonal drivers. The most significant of these is the El Niño Southern Oscillation (ENSO). The El Niño is a warming (La Niña is a cooling) of the surface waters in the equatorial Pacific (see Figure 3) which, as a result, yields atmospheric changes that have global teleconnections. El Niño events generally occur every three to seven years.
Within the Caribbean region, the warm sea surface temperature anomalies in the tropical Pacific produce abnormally wet or dry periods dependent on the period of the year. There is the tendency for the late wet season (August through November) to be dry during the year of an El Niño maximum, with the extent of drying dependent on many factors, including the severity of the El Niño (Ropelewski and Halpert 1986, 1987, Giannini et al. 2000, Chen and Taylor 2002, Taylor et al. 2002). This is due in part to the dominance of a divergent surface flow between the eastern tropical Pacific and western tropical Atlantic and stronger vertical shear induced over the primary region for easterly wave development in the tropical Atlantic region during the El Niño event (Arkin 1982, Gray et al. 1984, Aceituno 1988). The reduction in rainfall during the primary Caribbean wet season often has serious consequences for water availability in the region, and the problem is compounded when the El Niño persists through the first half of the following year, as was the case in 2009–2010 (see section below). In the later instance, the occurrence of an El Niño during the Caribbean dry period tends to induce opposite signals over the north and south Caribbean, with strong drying in the southern Caribbean but a transitioning to wetter conditions over regions north of Jamaica, particularly over north Cuba, The Bahamas, Puerto Rico and Florida (Stephenson et. al 2008). In general, La Niña conditions produce the opposite conditions in both the late wet season (wetter) and during the dry season (drier south Caribbean).

During the year of El Niño decline, there is the opposite tendency for the early wet season to be wetter than normal (Giannini et al. 2000; Chen and Taylor 2002; Taylor et al. 2002), provided there is a timely decline by the El Niño phenomenon. In this case, the wetter Caribbean largely results from warm waters that develop in the eastern tropical Atlantic Caribbean four to six months after the peak in warm equatorial Pacific waters (Enfield and Mayer 1997), which favour convective development. The El Niño
(La Niña) can also impact the severity of the midsummer drying by increasing (decreasing in the case of La Niña) low level wind strengths in the southern Caribbean basin and inducing a drying (wetting under La Niña) of the region (Whyte et al. 2010).

Research suggests that El Niño events have increased in frequency, severity, and duration since the 1970s (Stahle et al. 1998, Mann et al. 2000). This would imply that there have been more extremes in weather in the region since the 1970s. Anecdotally, recent climatic events seem to support this. Gamble et al. (2010) note that “Farmer perceptions of increasing drought might reflect relative changes in the early (April–June) and principal (August–November) growing seasons. Specifically, many farmers commented in interviews that drought is becoming more prevalent”. There has, however, been little or no region-wide analysis undertaken to confirm these kinds of changes in weather extremes.

It is also to be noted that the extent to which an El Niño event impacts the region can be modulated by how warm or cool the Caribbean and/or equatorial Atlantic is at the time of the ENSO event’s occurrence (Taylor et al. 2002 and 2011). A number of recent studies show that when the gradient in temperature between the two basins is heightened, i.e. a warm equatorial Pacific/cool tropical Atlantic scenario exists, this is associated with decreased, late-season rainfall in the Caribbean and vice versa (Enfield and Alfaro 1999, Taylor et al. 2002, Taylor et al. 2011).

**ENSO Impacts**

It is more often the drying effect of the El Niño event that is most noticeable in the Caribbean region because of the onset of severe drought conditions and the attendant reduction in available water. El Niño events have coincided with many meteorological droughts across the region, such as the droughts of 1991, 1997–1998 and 2010 (Chen et al. 2005, Farrell et al. 2010) (see also Figure 4). Chen et al. (2005) note that an analysis of meteorological records for Jamaica reveals that since 1960, El Niño events have been the cause of many island-wide meteorological droughts, including in 1965, 1969, 1972, 1982–1983, 1991, and 1997. They also point out that the worst drought occurred in 1976 and 1991, when the island received 72% and 73%, respectively of normal rainfall with respect to the 30-year mean. Pulwarty et al. (2001) similarly note that the 1997–1998, El Niño event yielded 150 mm less than average rainfall in Trinidad between August and October. The Meteorological service of Puerto Rico also notes that 13% more precipitation falls during El Niño years than in La Niña years during the dry season (December through April), while 14% less rainfall falls during El Niño years during the wet season (May through November).

During 2009 and into 2010, most of the Caribbean experienced a severe to extreme drought (Farrell et al. 2010, Fonseca et al. 2010). Drought conditions began in the southern and eastern Caribbean in October 2009 and quickly spread northward, with significant declines in rainfall being recorded across the entire Caribbean from the wet season of 2009 to April/May in 2010 (Farrell et al. 2010). The onset and persistence of the dry conditions persisted through the first half of 2009 and was coincident with an emergence of a strong El Niño event in summer 2009 (Arndt et al. 2010, Blunden et al. 2011), which lingered through the mid-2010.
Farrell et al. (2010) analysed the impact of the drought on the Caribbean region. They note the most significant declines in rainfall were experienced in Grenada at the Point Saline International Airport, where the decreasing rainfall totals began earlier than at other regional stations, and where the rainfall in 2009 was the lowest in 25 years of records. Areas in the interior of the island that usually experience above 4000 mm of rainfall in the rainy season, with no dry months, experienced 1 to 2 dry months in 2009, while recorded rainfall was 50% of normal for March to September 2009, and 37–19% of normal for October 2009 to January 2010. Farrell et al. (2010) also note that Guyana and Dominica, which are known for abundant rainfall, were also significantly impacted by the 2009-2010 drought, with stations in both countries exhibiting significant declines in rainfall. They further point out that the severity of the drought’s impact was felt most by the region’s farming community and water resources sector, with many Caribbean countries being forced to implement water use restrictions. From mid-2009 through the first quarter of 2010, several Caribbean countries including Jamaica, Dominica and St Lucia reported significantly lower than normal flows in many of their streams.

It is interesting that whereas the southern Caribbean was severely affected by the El Niño at the start of 2010, the far north (including Cuba and Puerto Rico) recorded above average rain, due in part to the opposing impact of El Niño on the north versus south Caribbean during the dry season (Stephenson et al. 2008, Garcia et al. 2011). Additionally, the ENSO transitioned from a strong El Niño in early 2010 to a moderate-to-strong La Niña by the end of the year. By the end of the year, a number of Caribbean states were reporting near normal annual totals (in spite of the earlier drought) due to a wetter than normal late wet season associated with the La Niña event (Garcia et al. 2011).
**ENSO and Hurricanes**

Meteorologists have known for many years that ENSO strongly affects tropical cyclone activity around the world. In the tropical Atlantic basin, hurricane activity decreases during an El Niño event (Klotzbach 2011), primarily due to the increased vertical shear induced by stronger westerly winds in the upper atmosphere (Gray 1984, Shapiro 1987). La Niña events typically bring opposite conditions. The larger vertical shear accompanying El Niño events contributes directly to decreased numbers of both Atlantic tropical storms and hurricanes. This number increases under La Niña due to the smaller vertical sheer. El Niño and La Niña also influence where Atlantic hurricanes will form. During El Niño events, fewer hurricanes and major hurricanes develop in the deep tropics from African easterly waves. Goldenberg and Shapiro (1996) identify the area between 10°N and 20°N from North Africa to Central America (including much of the Caribbean region) as having the largest sensitivity to changes in vertical shear. Systems forming there have a much greater likelihood of becoming major hurricanes, and of eventually threatening the Caribbean. On the contrary, tropical storms and hurricanes forming over the subtropical waters farther north show a much weaker modulation due to ENSO (Landsea et al. 1999).

**Decadal Variability and Longer Timescales**

Though Caribbean rainfall variation on longer timescales is not as well studied, it is important to bear it in mind when discussing available water. Decadal variability can condition the region to be drier or wetter by yielding spells of wet or dry years because of the background conditions they impose. For example, in much the same way that El Niño is known to impact Caribbean rainfall on a year-to-year basis, there are known links between the North Atlantic Oscillation (NAO) and seasonal to decadal variability of Caribbean rainfall, especially over the eastern Caribbean (Giannini et al. 2001, Charlery et al. 2006, Jury et al. 2007, Jury 2009). In the positive phase of the North Atlantic Oscillation, there are anomalously high pressures across the subtropical Atlantic, which also induce cooler ocean surface waters and, as a result, the Caribbean is background conditioned to be dry. Gianni et al. (2001) point out that the combination of a positive phase of the NAO and an El Niño can cause the wet season drying, due to the latter’s occurrence, to be unusually intense. Similarly, the negative phase of the NAO (weaker sea level pressures and warmer ocean surface temperatures) can heighten the wetter conditions brought on during the early rainfall season in the year following the onset of an El Niño event.

Finally, it also bears noting that even longer-term variability, i.e. on multidecadal timescales, are to be found in the Caribbean rainfall record. The Atlantic Multidecadal Oscillation (AMO) is based on sea surface temperature variations in the North Atlantic and varies on a 50 to 90-year time scale. It has been in a warm phase since 1995. The historical records suggest that during warm phases of the AMO, the number of minor hurricanes (category 1 and 2) undergoes a modest increase. Perhaps more significant, however, is the fact that the number of tropical storms that can mature into severe hurricanes is much greater during warm phases of the AMO than during cool phases; at least twice as many (see Figure 5). The AMO is therefore reflected in the frequency of severe Atlantic hurricanes (Chylek and Lesins 2008). The AMO is expected to persist at least until 2015 and possibly as late as 2035. Enfield et al. (2010) assume a peak in the AMO around 2020.
The following points from the preceding subsections are noted:

- The Caribbean is characterized by a wet summer pattern during which much of the freshwater which falls as rain is received.

- ENSO is a primary modulator of rainfall availability because of its disruption of the mechanisms that give rise to rain in the Caribbean.

- ENSO’s impact depends on its phase (El Niño or La Niña), its severity, and the period of the year being considered.

- ENSO is most often associated with drought conditions brought on by El Niño events. There are several which appear in the Caribbean rainfall records.

- Late 2009 to early 2010 was significant for the effect of El Niño on water availability in the region.

- ENSO is not the only modulator of rainfall amounts in the region, decadal and multidecadal variability also exist.

**Figure 5** Atlantic Multidecadal Oscillation (AMO) and Major Atlantic Hurricanes.
The graph shows the correlation between the number of major hurricanes which form in the Atlantic basin (orange) and the moving averages for AMO (blue).
(Source: en.wikipedia.org)
Climate Change

Introduction

An assessment of the impact of global warming on the climate of the Caribbean involves identifying long-term trends that have already occurred and those that are likely to occur in the future. There are limitations to doing both in the Caribbean region, for example, the paucity of lengthy Caribbean climate records lends itself more to shorter timescale analysis, as was done in the previous section examining interannual and decadal variability, than deducing historical trends. Similarly, future projections require the use of global climate models (GCMs) whose spatial scales impose a limitation on the useful information that can be gleaned for islands that are smaller than the grid box sizes on which they produce results. Notwithstanding this, both the existing climate records and the use of GCMs afford ‘first guesses’ at past and future trends in Caribbean climate. Consequently, they are both utilized in this study to suggest how water availability has, and may continue to vary due to climate change induced by global warming. The emphasis is primarily on future projections of Caribbean rainfall for reasons already outlined. However, information on changes in temperature, Caribbean sea level rise and hurricanes are also provided for the role these can also play in determining water availability.

The following section provides a brief necessary introduction to scenarios and climate models as context for interpreting the results presented thereafter.

Of Scenarios and Models

To estimate future changes in climate, some assumptions have to be made about what the future world might look like, especially with respect to the concentration of greenhouse gas (GHG) emissions that will be in the atmosphere. Future concentrations of GHGs will depend on multiple factors, which may include changes in population, economic growth, energy use and technology. The Special Report on Emissions Scenarios (SRES) represent possible pathways for future GHG emissions premised on different storylines of change in the global development factors noted above (Nakicenovic et al. 2000). There are forty different scenarios or storylines divided into four families. Since none of the scenarios assume any future policies that explicitly address climate change, they represent a range of plausible, possible futures, i.e. low emission to high emission futures. For example, in Figure 5, A1FI is a high emissions scenario resulting from assumptions of a future with fossil fuel-intensive economic growth and a global population that peaks mid-century and then declines. In this scenario, CO$_2$ concentrations reach 940 parts per million (ppm) by 2100: more than triple pre-industrial levels. In comparison, B1 is a lower emissions scenario where atmospheric carbon dioxide reaches 550 ppm by 2100 in from current levels of 380 ppm. The B1 scenario is premised on a world with high economic growth, a global population that peaks by mid-century then declines, and a shift to less fossil fuel-intensive industries and the introduction of clean and resource-efficient technologies.
Emission scenarios are used to drive GCMs to produce representations of future climate, generally through the end of the century. GCMs incorporate the latest scientific understanding of the physical processes of the atmosphere, oceans, and the earth's surface via comprehensive mathematical descriptions. They simulate climate across the globe on coarse scales, generally of a few hundred kilometres and, as such, represent for regions like the Caribbean a first guess of their future climate. Though GCM results for the Caribbean are reported on in the following sections, the limitation due to their scale must be borne in mind, as their resolution precludes the provision of information at the scale of small island states.

Regional climate models (RCMs) or statistical models are used to downscale GCM output to obtain higher resolution results. RCMs are also comprehensive physical models of atmospheric, oceanic and land processes but with higher resolutions (e.g. 50 km or less), and which are run over limited areas using GCM output as boundary conditions. Results from the PRECIS–Caribbean Initiative (Taylor et al. 2007) — an initiative to produce downscaled climate scenarios for the Caribbean — are also reported on in this study. The PRECIS (Providing Regional Climates for Impact Studies) RCM was run at 25 km and 50 km resolutions over limited domains covering all or part of the Caribbean, Central America, Florida and the northern territories of South America, as well as portions of the Atlantic and Pacific Oceans, for both present day (1961-1990) and future (2071-2100) periods. The PRECIS RCM was forced with output from the HadCM3 GCM (Jones et al. 2004) and the ECHAM GCM (Jones et al. 2003), for both a relatively high GHG emissions scenario (A2) and a relatively low GHG emissions scenario (B2) to provide a range of projections. Details of the PRECIS-Caribbean initiative and the validation of the PRECIS model for present day Caribbean climate are given in Taylor et al. (2007) and Campbell et al. (2010) respectively.

Statistical downscaling model results are also reported on in the following sections. The technique involves the application of relationships developed between observations for a location (e.g. rainfall
measured at a station) and large-scale climate variables (e.g. surface pressure, temperature) to the output of the GCMs to determine future changes in the local variable. The technique assumes that the relationships obtained from current observations will remain unchanged in the future.

**Precipitation Trends**

*Past Trends*

Though there has been evidence of significant changes in amount, intensity, frequency and type of precipitation for various parts of the world, the Intergovernmental Panel on Climate Change (IPCC) suggests that statistically no significant overall trend for global precipitation exists for the past century (IPCC 2007). This is so because precipitation records exhibit considerable variability on interannual and longer timescales. Some specific global trends of relevance from the IPCC (2007) indicate that precipitation has generally increased over land north of 30°N from 1900–2005, but has mostly declined over the tropics since the 1970s. Additionally, there has been an increase since the 1970s in the prevalence of droughts—especially in the tropics and subtropics—and an increase in the number of heavy precipitation events over many regions of the globe.

Rainfall trends in Caribbean precipitation are, much like the global signal, characterized by significant variability on interannual to decadal timescales (Singh 1997, Peterson et al. 2002). This makes the identification of significant long-term trends in Caribbean rainfall difficult. One result of climate change may have been to increase the already high precipitation variability (Gamble 2006, Nurse and Sem 2001). The increase may in part be due to the fact that there has been an increase in the frequency, severity, and duration of El Niño events since the 1970s (Stahle et al. 1998, Mann et al. 2000), which would imply an increase in flood and drought extremes in the Caribbean since the 1970s (see previous section). Anecdotally, recent climatic events seem to support this.

A number of studies utilizing records covering differing time spans have nonetheless pointed to weak declining rainfall trends over the recent past. For example, Nurse and Sem (2001) suggest that mean annual rainfall has decreased by approximately 250 mm for Caribbean islands. Neelin et al. (2006) point to a modest but statistically significant drying trend for the Caribbean’s summer period in recent decades. Taylor et al. (2002) show a downward rainfall trend for a mean Caribbean rainfall index from the 1960s. Walsh (1998) suggests that the eastern Caribbean has shown multi-year fluctuations between drought and heavy rain, with the period post 1959 being one of low rainfall.

Gamble (2006) also presents a table of rainfall changes for ten locations in the Caribbean and near Caribbean region, gleaned from a variety of sources and covering varying periods (depending on availability of records at each location) between 1950 through 2000. Six of the ten locations show decreasing trends ranging from 100 mm less annual rainfall (Penal, Trinidad, data period: 1974-1986) to 427 mm less annual rainfall (Inagua, Bahamas, data period: 1960-2000). The other four showed increasing trends, including Piarco, Trinidad and New Providence, Bahamas. Gamble (2006) summarizes his analysis of Caribbean precipitation trends by noting that multiple studies do indicate a decrease in precipitation for the central Caribbean and an increase in precipitation at peripheral locations, such as Nassau and Maracaibo. Gamble et al. (2010) also note that farmer perceptions of increasing drought
might reflect relative changes in the early (April–June) and principal (August–November) growing seasons and an increasing prevalence of droughts.

It is important to note, however, that many of the studies referred to above were conducted prior to, or just as the Atlantic Multidecadal Oscillation swung back into its warm phase at the end of the last century (see previous section) and just prior to the related recent increase in tropical cyclone from 1995 to the present (Mimura et al. 2007). As a result, the reanalysis of the long-term regional trends may suggest a recent change to a slightly wetter background regime with, however, considerable short-term variability. The analysis is, however, yet to be done. The Caribbean changes reported on are, nonetheless, not dissimilar to those reported from global analysis for the tropical regions (Trenberth et al. 2007).

Figure 7 from Peterson et al. (2002) shows that in terms of extreme precipitation, very heavy rainfall has increased in the Caribbean. The R5D index represents the greatest 5-day rainfall total and is used to capture the fact that heavy rains that induce flooding may occur over the course of several days. R5D is increasing for the Caribbean (significant at the 10% level) but with considerable variability. On the other hand, the maximum number of consecutive dry days (CDD, also depicted in Figure 7) has seemingly decreased, with the linear slope significant at the 1% level. The results, however, are for mean Caribbean indices and may not take into account differences in the precipitation regime between the north and south Caribbean. Campbell et al. (2010) does show a general trend of increasing heavy rainfall events for most of the eight countries they analysed, including The Bahamas to the north and Trinidad and Tobago to the south.

![Caribbean Rainfall Indices](image)

**Figure 7** Caribbean Rainfall Indices.
Left Panel: Mean index of the greatest annual 5 day rainfall total (R5D).
Right panel: Mean regional maximum number of Consecutive Dry Days index (CDD). (Peterson et al. 2002)
**Future Trends**

The Big Picture

Most projections for the Caribbean suggest that by the end of the current century there will be less rainfall, which is indicative of a decrease in available water. Table 5, from the Fourth Assessment Report of the IPCC shows that for the region as a whole, the end of century change varies from -39 to +11%, with a median of -12%, as computed from GCM projections (Christensen et al., 2007). The accompanying spatial pattern (Figure 8) confirms drying as the consensus of the 21 models analysed, and shows that the annual mean decrease is spread across the entire region without exception (left panels). The drying will firmly establish itself somewhere in the middle of the current century as indicated by the T values in Table 5, implying that, until then, interannual variability will be a strong part of the rainfall pattern, i.e. superimposed upon the drying trend. By the end of the century, there is only a 3% chance of an extremely wet year compared to present day conditions but a 39% chance of an extremely dry year.

Both Table 5 and Figure 8 also suggest that in December, January and February (DJF), some areas of increased rainfall may be evident in the far north Caribbean (middle panels of Figure 8.). However, by June, July and August (JJA), the decrease is region-wide (right panels) and of a larger magnitude (-57% to +8%, median -20%). Largest drying is over the Greater Antilles, where the model consensus is also highest (right bottom panels).

**Table 5** Regional averages of temperature and precipitation projections from a set of 21 global models for the A1B scenario

<table>
<thead>
<tr>
<th>CAR</th>
<th>Temperature Response (°C)</th>
<th>Precipitation Response (%)</th>
<th>Extreme Seasons (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Season</td>
<td>Min</td>
<td>25</td>
</tr>
<tr>
<td>10N,85W to 25N,60W</td>
<td>DJF</td>
<td>1.4</td>
<td>1.8</td>
</tr>
<tr>
<td></td>
<td>MAM</td>
<td>1.3</td>
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</tr>
<tr>
<td></td>
<td>JJA</td>
<td>-</td>
<td>-</td>
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<td></td>
<td>Annual</td>
<td>1.4</td>
<td>1.8</td>
</tr>
</tbody>
</table>
The table shows the minimum, maximum, median (50%), and 25 and 75% quartile values among the 21 models, for temperature (°C) and precipitation (%) change. Regions in which the middle half (25–75%) of this distribution is all of the same sign in the precipitation response are coloured light brown for decreasing and light blue for increasing precipitation. Signal-to-noise ratios for these 20-year mean responses is computed. These estimates of the times for emergence of a clearly discernible signal are only shown for precipitation when the models are in general agreement on the sign of the response, as indicated by the colouring. The frequency (%) of extremely warm, wet and dry seasons, averaged over the models is also presented. Values are only shown when at least 14 out of the 21 models agree on an increase (bold) or a decrease in the extremes. (Source: IPCC 2007)

![Figure 8](image)

**Figure 8** Precipitation changes over the Caribbean from the A1B simulations.  
Top row: Annual mean, DJF and JJA fractional precipitation change between 1980 to 1999 and 2080 to 2099, averaged over 21 models.  
Bottom row: Number of models out of 21 that project increases in precipitation. (IPCC 2007)

The drying patterns of the global models in the Caribbean are largely repeated in the PRECIS regional model (Campbell et al. 2010). Recall the advantage offered by regional models versus global models, which have limitations due to their coarse resolution. Under the A2 scenario, the regional model projection is for drying in the main Caribbean basin of between 25% and 30% by the end of the century, which is consistent with upper end values obtained from GCMs (Christensen et al. 2007, Rauscher et al. 2008, and Simpson et al. 2009). Figure 9 shows that the PRECIS model similarly depicts a pattern of basin-wide drying, which is evident throughout the entire year. Exceptions are in December, January and
February, when the far northern Bahamas is projected to have a slightly wetter transition season, and in February, March and April when Cuba, The Bahamas, and Haiti are projected to have slightly wetter dry seasons. The traditional wet season months are, however, projected to see the most severe drying under the A2 scenario, with all months between June and October exceeding 30% (see panel f of Figure 9). During these months, no Caribbean island is exempt from the drying trend. It is to be emphasized that the projected summer drying is a common feature of all the modelling studies of the Caribbean (see also Christensen et al. 2007, Angeles et al. 2007, Rauscher et al. 2008, Simpson et al. 2009). The implications of a much reduced wet season are serious for the Caribbean region.

Some of the modelling studies also support the idea that the proportion of total rainfall that falls in heavy events for most of the Caribbean decreases toward the end of the century, even as there are more dry days (McSweeney et al. 2008, Campbell et al. 2010).
Figure 9 Rainfall projections for 2071-2100 relative to the 1961-1990 baseline under the A2 scenario. Percentage change is presented. Panels (A), (B), (C), (D), and (E) represent annual, NDJ, FMA, MJJ and ASO respectively. Panel (F) shows monthly, seasonal and annual changes calculated by averaging over the domain shown in (A)–(E). The solid red line represents one standard deviation as calculated from the observed data. (Campbell et al. 2010)
Country Projections

A number of recent studies compile rainfall projections for individual countries across the Caribbean region. The UNDP Country Profiles (McSweeney et al. 2008) are useful compilations of mean GCM projections of rainfall change for three future time slices (2030, 2050, and 2080). They provide minimum, maximum and median projections for annual and three-month seasonal change in total rainfall, and for a range of extreme precipitation indices under low (B1) and high (A2) emission scenarios. Table 6 (in Appendix A at the end of the document) is a compilation of some of the results. Only the mean annual change and the projected change for September, October, and November (meant as an indication of the wet season) are depicted, as well as the change in the annual amount of rainfall that falls in heavy events. It is to be borne in mind that projections are from GCMs (as opposed to regional models) and, as such, they are for grid boxes which swallow up and may not recognize the presence of the smaller land islands within them. Some observations to be made from the data include the following:

- By the 2030s, the median change for most countries hovers just below zero, i.e. is just depicting evidence of the onset of a drying trend. However, we note that it is when median values hover near zero that there is greatest uncertainty in the projections, as model consensus on a trend in one particular direction is low.

- The median decrease in precipitation is larger in magnitude toward the end of the century.

- The median drying trend for most countries is robust in September, October, November, and comparable to the values for the annual drying. This indicates that a drying out of the normal wet period is a significant contributor to the overall drying.

- The pattern of drying appears to establish itself earlier in the countries of the eastern Caribbean irrespective of scenario, with these islands also experiencing some of the largest changes in rainfall amounts.

- Rainfall decreases in the northwest Caribbean appear to be slightly smaller than for the eastern Caribbean and The Bahamas may not see an establishment of the pattern until the end of the century.

The CARIBSAVE project (Simpson et al. 2009) similarly offers projections for select Caribbean countries. In the first instance, they compile the percentage change in precipitation when the mean global temperature change, as calculated by an ensemble of GCMs, reaches +1.5°C or +2.0°C. They suggest that the earliest possible date for this to occur is 2023 and 2029 for the A1B scenario, and when global temperature anomalies of this magnitude do occur, the Caribbean as a whole will have mean temperature changes of +0.9°C to +1.7°C and +1.2°C to +2.3°C respectively (see the following sub section). Some of the rainfall change projections are extracted and shown in Table 7 of Appendix A at the end of the document. The information in this form is useful as CARICOM has been lobbying for a limitation of mean global temperature increase to +1.5°C. Table A.2 suggests that even with such targets the implications are significant for water availability from rainfall in the region.

The CARIBSAVE project also provides a compilation of end of century (2080-2099) percentage change in annual rainfall for three emission scenarios – B1 (low), A1B (medium), and A2 (high) – as well as
plots of the average monthly rainfall anomalies with respect to model predicted totals for 1980-1999 for the same selected islands. Again, the end of century data is extracted and presented in Table 7, while the plots are shown as Figure 13. The plots are particularly useful for their depiction of how the overall change in annual rainfall will be distributed across each islands’ monthly rainfall regime. Some observations from the plots are also offered in Table 7.

It is to be noted that a number of other projects are attempting to provide projections of rainfall for the present through the end of the century for individual Caribbean islands. The PRECIS project is noteworthy since it is providing regional model information (Taylor et al. 2007). The PRECIS model output for each country is available from the Caribbean Community Climate Change Centre (5 C’s) website or from the PRECIS-Caribe website for the project.

In summary, we note that although there may be considerable variability in the projections for each territory, the global and regional models consistently project a decline in precipitation across almost all Caribbean countries, in all scenarios. The declines become larger for the higher emissions scenarios. For most of the Caribbean countries, the decrease in precipitation is projected to occur during the months that are usually wet and particularly during the months of May to August. For those countries that are already facing issues of water insecurity, this is likely to increase the severity of their water resource problems. For those that currently have sufficient water resources, the decline in rainfall may introduce new water resources issues to be contended with.

Temperatures

The Fourth Assessment Report of the IPCC (IPCC 2007) indicates an increase in global temperatures of 0.74°C (0.56°C to 0.92°C) over the period 1906–2005. The rate of warming over the last half of the period is almost double that for the period as a whole, and the warming trend is evident in both daily maximum (day time) and minimum (night time) temperatures. Minimum temperatures are, however, increasing faster than maximum temperatures, resulting in a decrease in the diurnal temperature range. Land areas have also tended to warm faster than ocean areas and ‘winter’ months have warmed faster than summer months (IPCC 2007).

Recent studies suggest that the Caribbean has also recorded a warming trend of approximately 0.6 degrees Celsius since the 1960s or 0.12–0.14 degrees Celsius per decade (McSweeney et al. 2008). Plots of the frequency of very hot days and very hot nights reflect the increasing trend, with nights warming at a faster rate than days (see Figure 10) (Peterson et al. 2002). Peterson et al. (2002) also find that the frequency of very cool days and very cool nights has decreased over the fifty-year period: 1958-1998 (Figure 10), as has the annual temperature range, though the trend in the latter instance is not significant at the 10% level. Alexander et al. (2006) and Aguilar et al. (2005) show that the Caribbean changes are consistent with the rest of the globe and in agreement with changes in temperature indices calculated over nearby Central America and northern South America (including their Caribbean coasts).
Irrespective of scenario or technique employed, the Caribbean is expected to continue warming through the end of the century. Some of the IPCC projections for the Caribbean from GCMs were also given in Table 5 for the A1B emissions scenario (Christensen et al., 2007). In the Table, the small value of $T$ (column 8) implies a large signal-to-noise ratio, meaning that the temperature results ($T=10$ years) are significant and the warming will be well established in the very near future. The probability of extreme warm seasons is 100% and the magnitude of the warming is ‘large’ (in comparison to historical warming) by the end of the century. GCM simulated annual temperature increases for the Caribbean at the end of the 21st century range from 1.4°C to 3.2°C with a median of 2.0°C. Fifty per cent of the models give values differing from the median by only $\pm 0.4^\circ$C.

The PRECIS RCM likewise shows an increase in annual surface temperature of between 1 and 5°C, dependent on scenario, by the end of the century, i.e. over present day (1961-90) values. There is consistency with results generated using a Statistical DownScaling Model (Wilby et al. 2002) for stations in Trinidad (2.2 °C/1.6 °C), Barbados (2.3 °C/0.7 °C) and Jamaica (2.0–3.0 °C/1.5–2.3 °C) for the A2/B2 scenario (Chen et al. 2006), and with other results extracted from subsets of GCM realizations (Singh 1997a, 1997b, Angeles et al. 2007, Christensen et al. 2007, McSweeney et al. 2008). Warming is greater under the A2 (high) versus B2 (low) emission scenario and is across all seasons and for all countries in the region without exception. This is captured in Figure 11. The region-wide warming is also consistent with projections for other parts of the globe, and far exceeds historical variability of temperature within the region (see panel F of Figure 11).
Though the focus above is on air temperatures, increases in sea surface temperatures in the Caribbean are expected to be by similar amounts and similar to those for minimum air temperatures over coastal regions and islands (Simpson et al. 2010).

Though the IPCC report does not specifically address evapotranspiration, projected mean annual changes in evaporation for the A1B scenario is provided on a global scale and shown in Figure 12. From the figure, it appears that by the end of the century (2080-2099) evaporation in the Caribbean will increase by about 0.3 mm day relative to current (1980-1999) values. The values, however, largely reflect ocean changes and evaporation over land may be less.
Figure 11  Temperature projections for 2071-2100 relative to the 1961-1990 baseline under the A2 scenario. Absolute change is presented. Panels (A), (B), (C), (D), and (E) represent annual, NDJ, FMA, MJJ and ASO respectively. Panel (F) shows monthly, seasonal and annual changes calculated by averaging over the domain shown in (A)–(E). The solid red line represents one standard deviation as calculated from the observed data. (Campbell et al. 2010)
Sea Level Rise

During the 20th century, the IPCC notes that global sea levels rose at an average rate of 4.8 to 8.8 inches per century (1.2–2.2 mm/year), with most of the Pacific and Atlantic basins experiencing average to above-average sea level rise (IPCC 2007). There are very few records of sea level change for the Caribbean, as information from tide gauges is lacking, however, observed estimates over the period 1950 to 2000 suggest that sea level rise in the Caribbean has been near the global mean (Church et al. 2004). More recent examinations of satellite measurements estimate that global sea levels have risen at a faster rate of 9 to 15 inches per century (2.4–3.8 mm/yr) since 1993 (Bindoff et al. 2007). There is no reason to suppose that the greater rate of rise has not also occurred in the Caribbean.

Under an A1B scenario, mean global sea levels are expected to further rise by 0.21 to 0.48 meters by the end of the century (IPCC 2007). The IPCC models used to make these projections exclude future rapid dynamical changes in ice flow, which if accounted for may lead to a doubling or more of the estimates (see for e.g. Vermeer and Rahmstorf 2009, Grinsted et al. 2009, Jevrejeva et al. 2010). Large deviations among models make estimates of future regional distributions of sea level rise uncertain because it will not be geographically uniform. In the future, sea level rise may be more pronounced in the Caribbean than in other regions because of its proximity to the equator (Bamber et al. 2009, Hu et al. 2009). Notwithstanding the IPCC estimates given previously, Simpson et al. (2010) suggest that 1 and 2 metre sea level rise in the Caribbean may not be unreasonable by the end of the century. This is so, as even if GHGs emissions were stabilized now, sea levels would continue to rise beyond the end of the century.
Simpson et al. (2010) further suggest that the question is not if the Caribbean will face a sea level rise of 1m or 2m under either a 2.0°C or 2.5°C global warming scenario, but rather when.

**Hurricanes**

The consistency between high-resolution global models, regional hurricane models and scientific theories support the idea of increased tropical cyclone intensity under a global warming future. It is likely that with increased sea surface temperatures, future hurricanes will become more intense, with larger peak wind speeds and more, heavy precipitation (IPCC 2007). Oouchi et al. (2006) using a high-resolution global 20-km grid atmospheric model, project more intense hurricanes in the Atlantic with maximum peak wind speeds increasing by about 14%. Bender et al. (2010) also indicate that the number of category 4 and 5 hurricanes will increase by a factor of 2 to 1 (even though the number of hurricanes may decrease), but the trend will not be clearly detectable until toward the end of the 21st century. This translates into approximately three strong hurricanes per year by the end of the century if one considers that Category 4 and 5 hurricanes in the North Atlantic have increased from 16 (or 1.1 per year) in the period of 1975-89 to 25 (or 1.6 per year) in the period of 1990-2004 (Webster et al. 2005).

There is, however, less consensus about the frequency of hurricanes in the future. Though Oouchi et al. (2010) found a 34% increase in tropical cyclone activity in the Atlantic basin, a number of other recent studies (e.g. Knutson et al. 2008) find decreases in overall tropical storm activity; though when they do occur they will likely be more severe.

**Quick Summary**

- Climate change has and will manifest itself in the Caribbean region in a number of ways that will affect water availability.
- The impact on rainfall has been seemingly increased variability due in part to an increase in the frequency and severity of ENSO (El Niño and La Niña) events.
- The future impact is a long-term reduction in rainfall, which will be most evident by the end of the century.
- The proportion of rain that falls in the primary wet season (May through November) will be substantially decreased.
- The proportion of rain that falls as heavy events will be decreased.
- Climate change will also yield a much warmer (1–4 degrees Celsius) Caribbean.
- A warmer Caribbean will increase evaporation rates.
- Climate change will give rise to higher sea levels in the Caribbean, possibly up to 2 m under the worst-case scenario.
- Higher sea levels have implications for inundation, erosion, flooding and saline intrusion.
• There is uncertainty about climate change’s impact on hurricane frequency in the future. The tendency is for a decrease in the number of hurricanes.

• When hurricanes do occur they may be more intense, i.e. there may be more Category 4 and 5 storms in the future.

A Note on Water Quality, Demand and Management

The emerging picture in the Caribbean is one of reduced available water due primarily to increased patterns of rainfall variability in the present and near future, and also due to the long-term drying trend that is anticipated under global warming. Yet, climate change in particular poses other threats, including threats to water quality and demand, which in turn will also impact water availability. Hence, though not the primary focus of this document, a brief examination of the likely climate change impact on both issues is provided below.

Quality

Under climate change, the quality of water available from both surface and groundwater sources may be compromised. Both a drying and a rise in sea levels can increase the risk of saline intrusion into coastal aquifers. On the one hand, a reduction in precipitation reduces both available surface water reserves and the level of groundwater recharge, with the latter impact leading to increased risk of saltwater intrusion into aquifers, particularly those nearest to the coast. The net result is a reduction in the amount of available water within the aquifers. Sea level rise can in turn further exacerbate the effect of drier conditions on salinization of aquifers, as the reserves would be squeezed from both underneath via the rising saltwater layer, and above via reduced recharge rates.

Simpson et al. (2009) note that a number of CARICOM countries have already experienced saltwater intrusion into their aquifers including Antigua and Barbuda (particularly Barbuda), The Bahamas, Barbados, Grenada (particularly the Carriacou and Petite Martinique islands), Guyana, Haiti, Jamaica, St Kitts and Nevis (particularly St Kitts island), St Vincent and the Grenadines (particularly the Grenadines islands), Suriname and Trinidad and Tobago. Of these, they point out that Antigua and Barbuda, The Bahamas, Grenada, Suriname and Trinidad and Tobago are particularly vulnerable due to sea level rise because of their coastal aquifers, which would be threatened. An interesting case is that of Andros island (Bahamas) where the water table is only 30 cm below the surface and where high evaporation rates and increased brackishness is expected to be further exacerbated by warmer temperatures, sea level rise and increased storm surge (Chase 2008).

Increased rainfall intensity and storm activity may also result in increased sediment and pollutant transport into both surface and groundwater systems, particularly in a karst environment (Farrell et al. 2007, Cashman et al. 2010). Simpson et al. (2009) highlight that there are several reported cases where hurricanes have led to a reduction in water resource availability in some Caribbean countries. In Antigua and Barbuda, they point out that extreme rainfall from hurricanes has caused the loss of topsoil and has eroded gullies, which has led to increased surface runoff from even normal rainfall and subsequent reductions in groundwater recharge. They also note that in Dominica, temporary changes to the hydrological cycle in some watershed areas have been experienced due to damage caused to vegetation by
hurricanes. If hurricanes were to increase in frequency and/or intensity under global warming, these kinds of impacts would likely also increase. There is also the possibility of vegetation cover being reduced due to the declining rainfall, which would add to the vulnerability of areas particularly vulnerable to the kind of effects experienced in Dominica.

**Demand**

Demand for high quality, potable water in the region has risen due to development, increased importance of industry and population growth (Brown et al. 2007, Cashman et al. 2010). In the region, the tourism industry is one of the largest contributors to GDP in the Caribbean, and also has high water demands due to the need to maintain international standards (Cashman et al. 2010, Pulwarty et al. 2010). Similarly, agriculture is another critical industry in the region, which is already largely dependent on seasonal rainfall for crop scheduling and is also sensitive to the height of the water table and soil salinity (Pulwarty et al. 2010). Population growth and increased urbanization has also led to increased activity in coastal zones and along hillsides, which raises problems for waste, storm water and runoff management (Cashman et al. 2010).

Taken together, development and climate change will likely result in heavy stress on available water resources, due to increased competition amongst high demand sectors. Cashman et al. (2010) suggest that demand is already still largely unmet in much of the Caribbean region, even though approximately 60% of water usage is unaccounted for. With climate change, some of the already water-stressed islands of the Caribbean may continue to experience higher water demand than there is supply to satisfy it. This may be an exacerbation of what is already evident in the dry season in some territories, during which available water can be reduced by up to 40% (Cashman et al. 2010). It is instructive to note that in order to meet the rising needs for water, alternative routes have already been instituted in many countries. Among them is desalination, which has become a dominant means of water supply in countries like Barbados (Cashman et al. 2010). While this method offers a renewable supply of water to meet growing demands, it also has high economic, environmental and energy costs (Cooley et al. 2006). Rainwater harvesting is also being utilized, particularly for residences on smaller islands and for agriculture (Vörösmarty et al. 2005, Cashman et al. 2010).

**Management**

With much of the Caribbean considered to be water scarce (Cashman et al. 2010), management of available water will be a critical issue for the region. In addition to a reduction of direct water from rain, climate change may present its own challenges to management, including increased flood risks, impeded drainage and altered water table heights. Water resource management is predominantly governmental in the Caribbean, and has both social and economic influence. As is the case in many environmental agencies in the Caribbean, water resource provision is not a coordinated effort across responsible groups and in many cases is not considered to be a high priority (Farrell et al. 2007, Cashman et al. 2010). However, integrated water resources management (IWRM) has been taken on in recent years by a number of Caribbean islands and incorporated into national policy. The concept of IWRM acknowledges, among other things, the anthropogenic effects on water sources, as well as equal rights to water accessibility and the environmental and economic importance of water resources (Farrell et al. 2007, Cashman et. al 2010).
Conclusion

For Caribbean states, which are already facing issues of water insecurity, the issue of water availability is a serious one. Not surprisingly, freshwater resources rank very high on the priority list of small island developing states, given the sensitivity and vulnerability of the resource to extremes of climatic behaviour (UNEP, 2004). This document sought to examine the impact and influence of climate variability and change on water availability in the Caribbean region. In light of the discussion in the previous sections, the following ten conclusions are drawn about climate variability, climate change and water availability in the Caribbean region:

- Due to the limited number of alternative options, water availability in the Caribbean is intimately linked to precipitation. Many Caribbean states are increasingly vulnerable then to the dual challenges of increasing demand for water and fluctuating water availability due to climatic variability.

- One of the primary drivers of rainfall variability in the Caribbean is the ENSO occurrence. Water availability is significantly impacted by ENSO events. The impact is, among other things, dependent on the type of event (El Niño or La Niña), the time of year, and the location of the Caribbean territory. ENSO events seem to have become more frequent in the recent past. ENSO monitoring is critical for those engaging in water management.

- Caribbean rainfall also varies on decadal and longer timescale. Monitoring the relative phases of the known drivers on these timescales is also important, since they will cumulatively enhance or offset rainfall amounts in dry or wet seasons.

- The Caribbean is expected to become significantly drier under climate change: up to 30% drier in the annual mean. Drying will be most significant between May and November, when the region is normally at its wettest. This will likely significantly reduce available water by reducing both surface flows and water available for groundwater recharge.

- Declines in precipitation will likely lead to an increase in the risk of periods of drought for the Caribbean region. Drought may become more frequent and be more severe. Countries that rely mainly on surface water, rather than aquifers, may be the most vulnerable to declining precipitation levels, since surface water generally responds more rapidly to drought conditions than aquifers. Currently, those countries include Dominica, Grenada, St Kitts and Nevis, St Lucia and St Vincent and the Grenadines.

- The Caribbean is expected to be between 1 and 5 degrees warmer by the end of the century. A warmer region will contribute to reduced water availability by enhancing evaporation from surface sources and possibly driving up demand for cooling purposes.

- Sea levels will continue to rise in the region and may reach between 1 and 2 m by century’s end. Sea level rise may contribute to decreased water quality in many countries in the region due to its likely contribution to saline intrusion, particularly into coastal aquifers. Decreased water quality
will further exacerbate deficiencies in usable water resources brought about by less rainfall and warmer temperatures.

- More intense hurricanes, when they do occur, may characterize the region. The intensity of the associated rainfall may enhance runoff but not lead to more groundwater resources. The contamination of water sources from erosion, land slippage, or storm surge and the damage to infrastructure for extracting water may reduce the amount of freshwater available, especially during the passage of the extreme weather event.

- Climate variability and change is not the only thing impacting water availability in the Caribbean region. Population growth, industrial development and the expansion of irrigated agriculture, will likely impact availability amongst competing groups, each demanding more water resources.

- Decreased water availability will more than likely be a feature of the future Caribbean region in the future. The region is already dealing with fluctuations in water resources due to climate variability. Strategies to deal with these fluctuations, if well thought out and implemented, may well prove beneficial to also tackling some of the longer-term implications of climate change.

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CLIMATE CHANGE ADAPTATION IN CARIBBEAN AGRICULTURE: ENHANCING WATER MANAGEMENT


Appendix A – Rainfall Projections By Country

Table 6 Summary table of projected rainfall change for selected Caribbean states.
The change in mm/day is averaged over the whole country, and presented for the 2030s, 2060s and 2090s under SRES emissions scenarios A2 and B1. The climate models used are a sub-set of 15 from the 22-member ensemble used by the Intergovernmental Panel on Climate Change (IPCC) for their fourth Assessment report, published in 2007. Also shown is the percentage of total (% total) rainfall falling in Heavy Events (R95pct) for the year. In the Table, **** indicates data are not available. (Adapted from UNDP Climate Change Country Profiles. McSweeney et al. 2008. http://country-profiles.geog.ox.ac.uk)

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Table 7  Summary table of projected rainfall change for selected Caribbean states.
Leftmost panels: Projected percentage differences in annual rainfall at 1.5 and 2.0°C increases in global average temperature. Rightmost panels: Multi-model climate projections of total annual precipitation. Differences are based on the 1970-1999 precipitation mean. (Table adapted from Simpson et al. 2009).

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Largest decreases between May and August
Declines spread over Jan to Nov.
Projected increase in Oct and Nov
Declines spread over Jan to Sept.
Greatest declines in June and July
Drier June and July and wetter in October and November
Largest decline between
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June and Aug. May to Nov are projected as drier. All months in northern Guyana have declines. Increases in March to May and decreases for July to Oct. Majority decline May and August. Majority decline May and August. Majority decline May and August.
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Figure 13 Multi model mean climate projections of average monthly precipitation anomalies for 2080-2099 for Caribbean states, based on climate model predictions for 1980-1999. Projections for three SRES scenarios are shown: the light-grey/solid line is B1; medium-grey/dotted is A1B; and black/dashed is A2. (From: Simpson et al. 2009).
E-Discussion Synthesis Report

Question 1: How will changes in Climate continue, or begin, impacting the quantity and quality of the water harvested in Caribbean countries?

Thread builders:

➢ Which aspects of climate (temperature, rainfall, wind speed etc) will significantly impact water availability?

➢ Are there restrictions on availability caused by inter-sectoral conflicts?

➢ Are there hidden/overt changes in the cost of water?

Moderator’s Comment:

There were group-wide comments and shared experiences and perspectives as well as privately communicated views between professionals operating outside of the agricultural sector and the Moderator. A total of twenty-seven posts were associated with this thread.

E-Discussion:

Climate change will have a significant impact on the hydrological cycle as it pertains to the Caribbean region. With the exception of Dominica, most of the Leeward and Windward Islands do not have a sufficient water budget to meet their needs. There was a view expressed that the amount of rainfall received at present just meets their needs or is below what they require. Early in the discussion, it was mentioned that farmers are complaining about their inability to produce because of lack of water. Subsequently, issues of flooding were vented as well.

Traditional methods of flooded irrigation or sprinkler irrigation will have to be replaced by more water efficient methods, if these expected shortfalls persist. The use of fertilizers will also be impacted because the type and use of fertilizers will have to be modified, less water availability will mean that more water soluble or manmade fertilizers will have to replace the traditional NPK fertilizers developed by the industrialized countries. High temperatures will bring high humidity and subsequently higher evaporative rates and, as a consequence, this forcing function will dictate the type of vegetation that can survive in these types of climate.

Reduction in rainfall will have an impact on water quality because it will cause total dissolved solutes, hardness, iron and manganese levels in groundwater to rise. This phenomenon will be as a result of reduced percolation rates of water entering the soil. With respect to surface water, climate change will also have an impact on its quality because one can expect a rise in turbidity levels because of increased anthropogenic activities.

Soil and water management specialists suggested that there is need to adopt practices to increase the intake and storage of water in the soil itself. It was highlighted, by way of example, that Antigua is one of the countries that has been practicing rainwater harvesting for decades. Caribbean-wide records clearly
show that rainfall patterns over the last four decades have always been very variable and unpredictable (in other words the unpredictable nature is not a new thing). Yet, examination of temperatures gives a quite different picture, in that there has been a consistent rise by about 1.5 °C over the last 40 years.

With respect to rainwater harvesting, the discussion immediately noted two things:

1. Rainwater harvesting may break down from time to time, but it cannot be predicted when it will.
2. With rising temperatures the evaporation rate will be increasing, which means that storage reservoirs, ponds etc. will dry up faster if they are not replenished.

The participants noted that rainfall events tend to run the full gamut of intensities, including high intensity short bursts, which often result in flash flooding and excessive runoff. Much of this rainfall is not effective and hence adversely affects availability. The determinations of rainfall intensity and erosivity may not have been collated and analyzed over the years. Although man has no direct control over rainfall, it was suggested that intensity and isoerodent maps could be useful components of a regional toolbox.

A view from a very senior water executive was that, “There is need for Caribbean governments to adopt a clear policy on rainwater harvesting. To my mind it is not the amount or distribution of rainfall that is the issue but a comprehensive policy”. However, no feedback during the discussion dealt with the actual mechanism and sequencing to arrive at comprehensive location-specific policies.

The discussion turned to sectoral conflicts:

It was noted, without consensus, that there are likely to be inter-sectoral conflicts but it is not currently a major problem. There is more than enough water but the inequitable distribution is a major challenge. There are more and more farmers who are using irrigation and hence conflicts are likely to develop at some time, especially in Island States. There are also shifts in demography and hence there will be greater need for domestic and industrial water. Interestingly, by way of example, the cruise ship industry was seen as a large consumer of water in St Kitts, where a discussant felt it definitely competes with agriculture. Personnel at the local water department reported that they could never meet the estimated demand for domestic and agricultural water.

Potential grey water supplies from the capital cities could be used to complement other irrigation water sources but it was postulated that infrastructural costs might be very high. A possible area of research that would provide benefits revolves around finding low cost ways to use grey water safely. Grey water use for food crop irrigation would have to be accompanied by very strict guidelines, to prevent crop contamination.

Water cost:

As much of the water used is pumped, this is having serious repercussions on the cost of water, especially irrigation water, which in many countries is currently subsidized. Some persons may also be withdrawing from irrigation canals, since they see the pumped or channelled water as a free public good. The fact that some countries have more explicit laws on the “ownership” of all water, and exercise wide-ranging control of extraction was also raised. Although there are promulgated laws on extraction in all states, a sample bit of legislation on Trinidad and Tobago’s National Integrated Water Resources Management
Policy (2005), which addresses abstraction licensing since water is a finite economic resource, was also shared with the group. Water management (drainage and irrigation) is a critical risk reducing, yield increasing and production-enhancing strategy in agricultural production. In developing a water management policy for agriculture, other agricultural subsectors, such as livestock and aquaculture that require significant quantities of water, must be considered.

Crop production on small farms in Trinidad and Tobago and elsewhere is essentially rain fed. Water management and irrigation infrastructure exists at a rudimentary level. During the dry season, crop production is restricted by severe moisture deficiencies, lands are desiccated and cultivation is minimal (<10%). In the wet season, runoff volumes are high, drainage infrastructure is inadequate and farmlands are subjected to waterlogging, flooding and subsequent crop loss.

The point was well made that by international standards, some countries in the region cannot be described as water scarce. The Trinidad and Tobago Water Resources Management Unit (2005) is credited with the statement, “Expressed per capita, the water availability in Trinidad and Tobago is approximately 2,500 m\(^3\) per year. The international criterion for water scarcity is less than 1000 m\(^3\) per year, per person. Thus, by international standards, Trinidad and Tobago is not a Water-scarce Country”.

The problems of water management in general should be handled in a more holistic manner. A suggestion was that:

1. There is a need for domestic water management and that should be embedded in the building code.
2. Water harvesting should be done even in countries with an abundance of water as you can only conserve what you have.
3. Forest cover cannot be compromised for infrastructural development without proper environmental impact studies and public consultations, as the consequences of error can be irreversible.
4. Water for farms, where possible, should not be the standard treated supply.
5. In countries where no energy is required for pumping water, there is a need to maximize the advantages by discouraging highland farming through regulation and zoning.

The infrastructure of the smaller islands tends to locate the water winning and distribution systems close to the source. In the bigger islands, there are impounding reservoirs but the problem of distribution from the source is a major challenge. In order to conserve water, better water-efficient practices and machines will have to be developed. Several methods were proffered to conserve or win water, included generation from the atmosphere, collection from air conditioners and the reuse of grey water for the flushing of toilets.

There is another school of thought: that dams allow for too much evaporation and it would be better to construct wells. It was reiterated that it is important to carefully examine the eventual water collection source, bearing in mind design, sustainability and cost.
The resources of the Caribbean Land and Water Resources Network (CLAWRENET) could provide the kinds of professionals that would form the nucleus for a regional think tank. Their input could be augmented by extra-regional help as part of the management of the whole watershed.

A detailed analysis of the rudiments of pond and dam construction was provided for the benefit of participants. The details included general considerations for project implementation, design and overall functions.

As a final recommendation during this thread, it was suggested there needs to be a mechanism for placing the vital bits of information unearthed during the e-discussion in a manual/database, which could be managed by some regional organization such as CARDI, for the use of all concerned.
Panel discussion: Technical session I

CHAIRPERSON:

Dr Mark Bynoe, Caribbean Community Climate Change Centre

RAPPORTEURS:

Dale Rankine and Celia Edwards

Summary

Thought 1: The Caribbean context commands consideration of the issue, ‘Rainfall is King’, both for water supply and agriculture production. Our context shows that there is very high reliance on rainfall and therefore we are very Vulnerable to vagaries of climate.

Thought 2: The Science supports the consideration of it by suggesting how the vulnerability will play out. The key word for this thought is ‘Variability’. Seasonality is key for our rainfall availability- Summer rainfall is key (May-November). We need rain in wet season to last us through the dry period. Irregular disruptions to seasonality caused by ENSO (2-7 year variation in which early season is drier, late season is drier and early season drier in year of El Nino decline); North Atlantic Oscillation-longer-term (decadal) variability (10-12 year) wet/dry background set up for rainfall or drought.

Thought 3: The future depends on it - key word Viability. Climate change will affect rainfall for the Caribbean. The projection is for drier conditions by end of century, in particular in for May-November. Temperatures will increase so we will be warmer. Hurricanes will be more intense, and sea levels will rise.

Discussion Notes and Speakers

Mr Maurice Rawlins (Cropper Foundation, Trinidad and Tobago): Has feedback been considered in climate modelling e.g. possible changes in the size of forest cover and with respect to the extension of ENSO into early 2010, are any changes to be expected?

Dr Michael Taylor (UWI, Mona): Modelling has been done on a large scale. In the Caribbean, we are looking at sizes of 25 km. so the modelling is on too large a scale to account for the particular impacts on such a specific forest cover. There are other groups where smaller than 25 km modelling is done and maybe forest cover alterations and impacts on rainfall can be assessed. With respect to ENSO, the upped-ante mechanism might be in the offering for the future. Recent studies suggest that ENSO variability has increased and so has its frequency. This could mean a perpetual ENSO-like state under global warming..

Mr Kurt Harris (SLAFY, St Lucia): Are there any consideration for the recycling of grey and black water?
Mr Steve Maximay (Workshop Facilitator, Trinidad and Tobago): There were some comments on the use of grey water during the e-discussion, I am not certain about black water. The deliberations will be presented in subsequent sessions.

Dr Leslie Simpson (CARDI, Jamaica): The recycling of water (grey, black) is a management issue; it will be covered tomorrow.

Dr Lystra Fletcher Paul (FAO, Guyana): There is a pecking order for water allocation in the Caribbean: there is tourism, industry, domestic uses etc. and then there is agriculture at the bottom. Agriculture is never given priority. How are we going to address this?

Mr Steve Maximay: Regionally, we see that there is very little priority for agricultural water. We will show this later in subsequent discussions.

Mr Vincent Sweeney (UNEP, St Lucia): I was interested in this group meeting in Dominica out of curiosity and seeing how water management is being dealt with. I just left the 20th conference of the Caribbean Water and Wastewater Association (CWWA) in Guadeloupe. I can say with confidence that I am the only person that attended both meetings. The priority issues mentioned at CWWA are very different from the ones being discussed here. Why? For the CWWA, financing, equity and sustainability were the priorities identified. Agriculture was not mentioned at all over the two days of the CWWA Conference. Recommendations from the CWWA meeting will be forthcoming; I will try to get them and share the same with this meeting.

Mr Steve Maximay: I have wondered over the years how CWWA priorities are arrived at. We are represented at the CWWA but direct concerns of agriculture are thrown out. They seem to think that agriculture is a burden on water resources.

Mr Ramgopaul Roop (TTABA, Trinidad and Tobago): Our future depends on water for agriculture. How are we going to communicate this information to farmers? More than 60% of farmers are involved in smallholder production systems that are rain fed. Moreover, we have an ageing population of farmers that have bad farming and unsustainable practices (e.g. Slash and burn, poor water use etc.). How are going to change these things? What do we mean when we say water for agriculture? Are we only considering just the watering of crops? What about livestock, what kind of water do they need? What quality of water is needed for agro-processing? How can we recycle water and make good use of grey water? In Trinidad, there are regulations on how we manage storm and grey water, how we process this before it is discharged to the open environment.

Dr Mark Bynoe: Adrian Trotman can you kindly point out what is being done by CIMH for the region in light of Mr. Roop’s questions?

Mr Adrian Trotman (CIMH, Barbados): We give climatological information to the region; not water management information. This info helps in making decision. With respect to farmers, we must link weather and climate to farm activities. We must engage farmers and decision makers in one forum. The Caribbean Agrometeorological Initiative (CAMI, a regional project) is one such initiative. We hope to start producing this week, monthly regional bulletins for farmers. It will give details of 3–6 months of anticipated climate conditions and past conditions experienced in the last couple of months. We already
do climate modelling for the Caribbean and maintain an operational drought-monitoring network. Research must be part of our on-going work. We must link what happened in the past (e.g. recent drought) with impacts on agriculture (and other sectors) and use this to make future inferences for the future. We don’t record things well in this regard. We must start to document things that happen. CIMH has Rainfall Impact Reporter online; it is available for researchers in all member countries to document impacts of rainfall events that take place in their respective countries. On the matter of water allocated for agriculture: production is still mostly rain fed, and we have not been able to use rain-fed conditions efficiently. What is needed is more effective soil moisture management. CIMH trying to provide forecast for farmers so that rainfall can be used more efficiently.

Mr Stanley Rampair (National Irrigation Commission, Jamaica): Only 10% of agriculture is irrigated in Jamaica; 90% is still rain fed. We must get information to farmers so they see latest scientific evidence, including seasonal variations that are taking place. What is the historical evidence of climate change; do we have sufficiently long time series to prove what we are claiming? Does the Water and Sewerage Authority (WASA) control all water in Trinidad? Is there a water resource authority and isn’t there a conflict of interest?

Ms Jewel Forde (Media, Barbados): How will you break communication barrier between farmers and scientists, especially with ageing farmers. How do we get past historical traditions and other barriers?

Mr Steve Maximay: We need to improve our communication mechanisms. In Trinidad, we have a well- written act and documents.

Mr Ramgopaul Roop: WASA owns all water in Trinidad and Tobago. The Water Resources Authority (WRA) is part of WASA. We issue all licences.

Mr Stanley Rampair: In Jamaica, we have the Water Resources Authority as independent body that allocates water. The National Water Commission (NWC) is the equivalent of WASA in Trinidad. We need independent regulatory (at local levels) body that allocates water to improve water management.

Dr Leslie Simpson: Let us get back on track. We have a lot of talk but no action. Vincent Sweeney and I sit on a committee to discuss water resources management. CARICOM is key, but they are not here now. How do we get past the piecemeal way in which we look at water management? We need integrated water resources management. We need something concrete from this meeting to present to the policy makers.

Dr Lystra Fletcher Paul: In discussing the management of water, it is important for to have an idea of the amount of water needed. We need to know the water demand for each sector. Figures are needed, especially for some water stakeholders (e.g. engineers). We need a water information system.

Dr Mark Bynoe: We cannot talk of segmented approaches. We need integrated management and it must be holistic. We need a clear understanding of challenges we face: The amount of water we can recycle, and what water (grey, black).
TECHNICAL SESSION II
Executive Summary

Introduction

Climate modelling for the Caribbean region under a range of scenarios suggests a continuation of a warming in average temperatures, a lengthening of seasonal dry periods, and increases in frequency of occurrence of drought conditions. This clearly has implications for society, economic sectors and biodiversity. Current and projected climate impacts are therefore compounding the Caribbean’s current challenges of securing watersheds from degradation and pollution from agricultural practices and land conversion (affecting both quality and quantity); and the equitable and reliable delivery of water to meet competing demands from the various sectors of economic activity, i.e. tourism, industry (energy generation, manufacturing), health, agriculture, and domestic consumption.

A consortium comprising the Co-operative Programme on Water and Climate (CPWC), the International Water Association (IWA), the International Union for Conservation of Nature (IUCN) and the World Water Council have identified small island states, such as those in the Caribbean, as a ‘hotpot’ where climate change effects are felt and where urgent action is needed within the water sector. The region shares this view, and has developed and implemented a number of initiatives geared towards integrated water resources management (IWRM). IWRM promotes the coordinated development and management of water, land and related resources in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems. Some the important regional initiatives and successes include:

1. The assessment of the impacts of climate change on water resources in the Caribbean conducted under the Mainstreaming Adaptation to Climate Change (MACC) project, which was implemented by the Caribbean Community Climate Change Centre (CCCCC).

2. The Integrating Watersheds and Coastal Areas Management (IWCAM) project in thirteen Caribbean small island developing states (SIDS), which aims to strengthen the commitment and capacity of the participating countries to implement an integrated approach to watershed and
coastal areas management, being implemented by the Caribbean Environmental Health Institute (CEHI). IWCAM has also implemented a number of pilot projects, through which it has:

a. Encouraged empowerment and capacity building in communities through the use of its Community-Based Resource Assessment (CBRA) Tool

b. Successfully supported the designation of the Basseterre Valley Aquifer (a major watershed) as a National Park

c. Built the capacity and awareness of regional journalists on integrated watershed management issues

d. Engaged in extensive public education and outreach

e. Identified ‘hotspots’: areas that contain significant sources of pollution or sensitive areas at high risk of being contaminated by specific pollutants

f. Built capacity to implement an integrated approach to the management of watersheds and coastal areas in communities

3. The CARICOM Consortium of CARICOM Institutions on Water, which is assisting member countries in developing a ‘Common Water Framework’ through:

a. The development of a Common Water Framework for member states

b. A consolidated work programme for 2011-2012 that reflects all members

c. A database of water resources projects for the Caribbean

d. The collation of Country Water Assessments for member states

4. The Global Water Partnership, Caribbean (GWP-C) through its IWRM initiative to address water and development issues in the region, in particular, water security and climate resilience. Their work covers resilience in three key areas:

a. Integrating water security and climate resilience in development planning processes

b. Development of partnerships and capacity of institutions and stakeholders to build resilience to climate change through better water management

c. Development of ‘no regret’ investment and financing strategies for water security and climate change adaptation

5. IWCAM has also implemented a number of pilot projects, through which it has:

a. Encouraged empowerment and capacity building in communities through the use of its Community-Based Resource Assessment (CBRA) Tool
b Successfully supported the designation of the Basseterre Valley Aquifer (a major watershed) as a National Park

c Built the capacity and awareness of regional journalists on integrated watershed management issues

d Engaged in extensive public education and outreach

e Identified ‘hotspots’: areas that contain significant sources of pollution, or, sensitive areas at high risk of being contaminated by specific pollutants

f Built capacity to implement an integrated approach to the management of watersheds and coastal areas in communities

Climate change and water resources in the Caribbean

Water resources in the Caribbean region include both surface and subsurface (ground) waters. The relative importance of each, from an economic perspective, varies from island to island. When groundwater is the primary source of water, as in Barbados, this has significant economic value. This is contrasted to the Windward Islands, whose main water supply is from surface sources, thus having a greater economic value than groundwater.

The management of water resources throughout the Caribbean lies under the responsibility of a number of agencies and, as such, management responsibilities (policymaking, service provision and regulation) are dispersed. Such a fragmented approach cannot result in satisfying the needs of stakeholders in this sector.

Projected changes to precipitation levels was provided for each CARICOM state by Simpson et al. (2009), based on global climate model (GCM) outputs used for the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4) (Meehl et al. 2007). A reduction in precipitation reduces both the available surface water reserves (by lowering stream flows) and also, the level of groundwater recharge. This latter impact can lead to increased risk of saltwater intrusion to aquifers, particularly those close to the coast, and reduces the amount of available water within aquifers. Most CARICOM nations have already experienced saltwater intrusion into aquifers: Antigua and Barbuda (particularly Barbuda), The Bahamas, Barbados, Grenada (particularly Carriacou and Petite Martinique islands), Guyana, Haiti, Jamaica, St Kitts and Nevis (particularly St Kitts island), St Vincent and the Grenadines (particularly the Grenadines islands), Suriname and Trinidad and Tobago.

Water quality in the Caribbean is a particularly important management issue due to the small size and interconnectivity of water catchments. Population size and urbanization lead to direct human interactions with many catchment areas and a significant potential for contamination of watercourses. The main factors affecting water quality range from agricultural activities, impacts of the domestic population on the environment and natural disasters.

The expansion of human settlements and agricultural activities on hill slopes has consequences for the environment. This is particularly evident in mountainous islands, such as St Lucia, Jamaica and Dominica, where land erodes due to development close to watercourses, and there is pollution from
household waste and sewerage contamination from latrines. Natural disasters create further destruction to degraded water catchments.

**Socio-economic Impacts of Climate Change on Water Resources**

Increased precipitation can cause flooding, and subsequent water logging of roots and crop death. Other indirect effects of floods include the spread of pests such as rodents, which attack certain crops, for example root crops in Grenada (Thomas 2011). Reduced rainfall results in drought conditions that decreases soil moisture and can result in a loss of crops.

The impacts on the health sector are also significant because of diseases associated with poor sanitation and insufficient water supply, as well as poor water quality due to contamination, particularly from sewage. This is especially so with respect to food-borne illnesses and gastroenteritis, e.g. gastroenteritis outbreak in the Turks and Caicos Islands (CAREC 2005). Water quality can have an impact on health, resulting in a number of other diseases including leptospirosis and Hantavirus, gastrointestinal diseases, and food-borne illnesses such as shigellosis, salmonella, campylobacter and cholera.

Countries experiencing some of the highest rates of water scarcity are also some of the most attractive in terms of tourism and, therefore, they experience the highest rates of increased demand for water. Wastewater management and solid waste disposal practices of the tourism industry are generally of concern with regard to water resources management, especially since the impacts from such practices are largely confined to the coastal marine environment—the primary resource of the Caribbean tourism industry.

When water resources are low, this affects sectors that depend on hydropower for their energy supply (Contreras-Lisperguer and Cuba 2008). An example of a country where this may be of relevance is Dominica, where there is already a reduction in energy generation from March to June annually due to reduced flows (ECU 2001). In St Lucia, the vulnerability of the water system was most clearly demonstrated due to Hurricane ‘Tomas’ passing. The reliance on one storage unit to provide the water resources for the majority of the country proved to be a critical component, crippling disaster recovery when the dam failed (Mr. Nichols, personal communication, 2011).

**Adaptation of policy and management practices in water resources management**

According to the study conducted under the MACC project, adaptation in the water resources sector is necessary from both supply and demand sides. Supply side adaptation involves:

- Modification of existing physical infrastructure
- Construction of new infrastructure
- Alternative management of the existing water supply systems

Demand adaptation includes:

- Conservation and improved efficiency
- Technological change
- Market/price-driven transfers to other activities
- Greater emphasis on rainwater harvesting, even in water-rich countries
- Increased storage, which should be distinguished from infrastructure in general like pipelines, filtration systems and intakes

Climate change adaptation strategies are also found in the climate change policy of all countries that have completed them. Some countries do not have the resources to directly execute climate change related projects but utilise funding from other sources; usually in fulfilment of objectives under multilateral environmental agreements (MEAs) addressing land degradation and biodiversity. Many of the vulnerabilities that exist in the water sector are tied to poor water management practices and strategies. This has been identified as a limitation in a number of countries such as St Lucia (MPDEH 2006). This means, however, that interventions in this sector could be made at smaller scales, thereby contributing to overall water resources management.

**Research Gaps and Path Forward**

Given the likely decrease in rainfall, lengthening of dry seasons and temperature increases, less water resources will be available throughout the region; therefore, countries of the Caribbean must make concerted efforts to raise the profile of water both at home and in the global climate discussions. It is clear that what is required to manage the impact of climate change on water is the adoption of Integrated Water Resources Management practices. Small Island States should urgently embrace this concept, since the time and distance between watersheds and water use is short, and climate as well as non-climate impacts to local and regional water resources will continue to be significant.

Further, there is need for:

- Careful monitoring and inventory of critical variables and indicators (available and gaps) since limited data exists particularly of groundwater resources in a number of islands. Stream flow monitoring is not consistently carried out in many countries.
- 'Upscaling’ local climate/meteorological/hydrologic data and experiences as well as 'downscaling’ models
- Detailed analysis and modelling of groundwater flow to account for the impact of sea level rise and reduced recharge rates on groundwater levels
- In some states, feasibility studies for the artificial recharge of groundwater
- In-depth water quality monitoring programmes
- Investigations into the feasibility of alternative water generation technologies
• Integrated assessments of water resource management to identify and reduce inefficiencies in water systems, including assessments of the implementation of management practices such as broadscale wastewater recycling.

Introduction

Centuries ago, economist Adam Smith rightly observed that even though water offers far more utility than diamonds – it is essential for life – the price of diamonds far exceeds that of water pound-for-pound. Consequently, low water tariffs that seem to be endemic to much of the Caribbean region, fail to signal to consumers the scarcity and value of water, and sadly water service providers often admit to high percentages of leakage and wastage in distribution systems. However, there is less discussion today as to the cost of water and more about how it is managed from source to user. Despite its importance, integrated water resource management remains a challenge throughout much of the developing world.

Water not only plays a major role in maintaining a healthy quality of life but is also a factor of production in many socio-economic sectors. The Caribbean currently faces the challenges of securing watersheds from degradation and pollution from agricultural practices and land conversion (affecting both quality and quantity); and the equitable and reliable delivery of water to meet competing demands from the various sectors of economic activity, i.e. tourism, industry (energy generation, manufacturing), health, agriculture, and domestic consumption.

Most countries in the wider Caribbean region have sought to initiate policy and institutional efforts to mitigate the negative impacts of development and demographic change on water resources. However, among other things, the high debt burden of many of the countries in the region has, in some cases, led to restrictions on the ability of the state to invest in public services, such as water management and services.

In addition to these factors, variable rainfall, stronger storms, accelerating run-off, floods, droughts, decreasing water quality and increasing demand for water are placing additional pressure on water availability, making management all the more difficult with the complex interaction among various threats. As such, water resources management remains a hot topic as it remains clear that limited freshwater availability requires prudent management for sustainable development. This is especially so in countries like Barbados, where water demands exceed a ‘sustainable yield’ and this conclusion is premised upon the consumption patterns and present supply (Inniss 2001).

A consortium comprising the Co-operative Programme on Water and Climate (CPWC), the International Water Association (IWA), the International Union for Conservation of Nature (IUCN) and the World Water Council have identified small island states, such as those in the Caribbean, as a ‘hotpot’ where climate change effects are felt and where urgent action is needed within the water sector. In fact, the Mauritius Strategy highlighted the importance of both water resources and climate change, and requested assistance from the international community for SIDS in the implementation of priority actions to address water issues (Overmars and Gottlieb 2009).

Similarly, there are several regional initiatives that share this view and seek to address water management issues and, in particular, the impacts of climate change. The Mainstreaming Adaptation to Climate Change (MACC) project, which was implemented by the Caribbean Community Climate Change Centre
(CCCCC), assessed the impacts of climate change on water resources in the Caribbean. The CCCCC has subsequently identified climate change impacts on water supply as one of the largest threats to the well-being of Caribbean people in its regional framework for achieving climate-resilient development.\(^2\)

The Caribbean Environmental Health Institute (CEHI) is implementing the Integrating Watersheds and Coastal Areas Management (IWCAM) project in thirteen Caribbean SIDS in order to strengthen the commitment and capacity of the participating countries to implement an integrated approach to watershed and coastal areas management. The main issues addressed in this project are consistent with needs identified in other studies and various fora to improve water resources management, and include:

1. The concern over diminishing water supplies as a result of climate change
2. Impacts from land use changes or inappropriate land use
3. Impacts on health (and sanitation)
4. Lack of or limited data and information on critical variables and indicators
5. Inequitable distribution of potable water amongst sectors and user groups
6. The need to improve water governance
7. The focus of knowledge and capacity on managing infrastructure resulting in the lack of, or limited awareness about, the connection between managing natural resources and the quality of water we drink
8. Segmented/sectoral approaches to water resources management
9. Cost of production and operation of water

CARICOM is also committed to establishing effective mechanisms to support a harmonised approach to securing, managing and protecting its water resources. To this end, the Consortium of CARICOM Institutions on Water has been established in 2008 to assist member countries in developing a ‘Common Water Framework’. The Consortium is presently working on:

1. The development of a Common Water Framework for member states
2. A consolidated work programme for 2011-2012 that reflects all members
3. A database of water resources projects for the Caribbean
4. The collation of Country Water Assessments for member states

This approach of harmonization is consistent with that of the Global Water Partnership (GWP), which argues that water as a resource cuts across sectors and should not be treated separately as a sector. The

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GWP is an organization that was formed to promote integrated water resources management (IWRM), which they have defined as “a process which promotes the coordinated development and management of water, land and related resources in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems”. IWRM is a comprehensive approach to the development and management of water, addressing its management both as a resource and as the framework for provision of water services (Jønch-Clausen 2005).

Since 2005, Global Water Partnership, Caribbean (GWP-C) has convened high-level meetings to address water and development issues in the region, and water security was regarded as needing attention. They are currently working with regional partners to develop a programme on water security and climate resilience in three key areas:

1. Integrating water security and climate resilience in development planning processes
2. Development of partnerships and capacity of institutions and stakeholders to build resilience to climate change through better water management
3. Development of ‘no regret’ investment and financing strategies for water security and climate change adaptation

These approaches have in common, the recognised need for balance between environmental sustainability and social equity in the context of economic growth (including cost-recovery that should ensure reliable long-term operations of water capture and delivery systems); all of which can be summed up as IWRM. Perhaps one of the consequences of the advocacy of IWRM within the Caribbean region has been a growing realization on the part of policy makers that there is an urgent need to address the underinvestment in water infrastructure (CEHI 2007).

Although the interpretation of IWRM varies, there is general agreement that it includes concepts of good environmental stewardship, land management policies and practices and water governance in the context of political, socio-economic, and administrative systems (Eakin and Lemos 2006). Its main components include:

- Managing water resources at the lowest possible level (at the river basin or watershed scale)
- Optimising supply
- Managing demand
- Providing equitable access to water resources through participatory and transparent governance and management
- Establishing improved and integrated policy, regulatory and institutional frameworks
- Utilising an inter-sectoral approach to decision making

Integrating management means that multiple benefits are received from a single intervention. This paper draws on several studies conducted in the English-speaking members of CARICOM on fresh water
resources management and climate change. It has been greatly informed by the work of Simpson et al. (2010), which provides the most recent projections of biophysical impacts on water resources for CARICOM nations under various climate change scenarios, and syntheses observations recorded in that and other studies of such impacts. The paper also explores the Caribbean context of water resources management, and presents a synopsis of the results from studies on the socio-economic impacts of climate change; recent efforts at policy research and policy formulation to address the growing concern about water resources; and finally identifies the research gaps that remain.

Table 1 represents a summary of biophysical and socio-economic impacts of climate change on Caribbean water resources discussed through this paper.

### Table 1 A summary of climate change impacts on water resources

<table>
<thead>
<tr>
<th>Climate change</th>
<th>Bio-physical impact</th>
<th>Socio-economic impact</th>
</tr>
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</table>
| Sea level rise and salt-water intrusion| Salinization of water lenses Less fresh water available | • Domestic consumption  
• Sanitation and health could be compromised at community and household levels  
• Water suppliers (costs for augmentation)  
• Farmers and those in agro-forestry have to augment supplies and/or change farming strategies |
| Reduced average rainfall               | Less fresh-water available Drought           | • Reduced aquifer recharge rates  
• Crop and biodiversity loss  
• Water rationing for certain uses  
• Investment in cisterns and reservoirs |
| Increased evapotranspiration rates     | Run-off and soil erosion Flooding            | • Reduced yields and volume of crops and forest cover                                  |
| Increased rainfall intensity           |                                              | • Reduction in crop production  
• Increased habitat conditions for disease vector production  
• Sedimentation of water bodies  
• Blocked storm water wells          |

Adapted from Hurlston (2004)

### Climate change and water resources in the Caribbean

The region has a maritime tropical climate with wide variation in rainfall, influenced by topography and size of landmass. Seasonal variability of rainfall is marked by a distinct dry period, usually December to March/April, and peak rainfall coinciding with the hurricane season of June to November. Water resources in the Caribbean region include both surface and subsurface (ground) waters. The relative importance of each, from an economic perspective, varies from island to island. In the case of countries like Barbados, Grenada and The Bahamas, more than 80% of the potable water is abstracted from
groundwater aquifers and pumped to the reservoirs (Cashman et al. 2010). As such, groundwater, as the primary source of water for all socio-economic activities, has significant economic value. However, in many of the Windward Islands, greater economic value is attached to surface water relative to groundwater (Farrell et al. 2007), with the latter being available but untapped in some cases.

The management of water resources throughout the Caribbean lies under the responsibility of a number of agencies and as such, management responsibilities (policymaking, service provision and regulation) are dispersed. In some instances, public-private partnerships are being created to better manage supplies and the cost of water is determined independently from the body responsible for producing it. Whilst such an arrangement may result in more reliable supply, it can often hinder an integrated and holistic approach to water resources management resulting in wastage, unsatisfied end-users and under-resourced water managers.

The Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4), projected a decrease in overall precipitation over many sub-tropical areas, including tropical Central America and the Caribbean region, which are also projected to experience shorter rainy seasons. In addition, it is considered likely that when precipitation occurs it will become more concentrated in shorter duration, intense events interspersed with longer periods of relatively dry conditions (Bates et al. 2008). Not only would this high runoff increase the risk of flooding and cause soil erosion, it would also reduce the amount of groundwater recharge that occurs and cause problems for those countries that are dependent on surface water but do not have sufficient water storage. A significant increase in the number of consecutive dry days has also been found for the Caribbean region (Bates et al. 2008). Clearly, increasingly variable rainfall, prolonged drought conditions and hurricanes, as experienced by countries in the Caribbean, are significant enough to threaten economic development. This concern has been noted in several areas of research and regional agendas, and notably, ‘Climate change and adaptation’ was a central topic on the Fifth World Water Forum.

Cashman et al. (2009) evaluate the existing availability of water resources, projections of potential demand trajectories, and the impact on existing service provision strategies, and critique some of the proposed responses to tackle water scarcity, such as desalination. They conclude that, irrespective of which climate change scenario is used, water resources in the Caribbean basin will come under increasing pressure, with decreasing rainfall and increasing demand. The Caribbean will suffer from reduced fresh water resources, which will become insufficient to meet demand during low-rainfall periods. For example, at the beginning of January 2010, several Caribbean countries began experiencing severe water shortages due to lack of rain (International Federation of Red Cross 2010).

Projected changes to precipitation levels was provided for each CARICOM state by Simpson et al. (2009), based on global climate model (GCM) outputs used for the IPCC Fourth Assessment Report (Meehl et al. 2007). Projections were based on global mean temperature rises of 1.5 °C and 2.0 °C and the B1 (sustainability), A1B (balanced) and A2 (high population growth, fossil fuel dependent) Special Report on Emissions Scenarios (SRES) (Nakićenović and Swart 2000). Of the projected decreases in precipitation over many sub-tropical areas (including tropical Central America and the Caribbean), the greatest declines were found to be projected for the higher levels average warming, with average annual precipitation in CARICOM states declining by -7.0%, -14.3% and -21.3% for the B1, A1B and A2 scenarios, respectively, and -5.9% and -8.0% for 1.5 °C and 2.0 °C global mean temperature rises. For
those countries that already face issues of water insecurity, these declines would be likely to increase the severity of water resource problems; for countries that currently have sufficient water resources, a decline in precipitation may introduce new water resources issues (Simpson et al. 2009). In addition, declines would increase the risk of periods of drought for the Caribbean region, which are likely to occur more frequently and to be more severe.

**Biophysical Impacts of Climate Change on Water Resources**

The impacts of climate change on water resources management in the Caribbean are tied to the demand for water and the ability of water utilities to supply water from natural and anthropogenic sources (Farrell et al. 2007).

Simpson et al. (2010) modelled the total annual precipitation for CARICOM states in 2080–2099 under three scenarios: B1, A1B and A2, and these results are discussed in the following section. Table 2 provides the definition of the various scenarios used.

**Table 2**  
SRES storylines and scenario families

<table>
<thead>
<tr>
<th>Storyline and scenario family</th>
<th>Description</th>
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| A1                           | Very rapid economic growth; global population peaks mid-century and declines thereafter; rapid introduction of new and more efficient technologies; increased social and cultural interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario family develops into 3 groups:  
  - A1F1: Fossil intensive  
  - A1T: Non-fossil energy sources  
  - A1B: Balance across all sources. Best estimate temperature rise of 2.8 °C with a likely range of 1.7 to 4.4 °C (5.0 °F with a likely range of 3.1 to 7.9 °F). Sea level rise likely range [21 to 48 cm] (8 to 19 inches) |
| A2                           | A very heterogeneous world; self-reliance; preservation of local identities; continuously increasing global population; economic growth is regionally oriented and per capita economic growth and technological change are slower than in other storylines. |
| B1                           | A convergent world with the same global population that peaks in mid-century and declines thereafter, as in the A1 storyline, but with rapid changes in economic structures toward a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social, and environmental sustainability, including improved equity, but without additional climate initiatives. |

**Assessment of biophysical impacts on hydrologic resources**

While there is considerable variability in model projections of precipitation, on the whole greater declines are projected, with the higher levels of average warming in scenario A2 (3.4 °C by 2080–2099), compared to scenarios B1 (1.8 °C) or A1B (2.8°C). Across all CARICOM states, projected changes to total annual precipitation ranges from +1.9% to -15.8% for the B1 scenario, -2.9% to -27% for the A1B, and -6.9% to -33.8% for the A2 scenario. The average projected changes in CARICOM states are -7.0%, -
14.3% and -21.3% for the B1, A1B and A2 scenarios, respectively. When GCMs reach the threshold global mean temperature rises of 1.5 °C the average projected change in precipitation across all CARICOM states is small at -0.4% (range: -27.2% to +34.1%); for 2.0 °C, the average projected change is -1.8% (range: -32.0% to +37.4%). For several nations (The Bahamas, Barbados, Belize, Dominica and Grenada), there is an average projected increase in precipitation levels at 1.5 °C and 2.0 °C; these changes revert to a decline in precipitation by 2080–2099 under B1, A1B and A2 scenarios. A reduction in precipitation reduces both the available surface water reserves and also, the level of groundwater recharge. This latter impact can lead to increased risk of saltwater intrusion to aquifers, particularly those close to the coast, and reduces the amount of available water within aquifers. Sea level rise will exacerbate the effect of drier conditions on salinization of aquifers – the reserves would be squeezed from both underneath via the rising saltwater layer, and above via reduced recharge rates.

Most CARICOM nations have already experienced saltwater intrusion into aquifers: Antigua and Barbuda (particularly Barbuda), The Bahamas, Barbados, Grenada (particularly Carriacou and Petite Martinique islands), Guyana, Haiti, Jamaica, St Kitts and Nevis (particularly St Kitts island), St Vincent and the Grenadines (particularly the Grenadines islands), Suriname and Trinidad and Tobago. Of these, countries with coastal aquifers that are particularly vulnerable to sea level rise are Antigua and Barbuda, The Bahamas, Grenada, Suriname and Trinidad and Tobago. Should sea levels rise substantially, all coastal aquifers would be threatened. A decline in precipitation levels would reduce the level of groundwater recharge, which, along with increasing sea levels, could increase the risk of saltwater intrusion.

CARICOM nations that have been particularly prone to water shortages or drought conditions are: Antigua and Barbuda, The Bahamas, Barbados, Dominica (in the dry season when demand is also highest), St Kitts and Nevis (particularly Nevis island) and St Lucia (in the dry season). Of these, the aquifers in Barbados have experienced saltwater intrusion due to the drought conditions reducing the amount of groundwater recharge. Antigua and Barbuda are heavily reliant on desalinization, particularly during periods of drought.

Declines in precipitation would lead to an increase in the risk of periods of drought for the Caribbean region, which are likely to occur more frequently and be more severe. Countries that rely mainly on surface water rather than aquifers could be affected by declining precipitation levels, since surface water generally responds more rapidly to drought conditions than aquifers where flows in rivers decline or stop altogether. Dominica, Grenada (main island), St Kitts and Nevis (St Kitts island), St Lucia and St Vincent and the Grenadines (St Vincent island) are all nations that rely on surface water rather than obtaining supplies from aquifers. Declining precipitation levels may make these nations vulnerable to water shortages, particularly if they have already experienced periods of drought, such as Antigua and Barbuda, The Bahamas, Barbados, Dominica, St Kitts and Nevis and St Lucia.

There are several reported cases where hurricanes have led to a reduction in water resource availability in some countries. In Antigua and Barbuda, extreme rainfall from hurricanes has caused the loss of topsoil and has eroded gullies. This has led to increased surface runoff from normal rainfall with a subsequent reduction in groundwater recharge (USACE 2004b). In The Bahamas, storm surges from hurricanes have damaged aquifers via contamination from flooding. Sea level rise would exacerbate this problem. In Dominica, temporary changes to the hydrological cycle in some watershed areas have been experienced.
due to damage caused to vegetation by hurricanes. If hurricanes were to increase in frequency and/or intensity, as some research suggests (e.g. Knutson and Tuleya 2004; Trenberth 2005; Emanuel 2005), these kind of impacts would likely increase. Vegetation cover could also become reduced in some areas due to declining precipitation levels. If this were to occur, these areas would be particularly vulnerable to the kind of effects experienced in Dominica.

Decreased precipitation reduces surface water sources by lowering stream flows. Due a lack of data, consistent monitoring and data collection in many Caribbean islands, the change in stream flows over the last three to four decades cannot be assessed. However, reduced rainfall itself has been documented. In Grenada, rainfall has been reduced by as much as 30 to 40% (Farrell et al. 2010). The 2009 drought also affected Jamaica (Barnett 2010).

Aquifers are prone to saline intrusion because of their close proximity to populated areas where water withdrawal rates for domestic, agricultural and industrial needs is often very high. The proximity of aquifers to the sea and the karstic nature of the limestone aquifer also increase the vulnerability of some aquifers to saline intrusion (Karanjac et al. 2000). For example, in Jamaica all of these factors have contributed to over-abstraction of water resources, which has resulted in saline intrusion of groundwater resources (G Marshall, personal communication, 2011).

Sea level rise also results in saline intrusion, where islands with shallow aquifer lenses are particularly vulnerable. For example, The Bahamas has shallow subterranean freshwater lenses (Buchan 2000) over 90% of which rest 1.5 m below the surface of the ground (WSC 2011), making them particularly vulnerable to sea level rise. Uncontrolled abstraction also threatens water sustainability (Spencer et al. 2010), while lenses may also reduce in size if precipitation decreases. The threat of salt-water intrusion has affected a number of other islands in the Caribbean, including Grenada, St Kitts and Nevis and the Turks and Caicos.

Extreme weather events have become more frequent and intense in many regions, resulting in a substantial increase of water-related hazards. At the same time, demographic changes are exposing more people to increased flooding, tropical storms and droughts. The impacts of major flooding in Jamaica and St Lucia have recently resulted in many deaths and cost billions of dollars in damages. This is an indication of what could lie ahead from increased climate variability. At the other extreme, the more intense droughts experienced in the past decade, which have affected an increasing number of people, have been linked to higher temperatures and decreased precipitation.

Assessment of biophysical impacts on water quality

Water quality in the Caribbean is a particularly important management issue due to the small size and interconnectivity of water catchments. Population size and urbanization leads to direct human interactions with many catchment areas and a significant potential for contamination of watercourses. The main factors affecting water quality range from agricultural activities, impacts of the domestic population on the environment and natural disasters.

Agricultural activities that affect water quality include pesticide contamination via leaching through soil, washing of agricultural equipment into watercourses and erosion of areas in proximity to river courses,
which increases siltation. Wild bush fires and fires started by humans also affect the health of water catchments, leaving soils bare and resulting in erosion and siltation of watercourses such as in Dominica (ECU 2001).

The expansion of human settlements onto hill slopes has consequences for the environment. This is particularly evident in mountainous islands such as St Lucia, Jamaica and Dominica where land erodes due to development close to watercourses, and there is pollution from household waste and sewerage contamination from latrines. Other associated problems include the threat of water contamination from landfill leachate and industrial pollution and dumping of used oil, which is a problem in The Bahamas (BESTC 2005).

Natural disasters, in addition to exerting a natural selective process on the environment, create further destruction to degraded water catchments. Recent hurricane events have been so severe that virgin forests have been affected in the islands of St Lucia due to Hurricane Tomas (Mr. Sealey, personal communication, 2011) and in Grenada due to Hurricane Ivan. Fires, which more often than not are human induced but compounded by drought conditions, result in the denuding of surface soils, which then results in erosion and siltation of riverbeds and coastal regions. Drought events also result in a reduction of groundwater levels, which lead to an increase in dissolved salts rendering water supplies unsuitable as potable water.

Aquatic ecosystem integrity may impact both riverine and marine ecosystems. In river systems, decreased stream flows due to higher withdrawal rates has been shown to result in a reduction of fish species (Xenopoulos et al. 2005). Increased siltation also affects riverine invertebrates and thus alters the food chain also leading to compromised ecosystems. In Grenada, the effects of climate change on riverine systems has been linked to both sedimentation and changes in water temperature (UNDP/OCHA 2004).

**Socio-economic Impacts of Climate Change on Water Resources**

Climate change will directly affect the demand for water. The studies reviewed indicate that the sectors of critical importance to national economies and livelihoods in Caribbean SIDS are agriculture, health and tourism.

**Agriculture**

Increased precipitation can cause flooding, and subsequent water logging of roots and crop death. Other indirect effects of floods include the spread of pests such as rodents, which attack certain crops, for example root crops in Grenada (Thomas 2011). Reduced rainfall results in drought conditions that decreases soil moisture and can result in a loss of crops.

In the agricultural sector, both below average and average rainfall have consequences for agricultural productivity. In Jamaica, to adapt to drought conditions, farmers have estimated the onset of the drought season and have resorted to increased use of short-maturing crops. This has two negative outcomes: reduced overall crop output and reduced income generated during a season (Gamble et al. 2010). The dependence on rainwater for irrigation also has its implications during drought conditions. However, there is also the case of water wastage, as farmers are often not encouraged to use water efficiently in times
where there are sufficient water resources (Springer 2005). However, they also bear the brunt of added costs to truck water during drought conditions, such as occurred in St Lucia during the 2009-2010 drought season (DREF 2010). Salt-water intrusion also affects groundwater wells that farmers depend on, also resulting in reduction in crop yields. Overall reduction in food output also impacts the food security of a country and results in greater imports, which requires expenditure that could be directed into the labour market rather than lost externally.

**Health**

The impacts on the health sector are also significant because of diseases associated with poor sanitation and insufficient water supply as well as poor water quality due to contamination, particularly from sewage. This is especially so with respect to food-borne illnesses and gastroenteritis e.g. gastroenteritis outbreak in the Turks and Caicos Islands (CAREC 2005). Vector borne diseases, namely dengue fever and malaria, are an indirect consequence of above average annual precipitation. This places an added financial burden on the government-subsidized health sector, as cost of treatment and drugs can be significant.

Particular mention should be made in countries that use cisterns, such as the Turks and Caicos and Anguilla. In these countries, the use of cisterns is particularly relevant in the spread of vector borne diseases. This is also the case in countries that utilize a lot of water storage containers (other than cisterns), such as Jamaica where mosquito breeding has been found to be higher in parishes where barrels were used (Chadee et al. 2009). Increased cases of asthma, bronchitis and acute respiratory infections have also been linked with increased dust storms and seasonal changes in some countries e.g. Barbados (Inniss 2001) and St Lucia (Amarakoon et al. 2004).

Water quality can have an impact on health, resulting in a number of other diseases including leptospirosis and Hantavirus, gastrointestinal diseases, and food-borne illnesses such as shigellosis, salmonella, campylobacter and cholera. Other important diseases include typhoid, rabies and schistosomiasis. Legionnaires disease is associated with the cruise ship industry but is also a disease of other environments, most notably hotels. The disease has links to poor water quality and the contact with water contaminated by various disease causing agents. Children are particularly vulnerable.

**Tourism**

It is paradoxical that countries experiencing some of the highest rates of water scarcity are also some of the most attractive in terms of tourism and, therefore, they experience the highest rates of increased demand for water (Brown et al. 2007). Further, the tourism sector receives preferential water provisions because of its socio-economic importance (Cashman et al. 2009). The demand for water is increasing in countries such as St Kitts, where water demand is expected to double in the next 10 years (Dr. Sahely, personal communication, 2011). Aside from the greater luxury afforded to this sector, there is the case of tourists that come from developed countries where the water use per capita is higher than developing countries, which compounds overall water consumption in this sector.

During drought conditions, if visitor arrivals decrease due to concerns of drought or flooding and the implications for health and quality of their experience, this affects employment. Additionally, during
drought conditions, agricultural productivity decreases and as a result locally produced food becomes more expensive. This translates into food crops used in the tourism industry becoming more expensive and subsequently making the entire tourism product more expensive. Health impacts on the local population can also affect the tourism industry as tourists represent a group susceptible to tropical diseases endemic to the Caribbean region. Those of particular relevance include vector borne diseases such as dengue and malaria.

Wastewater management and solid waste disposal practices of the tourism industry are generally of concern with regard to water resources management, especially since the impacts from such practices are largely confined to the coastal marine environment—the primary resource of the Caribbean tourism industry. Most of the water supply infrastructure is upstream of the main tourism zones and are therefore not susceptible to impacts of waste disposal from tourism facilities (Emmanuel and Spence 2009).

The demand from the tourism industry is often a challenge to address. The tourism industry has utilized truck borne water on occasion to meet its water needs. For instance, truck borne water was supplied twice a day to a number of hotels after Hurricane Ivan (Mr. Nichols, personal communication, 2011). In some instances, where tourism is significant to national economies, private desalination plants are utilized in the tourism sector, as is the case in St Kitts, Grenada and the Turks and Caicos Islands.

**Domestic Sector**

When water resources are low, this affects sectors that depend on hydropower for their energy supply (Contreras-Lisperguer and Cuba 2008). An example of a country where this may be of relevance is Dominica, where there is already a reduction in energy generation from March to June annually due to reduced flows (ECU 2001). Greater dependence on diesel for energy involves a greater economic burden to the country. This is particularly important for countries that utilized desalination water such as the Turks and Caicos Islands. The source of salt water for desalination also affects the cost of water. For countries that have access to brackish water (ECLAC 2008), the operating cost to remove the salt is less than if pure sea water has to be used. Despite the high costs associated with it, desalination has been deemed necessary to meet domestic demands in some countries such as Antigua and Barbuda and Barbados.

Sea level rise and the effects of storm conditions and hurricanes can also impact desalination infrastructure (Byron 2011) increasing the costs to consumers to repair them or resulting in debt to the country. The passage of hurricanes can result in the damage to water infrastructure and siltation of water bodies and dams, such as in St Lucia where disruption of the water supply can exist for up to four days (Mr Nichols, personal communication, 2011).

In St Lucia, the vulnerability of the water system was most clearly demonstrated due to Hurricane Tomas’ passing. The reliance on one storage unit to provide the water resources for the majority of the country proved to be a critical component, crippling disaster recovery when the dam failed (Mr. Nichols, personal communication, 2011).
Commercial Benefit in water-rich countries

In countries that have greater water resources, the export of water is a positive outcome of climate change. However, it requires them to better manage their water resources because often such countries suffer from localized inefficient distribution of water. The most notable example of this is in Dominica where the abundance of water resources has allowed the country to capitalize on water for export to other countries as well as to the cruise ship industry (Chase 2008). During the 2010 drought period, approximately two million gallons of water per week were purchased by St Lucia Hotel and Tourism Association during off-peak periods at night so as not to hamper any local activities (Dominica News Online 2010).

Adaptation of policy and management practices in water resources management

According to the study conducted under the MACC project, adaptation in the water resources sector is necessary from both supply and demand sides. Supply side adaptation involves:

- modification of existing physical infrastructure
- construction of new infrastructure
- alternative management of the existing water supply systems

Demand adaptation includes:

- conservation and improved efficiency
- technological change
- market/price-driven transfers to other activities
- greater emphasis on rainwater harvesting, even water-rich countries
- increased storage, which should be distinguished from infrastructure in general like pipelines, filtration systems and intakes

Caribbean countries have agreed to develop a National Water Policy. Currently such a document has been developed in a number of countries, most notably the Grenada National Water Policy in 2007, the Jamaica Water Sector Policy Strategy and Action Plan 2004 and St Lucia National Water Policy 2004. Some countries do not have a water policy, most notably the water-rich country of Dominica but also drier islands such as St Kitts and Nevis. The National Water Policy attempts to create an overall picture of all water resource issues and identify the most suitable ways to address them, and to develop institutional and regulatory and management of resources as well as infrastructure and human resources.

Climate change adaptation strategies are also found in the climate change policy of all countries that have completed them. Some countries do not have the resources to directly execute climate change related
projects but utilize funding from other sources; usually in fulfilment of objectives under multilateral environmental agreements (MEAs) addressing land degradation and biodiversity. However, there is often the requirement to commit to one to one co-financing agreements, which are beyond the financial scope of cash strapped institutions, as is the case in Jamaica (A Haiduk, personal communication, 2011).

In countries without a climate change policy, overall options to augment water indirectly contribute to measures to address water insecurity. For example, The Nevis Water Department has devised The Nevis Water Enhancement Project to supplement the water it can produce with an additional one million gallons of storage. The Department also plans to increase its capacity to store water and will upgrade its pipeline network. (Mr Morris, personal communication, 2011). Indeed, the experience of the last decade in water resource management demonstrates the need for water augmentation throughout the Caribbean. Many countries are resorting to the restoration of existing groundwater resources, such as Jamaica (Government of Jamaica 2004) and Anguilla (PAHO 2007b).

Many of the vulnerabilities that exist in the water sector are tied to poor water management practices and strategies. This has been identified as a limitation in a number of countries such as St Lucia (MPDEH 2006).

Results from the IWCAM project suggest that with very few exceptions—notably Barbados, Cuba and Jamaica—Caribbean countries are some distance away from the ideal institutional arrangement that would permit integrated management of watersheds and coastal areas. The report also highlights the reasons for the inadequate institutional arrangements, all of which point to the fragmented management responsibilities of various aspects of the water sector, environmental and development issues; and poor governance.

Importantly, IWCAM has also implemented a number of pilot projects through which it has:

- Encouraged empowerment and capacity building in communities through the use of its Community-Based Resource Assessment (CBRA) Tool
- Successfully supported the designation of the Basseterre Valley Aquifer (a major watershed) as a National Park
- Built the capacity and awareness of regional journalists, on integrated watershed management issues
- Engaged in extensive public education and outreach
- Identified ‘hotspots’: areas that contain significant sources of pollution or sensitive areas at high risk of being contaminated by specific pollutants
- Built capacity to implement an integrated approach to the management of watersheds and coastal areas in communities
Research Gaps

Uncertainty over specific impacts from climate change in SIDS should not hamper adaptation in the water sector. The region’s inability to cope adequately with current non-climate and climate stresses and high confidence in regional projections should provide sufficient incentives for ‘no-regrets’ approaches. However, to truly succeed at integrated water resources management in the context of a changing climate, some gaps remain. There is need for:

- Careful monitoring and inventory of critical variables and indicators (available and gaps) since limited data exists particularly of groundwater resources in a number of islands. Stream flow monitoring is not consistently carried out in many countries
- 'Upscaling' local climate/meteorological/hydrologic data and experiences as well as 'downscaling' models
- Detailed analysis and modelling of groundwater flow to account for the impact of sea level rise and reduced recharge rates on groundwater levels
- In some states, feasibility studies for the artificial recharge of groundwater
- In-depth water quality monitoring programmes
- Investigations into the feasibility of alternative water generation technologies
- Integrated assessments of water resource management to identify and reduce inefficiencies in water systems, including assessments of the implementation of management practices such as broadscale wastewater recycling

Path forward for water resource management in the Caribbean

The Caribbean consists of countries at various stages of socio-economic development. Consequently, water resource management systems have been developed to different degrees depending on the complexity of the water sector, which is usually related to the size of the country and the severity of water shortages that are experienced. Traditional approaches to water resources management have been fragmented but this needs to change.

Given the likely decrease in rainfall, lengthening of dry seasons, and temperature increases, less water resources will be available throughout the region; therefore, countries of the Caribbean must make concerted efforts to raise the profile of water both at home and in the global climate discussions. The region simply cannot afford to hinder action to protect its water resources, especially as it is certain that overall demand for water will grow. The economic and societal value of water resources should therefore form the basis for the development of adaptation strategies. Caribbean countries overall have already embarked on responses to climate change and, to a larger extent, have implemented sustainable development initiatives. It is prudent therefore to couple adaptation in the water sector with sustainable resource management, taking future demand into consideration.
It is clear that what is required to manage the impact of climate change on water is the adoption of Integrated Water Resources Management practices. Small Island States should urgently embrace this concept, since the time and distance between watersheds and water use is short, and climate as well as non-climate impacts to local and regional water resources will continue to be significant.

Water resources in the Caribbean are particularly vulnerable to climate change, especially from reduced rainfall rates leading to an increase in periods of drought and a reduction in aquifer recharge, and sea-level rise leading to an increased risk of salinization of aquifers. Some countries are well advanced in the planning of adaptation measures for water resources under climate change, however the geographic nature of many states makes the implementation of these measures particularly challenging. There are some clear areas that can be addressed, however, particularly in areas of water use efficiency, water-recycling schemes and continued developments to supply structures and organization. The following recommendations are made:

1. Develop pilot projects to assess the artificial recharge of aquifers. The injection of water into aquifers has been suggested to buffer the effects of saline intrusion. Aquifers act as large reservoirs of fresh water that reduce vulnerability during periods of drought. Upstream injection increases recharge volumes and downstream recharge increases the barrier between saline and freshwater. Maintaining sufficient groundwater recharge would reduce the risk of saline intrusion and help to maintain water quality. The source of water used for artificial recharge should be selected carefully to avoid issues with nitrates entering groundwater.

2. Assess the possibility of broadscale implementation of localized wastewater recycling schemes and legislation, including for agricultural irrigation. Drought management is a challenge that requires a multifocal approach due to the non-structural nature and complex spatial patterns of drought.

3. Review legislation mandating the purchase of potable water from national water providers with a view to easing restrictions, where they exist, on investing in private desalination plants.

4. Develop measures to protect water resources from contamination to ensure water quality. Enforce environmental legislation to protect upper watersheds. Robust land use planning and management is critical for the protection of water resources to avoid contamination with pollutants including sediments, sewage and agro-chemicals into water systems. Groundwater should be protected as a water resource for development. In particular, (i) residential development in groundwater catchments should be constrained; (ii) existing forest reserves should be protected; and (iii) deforested areas should be restored.

5. Undertake public education in water resources. In particular, communities and the population should be educated in conservation and treatment of water, and the proper use of rainwater harvesting systems. This will lead to a greater public awareness of the need to conserve water and capture rainwater. The population should be encouraged to develop domestic supplies. Public awareness of climate change issues should be increased.
6. Encourage private sector participation: The role of the private sector in IWRM should not be overlooked. Comparatively high unit costs of developing new sources of drinking water can be brought down by ‘piggy-backing’ on projects to deliver the much higher volumes needed for irrigation. Where possible, dam and reservoir costs can be shared.

7. Encourage NGO participation, particularly for training and capacity building.

8. Development of efficient irrigation practices in agriculture: Higher temperatures and longer dry seasons would increase soil water deficits and lead to an increased need for irrigation. Efficient irrigation schemes should be developed to minimize water loss.
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Case study:
Innovative on-Farm Water Management in Barbados: The Case of A.T. Nicholls Farm, Mount Wilton, Saint Thomas, Barbados

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Summary
On-farm water management (OFWM) is a holistic approach to the utilization of water resources to achieve higher agricultural outputs in a sustainable and environmentally friendly manner. Climate change is one factor that can influence the good management practices that will fashion innovative on-farm water management. Mr. Anderson Nicholls, a crop farmer in Mount Wilton, St Thomas has all of the components of OFWM. This case study will highlight the challenges, impacts and lessons learnt. The information can assist policy-makers and institutions in the development of strategies for moving our water resources management into an age where agriculture, population and the environment can coexist.

Introduction
It is suggested that the Caribbean region would experience an increase in temperatures of up to 3°C by 2100. Annual rainfall totals are expected to decline by 20 to 30% by 2100. This could have grievous implications for agricultural production and food processing (Kirton-Reed et al. undated).

The International Commission on Irrigation and Drainage has defined water management as “the planned development, distribution and use of water resources in accordance with predetermined objectives, while respecting both the quantity and quality of water resources. It is the specific control of all human interventions concerning surface and subterranean water. Every planning activity relating to water can be considered as water management in the broadest sense of the term.” (ICID 2000 in Forest 2011)

Dr. Honourable David Estwick. Minister of Agriculture, Food, Fisheries and Water Resource Management has said that, ‘We can no longer simply rely on when the rain falls; and to set up your planting cycles around when you have rain and when you do not have rain, is a rather precarious way of managing your output. And therefore, establishing policies where legitimate farmers are going to be encouraged to establish water harvesting and water management systems, is going to rebound to significant enhancement in agricultural production in the country.’ (BGIS 2001)

Mr. Anderson Nicholls, a crop farmer in Mount Wilton, St Thomas, has all the components of innovative on-farm water management (OFWM). This case study will highlight the challenges, impacts and lessons learnt in implementing OFWM and the role of climate change in decision making.
Description of the On-Farm Water Management

Location

The A. T. Nicholls farm is located in the parish of St Thomas, a centrally located parish in Barbados, at an elevation ranging from 288 m above sea level to 313 m above sea level (Figures 1. and 2)

Figure 1  Location Map for Farm
Farm History

The farm has been in operation from 1987 at its present location. Prior to this Mr. Nicholls started his very first farm of two acres in 1973 in Sturges, which is in the same parish, but the small farm size coupled with gluts on the produce market, led him to sell the farm and look to lease a larger area to farm. At the present location at Mount Wilton, Mr. Nicholls has the following crops under cultivation: sugar cane, plantain, banana, coconut and cash crops such as tomato and cabbage.

Main Crops

The main crops are listed in Table 1.

Table 1  Main Crop Acreage

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<th>Crop</th>
<th>Cultivated Area (HA)</th>
<th>Irrigation Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sugarcane</td>
<td>2.16</td>
<td>-</td>
</tr>
<tr>
<td>Plantain</td>
<td>1.18</td>
<td>-</td>
</tr>
<tr>
<td>Banana</td>
<td>0.4</td>
<td>-</td>
</tr>
<tr>
<td>Coconut</td>
<td>4.72</td>
<td>-</td>
</tr>
<tr>
<td>Cash crops</td>
<td>Variable</td>
<td>Drip/Sprinkler</td>
</tr>
</tbody>
</table>

There are several factors that influenced the choice of crops. These are:

- Produce scarcities and gluts on the market
- Ability to pay regular statutory deductions for employees
- Retirement income
• Pesticide use

Land Tenure

The land on which this farm is located is owned by the farmer.

Water Rights

The farmer has no water rights issues.

Soil Type

The soil in this area is a clay soil found on the upland plateau at an elevation of over 300 m above sea level. It is classified as a Red Brown Association comprised predominantly of a Normal Associate and a lesser Shallow Associate. For a more in-depth understanding of these terms, please refer to Table 2.

Table 2  Comparative characteristics of Shallow Associate and Normal Associate Soils

<table>
<thead>
<tr>
<th>CHARACTERISTICS</th>
<th>SHALLOW ASSOCIATE</th>
<th>NORMAL ASSOCIATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>External drainage</td>
<td>Medium</td>
<td>Slow</td>
</tr>
<tr>
<td>Internal drainage</td>
<td>Rapid</td>
<td>Medium to rapid</td>
</tr>
<tr>
<td>Overall drainage</td>
<td>Somewhat excessive</td>
<td>Well drained</td>
</tr>
<tr>
<td>Permeability</td>
<td>Moderately rapid</td>
<td>Moderately rapid to moderate</td>
</tr>
<tr>
<td>Moisture supplying</td>
<td>Low</td>
<td>Low to moderate</td>
</tr>
<tr>
<td>Capacity</td>
<td>Low</td>
<td>Low to moderate</td>
</tr>
</tbody>
</table>

The soil should have a pH of 7.0, organic matter at 4%, a low salt concentration, cation exchange capacity approximately 25 meq/100 ml, high calcium and relatively low exchangeable magnesium and potassium. The last soil test was completed in 2001 through the Eastern Caribbean Fertilizer Limited (refer to Appendix 1). These results show a pH of 8.0, organic matter of 0.8%, cation exchange capacity of 18.8 meq/100 ml, magnesium at 0.76 meq/100 ml (low), and potassium at 0.6 meq/100 ml (optimum).

The agronomic features of the soil are outlined in Table 3 and Table 4.

Table 3  Agronomic Features of the Soil type in the study area

<table>
<thead>
<tr>
<th></th>
<th>Normal</th>
<th>Shallow</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dominant Slope</td>
<td>2 – 10 degrees</td>
<td>4 – 20 degrees</td>
</tr>
<tr>
<td>Stoniness</td>
<td>Few stones</td>
<td>Strong</td>
</tr>
<tr>
<td>Erosion Hazard</td>
<td>Slight</td>
<td>Slight to moderate</td>
</tr>
<tr>
<td>Limitations to root penetration</td>
<td>Compaction in deeper sub-soils</td>
<td>Bedrock at 20 ft or less</td>
</tr>
</tbody>
</table>
Table 4  Land Capability Classification for Shallow and Normal Associate soils

<table>
<thead>
<tr>
<th>Classification</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shallow (61D)</td>
<td>Class III – Moderate to steep slopes with gentler slopes of less favorable soil. Suitable for cultivation with strong limitations. Limiting factor ‘S’. Classified as a strong or shallow soil.</td>
</tr>
</tbody>
</table>

Rainfall Pattern

The parish of St Thomas has an average annual rainfall of 2,160 mm due to its elevation and location in relation to the prevailing trade winds (Figure 3).

There are two seasons: dry and wet. The Dry season is from January to May and the Wet season is from June to December.

Figure 3  Rainfall Distribution in Barbados

*Barbados Rainfall*

average about 1422 mm
56 inches
Factors affecting OFWM

The factors affecting OFWM are as follow:

- Physical: soil type, depth, characteristics, field layout, water sources and sinks
- Climatic: precipitation potential, drought potential, rainfall amounts and intensity and temperature
- Economic: market prices, material availability, labour costs and availability
- Social: government regulations, environmental concerns and safety considerations

Components of OFWM

Irrigation Components

System Type

On this farm, both drip and sprinkler systems are used for irrigation. In-line compensating and non-compensating drip lines are used to irrigate tomatoes; whilst impact sprinklers are used to irrigate other cash crops such as cabbage, carrots and beans (Figure 4 and Figure 5).

Figure 4  Drip Irrigation system
The total acreage of the farm of 22.83 hectares classifies it as a medium farm. In addition, the total arable acreage is 18.11 hectares and the quantity of irrigated land is 2 hectares. The irrigated acreage is covered by 0.82 hectares of drip and 1.18 hectares of sprinkler systems.

In order for the water to reach the fields for irrigation, a system of electric and diesel pumps are used. The farm utilizes its own 20 k VA genset to supply electricity to the 2 hp centrifugal pump located at the pond. The genset consumes approximately 11.6 litres of diesel per day. The estimated monthly diesel cost is US$316.12. The electric pump delivers the water from the pond to the storage tank at the main control head. Following on from there, a diesel pump conveys the water out to the fields via a 90 mm PVC mainline.
The sprinklers are ¾” brass impact sprinklers with a 27 degree angle trajectory. The sprinklers are spaced at 12.12 m along the lateral plane and 11.76 m between laterals in a rectangular wetting pattern. There is a maximum of seven sprinklers operating on a lateral. The flow rate of each sprinkler is 1,495 litres per hour (l/h) which makes the irrigation application rate 10.49 mm per hour (mm/h).

The three types of drip line used on the farm are outlined in Table 5.

**Table 5  Drip line performance data**

<table>
<thead>
<tr>
<th>Type</th>
<th>Drip Diameter (mm)</th>
<th>Emitter Spacing (M)</th>
<th>Emitter Flow Rate (l/h)</th>
<th>Irrigation Application Rate (mm/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-compensating-inline</td>
<td>16</td>
<td>0.3</td>
<td>1.89</td>
<td>3.75</td>
</tr>
<tr>
<td>Compensating- inline</td>
<td>16</td>
<td>0.4</td>
<td>2.27</td>
<td>3.38</td>
</tr>
<tr>
<td>Compensating- inline</td>
<td>16</td>
<td>0.5</td>
<td>2.20</td>
<td>2.62</td>
</tr>
</tbody>
</table>

**Irrigation Application and Scheduling**

On this farm, the farmer relies on the ‘feel test’ method for irrigation scheduling. Observations of both the soil and the crops indicate when and how much to irrigate.

The fact that the farmer employs these somewhat simplistic methods is by no means an indicator of his level of exposure to the newer technologies. He had some exposure to using tensiometers for irrigation scheduling and application. These tensiometers were on loan from the Ministry of Agriculture for a short period in the 1980s, and were in use on one of his earlier farms. However, he has expressed an interest in using the technology again, once he has access to the equipment.
Mr. Nicholls has a rain gauge to measure rainfall events but the information is not recorded. He was not aware that the drought and precipitation forecasts for three-month periods were available on the internet. He currently has no computer access on the farm to obtain this information.

**Conveyance Components**

**Main Control Head**

This consists of a diesel-powered centrifugal pump, one 50 mm disc filter, 32 mm Venturi fertilizer injector and a pressure gauge. Water is stored in a metal tank and pumped to the field via a main line.

![Main Control Head Image](image)

**Figure 8  Main Control Head**

**Main Line**

This comprises of a 3” PVC SCH 40 pipe, which is buried in most places. Along the main line at specific intervals, there are secondary control heads.
The secondary control head facilitates the control over sections of the farm. These heads consist of 50 mm PVC SCH 40 pipe with manual PVC ball valves.
Submains, Manifolds and Laterals

The irrigator can supply irrigation water to a number of plots from a secondary control head. Water is transported by a manifold to fields that are not close to the secondary control head. Distribution of water along the field is done by a submain of 50 mm low-density polyethylene (LDPE) or aluminium pipe. Drip line laterals or sprinklers on 20 mm risers are the final exit points for the irrigation water to the soil.

Figure 11 50 mm LDPE Submain Pipe

Figure 12 Sprinkler lateral-aluminium pipe

Drainage Components

Suck well

There is a suck well located close to the northern boundary of the papaya field.
In-Field drain

In the field, drains are cut to remove water from the depressions in the sloping fields.

Gully system

There is a natural watercourse on the farm that drains into a larger gully system.
Since there was no irrigation system design done prior to constructing the pond, the design capacity of the impoundment was not determined. The pond was simply built according to the shape or relief of the selected location.

The estimated actual capacity of the pond was approximately 17,035 m$^3$. The freeboard is not uniform in depth around the perimeter of the pond. The freeboard varies from 0.5 m–1 m and the maximum functional depth is 0.5 m (Figures 16 and 17).

The capacity is an estimate, since the pond depth is not uniform and its depth increases from north to south. The average depth is 6.7 m.

The side slopes vary from 11 degrees to 40 degrees along the perimeter of the pond.
Water is channelled into the pond via a 3 m x 10 m inlet with a boulder filter pack that reduces the suspended solids in the runoff water before it enters the pond. However, during a severe rainfall event, the inflow volume and velocity exceed the infiltration rate of the filter pack, and water with a high sediment load will overflow into the pond area. Sediment that accumulates in the inlet sump is periodically removed using a modified tractor (Figure 18) and reapplied to the fields (Figure 19).
Additionally, there is also the issue of mosquito breeding potential. Freshwater fish are being used to eliminate mosquito breeding but over population is resulting in smaller sizes and weight.

**Water Sources and sinks**

**Water Sources**

Over the 24 years of its existence, finding an appropriate source of irrigation water for the farm has been a system of trial and error. A surface water impoundment (pond) was built in the 1990s in a watercourse just northwest of the farm, so that Mr. Nicholls could have a steady irrigation water supply. Additionally, local springs were cleared so that water could be channelled into the pond for on-farm use. However, this pond had to be abandoned due to sedimentation over a 2–3 year period and problems with the submersible pump in the supply tank, which was destroyed every year due to high siltation. Crops on the farm were mainly rain fed during this period and potable water was only used to irrigate cash crops.

There are presently two sources of water for irrigation. The main source of irrigation for the farm is surface runoff from 5 hectares of cultivated land (Figure 20). The present pond was constructed in 2004 out of necessity, after the farmer was unable to get permission to dig a well on a portion of the farmland. No potable water is used for irrigation presently.
Figure 20 Catchment Area for the pond and irrigation layout

The second source is rainwater that is harvested from the roof of a farm building.
Sinks

On the other side of the coin, there is also the possibility of the catchment overflow during heavy rains. To manage this, a recess (Figure 22) was excavated to capture the overflow water and allow it to infiltrate into the soil. Any excess water that the recess cannot accommodate will flow into the gully on the western boundary of the farm via a natural watercourse.

Figure 21  Rainwater harvesting from roof of farm building.

Figure 22  Recess at the southern end of the pond
Innovation: Surface Water Impoundment

Causes that led to the Innovation

Before the surface water impoundment was implemented, the farmer was experiencing difficulties with harnessing enough water from the local springs around the farm. He was being constantly faced with dry springs in the dry season and he either used more expensive potable water, or he planted cash crops only in the rainy season. The farmer’s innovation in OFWM was the installation of a pond to harvest surface water runoff from upstream fields, and rainwater from the roof of a farm building.

There are only two other private farms that currently harvest water for irrigation in Barbados. This information is outlined in Table 6.

Table 6  Farms in Barbados having water catchment ponds for irrigation

<table>
<thead>
<tr>
<th>Farm</th>
<th>Location</th>
<th>Water source</th>
<th>Ownership</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bawden</td>
<td>St Andrew</td>
<td>Sub surface drainage</td>
<td>Government</td>
</tr>
<tr>
<td>Claybury Plantation</td>
<td>St John</td>
<td>Surface runoff</td>
<td>Private</td>
</tr>
<tr>
<td>Edgecumbe Plantation</td>
<td>St Philip</td>
<td>Surface runoff</td>
<td>Government</td>
</tr>
<tr>
<td>Greenland</td>
<td>St Andrew</td>
<td>Sub surface drainage</td>
<td>Government</td>
</tr>
<tr>
<td>Hampton Plantation</td>
<td>St Philip</td>
<td>Surface runoff</td>
<td>Private</td>
</tr>
<tr>
<td>River Plantation</td>
<td>St Philip</td>
<td>Stream flow</td>
<td>Government</td>
</tr>
</tbody>
</table>

Steps in Implementation

Faced with the uncertainty of water availability in the dry season, the farmer undertook the project of putting a pond in place for the purpose of crop irrigation. This surface water impoundment was installed based on a similar one observed at Claybury Farm in the parish of St John. The implementation process was as follows:

1. Identification of a suitable location
2. Rental of equipment for excavation purposes
3. Excavation of the pond and intake structure
4. Stone removal from the pond site
5. Installation of the liner
6. Installation of the pump
7. Commissioning of the pond
Organizations / Institutions involved

On initiation of the idea for the pond, the farmer approached the Government-run Soil Conservation Unit for assistance in implementation of the project. Since his farm was not located in the Scotland District, he did not obtain technical assistance and he therefore proceeded on his own with the project.

Financing the Innovation

This project was fully financed by the farmer. A breakdown of the costs is as follows:

- Labour and excavation US$20,000.00,
- Liner US$19,000.00.

Training

The construction crew received no training in catchment construction and liner installation.

Impact of the Surface Water Impoundment

Government Policy

There are a number of Government departments and divisions responsible for giving technical assistance to persons interested in OFWM.

A. Soil Conservation Unit

The Soil Conservation Unit, a division of The Ministry of Agriculture, exists to manage the soil conservation requirements of the Scotland District. Persons who wish to obtain any technical assistance from this government entity are only able to do so if their farm is located in the Scotland District. The Soil Conservation Unit can only construct surface water impoundments in the Scotland District. There is an absence of heavy clays outside the Scotland District, where the construction of earthen dams are very practical. It is more difficult to construct earthen ponds outside this area since the porosity of the soils will increase seepage. Thus, either clay would have to be transported outside the Scotland District, or an impermeable liner would have to be installed to prevent seepage from the pond. This additional lining approach however comes at a much higher construction cost output. The estimated construction cost of excavation of earthen dams is US$0.95 per cubic meter (Charleston Lucas, Deputy CAO, Ministry of Agriculture, Barbados. Personal communication, 2011).

B. Land and Water Use Unit

The Land and Water Use Unit (LWUU) was responsible for irrigation extension, groundwater monitoring, and irrigation system development. The LWUU was a part of the Ministry of Agriculture but has been defunct from 1994. Presently, persons can get assistance with irrigation design and installation but there is no monitoring of on-farm water use and efficiency.
C. Irrigation Engineering Unit

The Irrigation Engineering Unit (IEU) is a department of the Barbados Agricultural Development and Marketing Corporation (BADMC). It developed from the Integrated Rural Development Project (IRDP) which commenced in 1981, and was funded by the Inter-American Development Bank.

There are 13 Irrigation Districts in areas of St Lucy, St Andrew, St George, St Michael, Christ Church and St Philip. Water is sourced from 21 wells, of which 17 are leased from private owners. There are 609 service-connections operated by 495 farmers who have access 24 hours per day, except in the dry season when there is need for restrictions in some areas.

Currently, surface water sources that are not earmarked for potable water use are to be developed by the BADMC through a US$3,000,000 technical assistance project. This project is designed to alleviate the irrigation and drainage problems of farmers in the regions of Codrington (St John), New Castle (St John) and River Plantation (St Philip).

D. Town and Country Development Planning Office

The Town and Country Development Planning Office has significant input in the implementation of OFWM. Any construction that may potentially impact the water flow over, or under land, has to receive planning permission from this department.

E. Water Resource Management Department

The Water Resource Management Department (a division of Barbados Water Authority [BWA]) has responsible for granting permission to any entity requesting to dig a well for irrigation purposes. The following factors are considered:

a. The location of the well in the water zoning areas – There are five water zones with varying water restrictions. A well may be located in Zones 3 to 5 but permission will not be granted for a well in Zones 1 or 2.

b. The potential groundwater yield from the aquifer

c. The present abstraction rate from the aquifer

d. The proximity of the proposed well to the BWA water supply wells to determine if pumping will negatively or positively impact BWA wells

e. Other requirements include the depth to the water table, size of pump, abstraction rate, and purpose of the well

The WRMD advises that persons have to be careful with harvesting surface water, since there is a delicate balance between the interface of fresh and salt water. If there is not enough fresh water, then salt-water intrusion will occur. It is estimated that only 20% of rainfall reaches underground aquifers, and it takes 30 days to reach underground aquifers in Zone 1 and 90 days in Zone 5. The condition of the limestone bedrock, suck well density, soil infiltration rates etc. will influence the speed of percolating water. To stem the rate of runoff, check dams can be used to reduce the speed of surface flows and allow more time
for percolation. Currently, a forecast model is being developed by the WRMD to determine the best fit between surface runoff and groundwater recharge.

**F. Enterprise Growth Fund Limited**

Farmers who wish to obtain financial assistance for OFWM can apply to the Enterprise Growth Fund Limited, which manages the Agricultural Development Fund (ADF). The Fund provides loans for working capital purposes, retooling, introduction of new technology and implementing best practices in the agricultural and fisheries sectors. If the farmer requires funding of US$75,000 or less from the ADF, they must complete an application form. Additional paperwork, in the form of a thorough proposal, is required if the farmer is seeking to obtain funding in excess of US$75,000. All of the agricultural projects that are received by the ADF are routed to the Ministry of Agriculture for technical evaluation. The length of time taken to complete the evaluation will have an impact on the processing time of agricultural projects.

**Water Rights**

No water rights issues were observed for surface water impoundment on Mr Nicholls’ farm. Water is captured from surface runoff from on-farm fields and a farm building, and not from sources external to the farm.

**Social Impact**

The A. T. Nicholls Farm employs ten persons. These workers carry out various tasks on the farm, including planting, harvesting and packaging of product for the retail market. Males are outnumbered by females by a 2:1 ratio and the ages range from persons in their 50s to those in their 20s (Figure 23).

![Age of Employees](image)

**Figure 23** Age of Employees

On average, the weekly wages range from US$150.00 to US$175.00 per week, based on a five-day work week. Within the community around the farm, there is the perception that agriculture is a dying occupation with little returns for a high output of energy and time. It comes as no surprise then, that there is a diversity of non-nationals employed on the farm (Figure 24).
The farmer believes that if there was no water harvesting in place, his staff compliment would be reduced by about 40%.

**Economic Impact**

**Savings**

Since the construction of the pond, the farmer has seen significant cost savings. He saves approximately US$3500.00 to US$4000.00 per year in irrigation water cost by using stored runoff water. The amount of rainfall determines the frequency of cleaning the filter bed, but on average, the farmer expects cleaning to be at least three times a year at a cost of US$360.00 annually. With this in mind, the farmer estimates the lifespan of the liner to be ten years. However, an analysis of diverted irrigation costs and net water savings in Appendix 3 shows that savings should be from US$66,674.10 to US$83,473.40.

**Year-round Cultivation of cash crops**

Apart from the monetary savings of the irrigation water supply, there is also the benefit of year-round production of cash crops, especially during the dry season. With the pond in place, its performance during the drought experienced in 2009–2010 was outstanding (Appendix 2). The water level in the catchment fell by 50% before the rains came back again. Since the price of vegetables is lowest in January to March, planting of cash crops that require irrigation is generally started in March, so that there is no shortage of water.

**Crop Yields and Production**

Mr. Nicholls had indicated that before the pond he relied on potable water in the dry season to irrigate cash crops and in the rainy season he fertilized with poultry manure. He was, however, limited with
respect to the amount of crops he could grow although the yields were good. There is no data for the crop yields before the pond but currently cabbage yields are between 8,000–9,200 kg/ha and carrots yields are from 31,000–46,000 kg/ha.

The current market potential for the packaged products of cane juice and coconut water is high, with production currently failing to meet the demand. Currently his production for coconut water and cane juice are listed in Table 7.

Table 7  Estimated Annual Production output for cane juice and coconut water.

<table>
<thead>
<tr>
<th>Month</th>
<th>Sugarcane</th>
<th>Cane Juice</th>
<th>Coconut Water</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Min (MT)</td>
<td>Max (MT)</td>
<td>Min (L)</td>
</tr>
<tr>
<td>Dry Season</td>
<td>21.9</td>
<td>29.3</td>
<td>11,640</td>
</tr>
<tr>
<td>Wet Season</td>
<td>11.69</td>
<td>17.53</td>
<td>6,200</td>
</tr>
<tr>
<td>Year Total</td>
<td>201.54</td>
<td>280.98</td>
<td>107,040</td>
</tr>
</tbody>
</table>

Environmental Impact

With construction of any man-made structure comes the need for an environmental impact assessment, or at least some consideration for the implications that may result from its placement. The environmental benefits that have so far been derived from having the catchment in place are:

- The water is free of chlorine, which is better for the crops and the environment.
- The sediment from the inlet sump is re-applied to the fields.
- There is less storm water runoff, which reduces the flooding potential for communities downstream.

Conclusion

Assessment of the OFWM

Surface Water Impoundment

- The site of the pond was not ideal because water should go into a primary pond before it reaches the main pond. The primary pond should be lined and have baffles to reduce the velocity of the water and encourage sedimentation of suspended solids. This would reduce the turbidity of the water entering the main pond.
- The present pond is irrigating 2.0 ha of cash crops utilizing both drip and sprinkler systems. Using a 1638 mm rain year with a 50% chance of exceedance, 12,730 m³ is required for irrigation and 16,040 m³ will overflow from the tank over seven months of the year. If an additional 2.5 ha of cash crops are irrigated for the same design year, then the pond would supply 28,640 m³ of irrigation water and will overflow during October to January and 7300 m³ will flow into the downstream watercourse. (Appendix 4)
- Fencing should be in place around the pond to prevent unauthorized entry.
The intake structure should be lined and properly sized to handle average runoff flows so that the turbidity of the water in the pond can be reduced.

**Irrigation**

- From the pump curve of the 2 hp electric pump (Appendix 5), at a minimum head of 8 m, the maximum flow is 25.5 m³/h. While this flow is adequate for the main control for either 0.4 ha of non-compensating drip or 12 sprinklers, it cannot facilitate both drip and sprinkler operations simultaneously (Table 8). For Option 1, an additional 16.63 m³ of water storage is required at the main control head, coupled with a 3 hp pump to provide a flow of 36.4 m³/h. However, if the sprinkler area is increased to 0.4 ha, an additional 43.6 m³ of water storage and a 5 hp pump at 57.64 m³/h will be needed.

**Table 8  Flow balance for the main control head**

<table>
<thead>
<tr>
<th>Option</th>
<th>Sprinkler</th>
<th>Drip</th>
<th>Storage tank</th>
<th>Deficit</th>
<th>Additional Storage capacity</th>
<th>Pump rate</th>
<th>hp</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>17.94</td>
<td>15.18</td>
<td>18</td>
<td>-15.12</td>
<td>-16.632</td>
<td>33.12</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>42.46</td>
<td>15.18</td>
<td>18</td>
<td>-39.64</td>
<td>-43.604</td>
<td>57.64</td>
<td>5</td>
</tr>
</tbody>
</table>

- There was an inadequate filtration at the main control head. The 2” disc filter cannot handle the flow rate and suspended solids in the irrigation water. Based on the data in Table 8, the farmer can consider installing in a gravel filter array (2 x 30 m³/h) with a secondary filter 130 micron or an automatic screen filter at the main control head and pump straight from the pump using the diesel pump.

- The inclusion of automatic or semi-automatic valves at the main control head would facilitate pulse irrigation. Even though the soil is a clay soil, the farmer indicated that the soils drain rapidly after rainfall, so applying water in small, frequent quantities would increase the irrigation and fertilizer application efficiencies.

- Pressure regulating devices are needed at the secondary control head so that drip and sprinkler systems can be operated simultaneously.

- There were no flow measurement devices at the main control head, secondary control head and pond.

- The use of mulch in uncultivated and cash crop areas should be practiced throughout the farm to reduce water requirements and soil erosion.

- The use of soil moisture sensors will greatly improve the irrigation application and scheduling practices.
**Drainage**

- There were no cut-off drains and check dams to reduce the velocity of surface runoff flows.
- Infield wells and drains need to be maintained on a regular basis.
- The planting of grasses such as *Chrysopogon zizanioides*, commonly known as Khus Khus grass, along the field boundaries would help to reduce the soil removed during rainfall events.

**Replication Potential**

The factors affecting the replication potential are as follows.

- The degree of technical assistance in design and implementation
- Competency of equipment operators in earth dam construction
- Funding

The innovative use of rainwater on the A.T. Nicholls Farm can be easily replicated on other farms, provided that adequate and timely assistance and funding is in place.

**Lessons Learnt**

Based on the interviews conducted with Mr. Nicholls and research done within the time allocated for this study, the following points are noteworthy:

1. The farmer was more concerned with the frequency of gluts and scarcity cycles and his retirement planning than with the effects of climate change. His greatest concern was making the best cropping decisions that would, in turn, benefit his retirement savings plan and continue to make the scheduled payments to his staff.
2. The water pond was never dry during the prolonged drought of 2009 to 2010.
3. Mr. Nicholls has no succession strategy in place for the continued operation of his farm. His siblings are not interested in taking over the farms’ management in the future.
4. In his experience with running this farm for 24 years, finding adequately trained staff has been a challenge. This is due to the perception that agriculture is a dying sector; a view held by most persons in the community. He found it difficult to find workers from the community.
5. Not all farmers are computer savvy, so data that can assist with irrigation scheduling and application has to be presented in a way that is readily accessible to the average farmer. For this to be a reality, irrigation extension personnel will be required to transfer the appropriate technologies. Extension education programs will be required to continuously update their knowledge base.
6. A department is required within the Ministry of Agriculture to properly plan, design, implement and monitor a comprehensive water management program. This new unit should work with other government agencies and non-governmental organizations to develop a master plan to manage the effects of climate change on agricultural water use.

7. The implementation of a regulated crop production programme is urgently needed in Barbados. Frequent glut and scarcity cycles will greatly affect the level of capital investment a farmer will undertake. If there is a guaranteed price structure and consistent supply, investment decisions about OFWM will become more feasible. Unseasonal rains and droughts will impact crop production and farmers will be forced to consider investing in greenhouse technologies, row covers and fabric mulching to guarantee consistency and price competitive supply.

8. The reduction in fossil fuel use for power generation has to be encouraged through the use of renewable energy. Mr. Nicholls is considering using photovoltaic and biogas technology; however, a technical assessment will have to be performed to facilitate the design of a system.

9. The present pond has potential capacity for irrigation expansion of an additional 2.5 hectares of cash crops in a 1638 mm rain year. The pond should overflow during October to December and 7,300 cubic meters of water will flow into the downstream watercourse. However, the intake structure needs to be properly designed as a pre-filter for the suspended solids in the inlet water. The reduced sediment load will extend the capacity of the pond to hold water.

10. Mulching of the bare soils and cash crop areas upstream of the pond will reduce the rill erosion observed on the farm. The use of a mulch-spreading machine will greatly improve the attractiveness of using organic mulch sold by Sustainable Barbados Recycling Centre for field application. A mulch-spreading machine is currently budgeted by the Ministry of Agriculture for purchase in 2012. This will protect the soil, increase the soil organic matter, reuse organic waste and increase the water holding capacity of the soil. The higher percentage of organic matter will mean greater binding of pesticides and improved nutritional value of the food crops produced.

11. The choice of pesticides is critical to maintaining water quality. Water is collected from field runoff and toxic pesticides can kill the aquatic life in the pond and can be transferred to leaves of crops via the sprinkler system.

Bibliography


Appendices

Appendix 1  Soil Test results for the year 2001

<table>
<thead>
<tr>
<th>ELEMENTS</th>
<th>SOIL ANALYSIS</th>
<th>INTERPRETATION GUIDE</th>
<th>FERTILIZER SUGGESTIONS</th>
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<td>Act. Acidity</td>
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<tr>
<td>Calcium</td>
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<tr>
<td>Magnesium</td>
<td>Mg</td>
<td>Below</td>
<td>Potash (K₂O)</td>
</tr>
<tr>
<td>Potassium</td>
<td>K</td>
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<td>Calcium</td>
</tr>
<tr>
<td>Sodium</td>
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<tr>
<td>Ca/Mg Ratio</td>
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<td>Mg/K Ratio</td>
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<td>Zinc</td>
<td>Zn</td>
<td>Below</td>
<td>Magnesium</td>
</tr>
<tr>
<td>Other</td>
<td></td>
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<td>Magnesium</td>
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*If cost to apply rates of Ca or Mg in first year are too high then strive to apply within 3 years.*

The annual amounts shown for fertilizer suggestion should be split into 2 or more applications.
## Appendix 2  Rainfall for Station ISTMICHA2 Lodge Hill, St Michael - Elevation: 108 m above sea level

<table>
<thead>
<tr>
<th>Month</th>
<th>Rainfall mm/mth</th>
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<td>Variance</td>
<td>2010</td>
<td>30 Yr Average</td>
<td>Variance</td>
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<td>176.3</td>
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Courtesy of [www.weatherunderground.com](http://www.weatherunderground.com) and the Barbados Meteorological Office
## Appendix 3  Annual Estimated Cost Savings for 1638 mm Design Rain Year

<table>
<thead>
<tr>
<th>Irrigated Land Area</th>
<th>Design 1638mm Rainfall</th>
<th>Over flow Potential</th>
<th>Total Cost Savings</th>
<th>O&amp;M Costs</th>
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<td>HA</td>
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Appendix 4  Stantec Model of Irrigation requirements for the A. T. Nicholls Farm

For 2 ha Irrigated Area

<table>
<thead>
<tr>
<th>Irrigation Zones</th>
<th>Runoff Factor</th>
<th>Total Area (ha)</th>
<th>Net Lake Volume before Overflow</th>
<th>Net Lake Volume at Month End</th>
<th>Total Runoff Volume / mth</th>
<th>Total Irrigation Volume / mth</th>
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<tbody>
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<td>Coastal Zones</td>
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For 4.5 ha
Appendix 5  Pump curve for a 2 hp electric pump.
E-Discussion Synthesis Report

Question 2: What are the specific requirements for managing national water resources in light of changes in the climate?

Thread builders:

➢ What have you done, or plan to do, differently with regard to managing the water you need/use?
➢ Is the legislative framework in your country promoting proper management?
➢ Are there policies or strategies that you will like to see implemented?

Moderator’s Comment:

The discussants were asked to deliberate on mechanisms for managing water resources at regional, national and individual levels. The discussion thread led to 18 postings. It was agreed that the policy environment is a determinant of water management efficacy; the expectation being that the policy would inspire implementation. The policy goals of the National Integrated Water Resources Management Policy of Trinidad and Tobago were proffered as an example of far-reaching legislation. Such policies are geared to satisfying and managing the growing demands of all water users in a sustainable, efficient and effective manner.

E-Discussion:

The national goal for a water sector should be to support socio-economic development through the integrated management of the water resources and the water environment (land, air, flora and fauna); satisfying and managing the growing demands for all water users in a sustainable, efficient and effective manner, while maintaining and/or enhancing the quality of the environment and the integrity of ecosystems; and minimizing damage and losses to life and property due to water-related disasters.

The examples of specific objectives for water resources management given were:

- To ensure sustainable development, meaning improving the quality of human life while living within the carrying capacity of supporting ecosystems
- To protect and support human health
- To protect and co-manage watersheds and wetlands as sources of water
- To ensure a supply of water of sufficient quality and quantity to meet the needs of all present and future legitimate users at a reasonable cost
- To ensure the fair and efficient allocation of water
- To promote conservation and wise use of water resources
- To establish financially self-sufficient, integrated, water resources management programmes
To establish an integrated framework for water resources management, particularly as it relates to planning and environmental management

To maintain and enhance the quality of Trinidad and Tobago’s surface, ground, and coastal waters

To restore natural water systems in forests, rivers, wetlands and coastal areas so as to restore water conservation capacity and maintain healthy ecosystems

To protect water systems from pollution

To prevent and minimize the impacts of flood, drought, and other water-related emergencies

To protect and enhance the enabling environment of natural water systems (i.e. land, aquifers and natural ecosystems)

To integrate the management and development of watersheds and coastal areas

To stimulate future economic development and private sector investment for poverty alleviation and sustainable livelihoods

To increase human resource and institutional capacity for water resources management

To promote joint ownership, partnership, and collective responsibility between government and the people in the management of the nation’s water resources

To promote timely and reliable data and information to inform the design of hydrologic and hydraulic systems

To stimulate research and development activities in water resources management

To promote public education and awareness throughout all levels of society in support of effective integrated water resources management

In terms of legislation and implementing organizations, three Jamaican examples were given, namely the Water Resources Authority, the National Water Commission, and the National Irrigation Commission. Respectively, they monitor the water resources in the country, are responsible for the domestic and commercial supply of water, and manage sewerage and irrigation. These three are responsible for the licensing, extraction and distribution of potable and irrigation water.

Although the legislative framework is in place, enforcement is a major challenge. The Natural Resources Conservation Authority and the Forestry Department are responsible for the management and monitoring of watershed management units in the country. However, most of the grey water generated from domestic, commercial and sewerage treatment systems is not utilized. It was suggested that an education campaign and incorporation of the tenets of proper water resources management ought to be prioritized. Much of the irrigation water is used in the production of sugar cane, banana, pasture and vegetable and for aquaculture.

The question was posed, within the thread, as to the degree of sensitivity within the agriculture community that their policy requests are not given priority. Agriculture has been at the bottom of the
totem pole of requests because the policy makers have not seen it as having the same economic importance as other sectors. The respondent implied that the attitude is slowly changing as people realize that importing food is going to become more and more costly. There is a real possibility that imported food may become unavailable due to rising populations of middle classes in Asia, who will demand greater and greater shares of the food markets.

Policy was also viewed as another of the mechanisms through which poverty alleviation could be effected. One could fight poverty by improving access to agricultural water for its efficient use. Insecure access to reliable, safe, and affordable water keeps hundreds of millions of people from escaping poverty. Most of them rely directly on agriculture for their food and income.

Broadly conceived, water-related, policy, poverty-reduction strategies were seen to entail four elements:

1. Empowering people to use water better and targeting the right groups
2. Ensuring the right to secure access
3. Improving governance of water resources
4. Supporting the diversification of livelihoods

In regions like the Caribbean, where agriculture still constitutes a significant proportion of the rural economy, water management in agriculture will remain a key element in strategies to reduce poverty. Smallholder farmers possess the greatest unexploited potential to directly influence land and water use management. The group was urged to focus on livelihood gains achieved by the use of small-scale, individually managed water technologies. These include small pumps and innovative technologies such as low-cost drip irrigation, small affordable pumps, and small-scale water storage. These are affordable, even for some of the poorest members of the community, and can be implemented almost immediately, without the long delays of large projects. Private investments in pumps have improved the livelihoods and food security of millions of farmers and pastoralists in Africa and Asia. In the long run, these can be viewed as a first step, followed by additional investments in infrastructure.

Carefully implemented clarification of water rights was seen as a way to ensure secure access to water for agriculture for poor women and men. In certain circumstances, collective water rights might be preferable to individual water rights. Redistributive policies can give the rural poor access to assets, markets, and services. Acknowledging customary laws and informal institutions can facilitate and encourage local management of water and other natural resources. The capacity of people to manage their water resources can be enhanced through specific training. Local management should be integrated with basin, regional, and national institutions—and based within the broader context of rural development.

Small water management systems, built and operated by communities or individuals from groundwater, river water, and wastewater, are vital to many poor farmers but often are not officially recognized. Increased visibility of irrigation and water management of these informal systems will influence governments to provide policy and technical support and help to ensure poor farmers’ continuing access.

Policymakers need to focus on both design and development of water resources infrastructure from a multiple-use system perspective. By doing so, they can maximize the benefits per unit of water for poor
women and men, and ensure that institutional and legal frameworks guarantee the participation of rural people and marginal groups in all phases of policy development and decision making for infrastructure investments. Multiple-use systems for domestic use, crop production, aquaculture, agroforestry, and livestock effectively improve water productivity and reduce poverty.

A respondent believed that fisheries should be better integrated in water resources management. They are an important source of livelihoods and nutrition. The value of freshwater fish production to human nutrition and incomes is far greater than gross national production figures suggest. The bulk of production is generated by small-scale activities, with exceedingly high levels of participation not only in catching and farming but also in the ancillary activities of processing and marketing. Livestock, too, needs to be better integrated in water resources management.

Agricultural water management investments alone cannot eliminate poverty, so water management approaches need to be better integrated into broader poverty reduction strategies.

A participant expressed surprise that water use for agriculture was not in the top three priorities stated by leading technocrats in a recent conference in Trinidad. Apparently presenters were primarily interested in three major areas where dwindling water resources are concerned. They suggested that in the hierarchy of needs, water should address the following:

1. Potable use – sheer necessity for life
2. Health and sanitation
3. Environmental management

The e-group did not challenge the statement that one should probably look at reviewing the categories and include appropriate sub-categories that are more relevant to the regional situation.

**Strategies**

Rainwater harvesting is critical to the sustained development of small open economies where it is costly to pipe and truck water to some remote farm with elevations and terrains that will send any budget into ‘the red’. The few ideas given are listed verbatim:

1. How about respective governments and funding agencies embarking on a programme(s) to identify strategic locations in the various regions and assist communities, be it farming or otherwise, to build catchment tanks for harnessing and storing water.

2. Respective governments should make it a policy for water-harnessing systems (not just storage) to be included in all building plans. Buildings cannot be approved unless this requirement is fulfilled.

3. There should be an overall plan to develop desalination plants having proper environmental controls to provide another source of water.

Attitudes to the harvesting of water differ throughout the Caribbean. The Moderator confided that he had conducted farmer-training courses in every corner of Belize, whenever it was mentioned that ALL water in Trinidad and Tobago belongs to the Water Authority the farmers stared in disbelief. In Belize, they can
sink wells and build ponds without too much difficulty. Respondents reminded the discussion group that legislation exists in all territories regulating and licensing the extraction of water from surface and underground catchments.

For example, the management of water in Jamaica is vested in the Water Resources Authority. This does not mean that one could not harvest water from streams for irrigation. However, large-scale extraction of water and the sinking of wells are done based on approval and provision of a license.

One of the most forceful points made was the practicality of spending resources on rainwater harvesting where genuine farmers live and work and where they continue to produce most of the food. As opposed to Governments, the Inter-American Development Bank, World Bank and technocrats spending significant sums to dig wells, buy pumps and pipelines, then having to beg the people living in these low-lying areas to farm.

The policy discussion was framed against insights on the Global Water Project (GWP) and Integrated Water Resources Management (IWRM). The four overarching goals of the GWP and the thirteen Dublin Principles of the IWRM were also shared with the group.
Panel Discussion: Technical session II

CHAIRPERSON:

Mr Adrian Trotman, Caribbean Institute for Meteorology and Hydrology

RAPPORTEURS:

Maurice Rawlins and Renortha Penny

Summary:

- The CARIBSAVE Climate Change Risk Atlas
- There are research gaps in the examination of water resources in the Caribbean
- Recommendation – integrated water resources management
- Agriculture should be a priority in water allocation

Discussion Notes and Speakers

Mr Adrian Trotman (CIMH, Barbados): Can you provide more details on the Climate Change Risk Atlas?

Dr Matthew Wilson (UWI, St Augustine): The Climate Change Risk Atlas is currently in its first phase. It is developing risk profile for 15 Caribbean countries. It is putting together the current situation in each country with respect to livelihoods, health, water, agriculture. Questions are being asked such as How much water does a country currently have? Issues faced? Institutional needs? Rainwater harvesting used? How much groundwater available etc. It is an ideal reference point in determining the way forward. It does not make recommendations – further assessment is needed in order to make recommendations. Information is available on the CARIBSAVE website.

Dr Mark Bynoe (CCCCC, Belize): Would it be opportune to develop a risk management framework to build on the work of the atlas? There is a recurring debate on the contribution of agriculture in relation to other sectors according to fact-based analysis. Too often analysis is piecemeal. There needs to be adequate accounting for natural resources, including water and we need to take this beyond the scope of water and discuss the contribution.

Dr Matthew Wilson: Point agreed. There needs to be a next step beyond the atlas. The idea is that follow-up would include a risk management framework. Quantification is inevitable. IWRM tries to do a holistic analysis and assessment but data is an issue.

Dr Leslie Simpson (CARDI, Jamaica): It is a question of focus. We are managing some of the water in the watershed now – are we talking about using 100% of the water resource? We should focus on what is the total supply available and determine what that is before allocation to different sectors is undertaken.
Need to improve water governance and need to have a comprehensive idea of how much water resources are present. We need to understand and data is key.

Mr Steve Maximay (Workshop Facilitator): Based on e-discussion responses people were considering what they perceived as 100% of water available. There are attempts to quantify how much water is collected, lost and used; albeit on a small scale. There have been several localize assessments of need.

Dr Lystra Fletcher-Paul (FAO, Guyana): Feasibility studies have been undertaken in six Caribbean countries on water harvesting. In Grenada, Carriacou, Jamaica there was mapping of the areas where harvesting is feasible. In Belize there was the development of irrigation and drainage policy; determining first where irrigation was feasible, and what type of irrigation was possible before discussing policy.

Mr Stanley Rampair (National Irrigation Commission, Jamaica): 35-36% of water resources are exploited in Jamaica. We need to understand on the ground, the realities of water harvesting. Scale is important to consider. Large areas are needed for water harvesting and we need to consider the conditions and type of agriculture. We are now implementing water harvesting in Pedro Plains. It is expensive but these are bauxitic soils, the climate is excellent and therefore there is good potential.

Mr Steve Maximay: There are areas with concentrations of farmers that can benefit from less expensive, more low-tech (less engineering-complex) systems, that some view as part of the solution. In this context, rainwater harvesting makes sense i.e. a community that is already into farming. Context is important. There is a case for focusing rainwater harvesting on areas with interested farmers.

Mr Ramgopaul Roop (TTABA): Just last November CTA ran a seminar on Integrated Water Management for Sustainable Agriculture. There is so much information. How do we go forward in using the information that we have already have from sources such as the Global Water Partnership and CTA?

Mr Steve Maximay: Information does not solve problems; informed people do. We need to inform people to effect change. The Global Water Partnership was invited to join e-discussion. They did contribute and took on a monitoring role. In the context of this workshop, the e-discussion included the views of stakeholders who were not able to take part in eth discussion.

Dr Leslie Simpson: The result of the workshop with respect to the policy briefs and strategies will be developed. We need to discuss more wastewater management in agriculture. The Prince of Orange said that, “There is no waste water only water that is wasted”.

Dr Lystra Fletcher Paul: FAO Caribbean Water Policies Spanning The Spectrum gives examples of countries in the Caribbean and their issues in water management.
TECHNICAL SESSION III
Climate change with particular reference to the Caribbean

Global Climate Change caused by atmospheric pollution by greenhouse gases is predicted to significantly affect the Caribbean region. Kattenberg et al. (1996) have forecast a rise in temperature of the Caribbean Sea by 2 °C in the 2050s and 3.1 °C for the 2080s. The most significant outcome of this is expected to be a rise in the levels of the sea of about 5 mm per year. The main effects on the climate and environment are likely to be as follows:

- Less rainfall with its greater concentration in the wet seasons and the dry seasons becoming drier
- Higher atmospheric temperatures with greater evapotranspiration losses
- Rise in sea level with resulting flooding with salt polluted water in low-lying coastal areas, aquifers and river courses, and coastal erosion
- The above changes could lead to significant modifications in land use, especially in the newly flooded areas

In this scenario, it is imperative that there is greater production of food to achieve food security, and this can only be done through irrigation use to make food production as independent as possible of the seasonality of rainfall. Presently, there is some effort being made in this regard by utilizing high production technology systems in growth houses (protected structures) with drip irrigation and fertigation but only with vegetables crops. It is only in Guyana, Suriname, Cuba, the Dominican Republic and, to a lesser extent, Jamaica that limited staple food production is being achieved through irrigation.

Effect of expected climate change on the soils and agricultural environment

There are a number of soil, water and environmental features that could be affected in one way or another by a warmer climate. Trotz et al. (2001) outlined some of these features and the nature of these changes that would have implications on water use and management as the region proceeds with the goal of achieving food security.

Changes in precipitation and temperature, and hence evapotranspiration, will be expressed in soil water content. Increases in CO₂, through its stimulation of plant growth, will result in greater water use. Enhanced drying through higher temperatures can cause drought conditions even in normally moist areas.
In some places with drier dry seasons than normal, lower soil water contents would be expected and conversely, waterlogging may be experienced during wet seasons, thus, a set of deficient soil water conditions will be experienced as a result of climate change.

**Soil temperature** will undoubtedly increase because of higher atmospheric temperatures. In colder areas, this will be a distinct advantage as it would lead to enhanced biological activity and would result in greater production; but not in Caribbean areas. The main effect of an increase in soil temperature in Caribbean conditions would be an increase in evaporation rate, thus creating more demand for water.

**Soil workability** is largely dependent on soil water content plus some other aspects of soil behaviour. Any changes that will affect soil water content will influence the workability of the soil. For instance, increases in precipitation in already wet areas could reduce the workability and would have an overall negative impact on agricultural production. Likewise, in already wet areas, some reduction in precipitation can make soils more workable. The soils that would be most affected are the high activity clay soils, which are abundant in the region.

The adverse management features, which are characteristic of the wetting and drying cycles of these soils, would be more greatly expressed with external variations in precipitation and higher evaporation. These changes can lead to the evolution of different farming systems than those currently practised.

**Soil structure**—which is the arrangement of soil components resulting from natural soil forming processes—is influenced by organic and inorganic soil constituents, tillage operations, activity of soil organisms and physical processes such as wetting and drying. It is obvious that since so many interrelated factors are involved in the development of soil structure, climate change will impact on the formation and nature of the resulting structure. Again, the high activity clay soils would be most affected, since excessive drying would lead to the development of larger and deeper soil cracks, with implications on the movement of water and solutes caused by rainfall or irrigation. Changes in porosity and rate of water movement take place as a result of soil structural changes. Soil aggregates can also be made stronger or weaker and will then increase or decrease the difficulty of soil components to be dislodged and moved by agents of erosion.

Changes in evaporation and rainfall regimes can increase or reduce **soil salinity** with resulting land degradation and decrease in crop yields. Areas with reduced rainfall but increased evaporation can develop soil salinity and bad irrigation practices can make this worse, especially if the irrigation water is rich in dissolved salts. Along low-lying coastal areas, sea level rise can contribute to already existing salinity problems.

Enhanced leaching of cations in areas with higher rainfall and rainfall intensities can cause soil acidification. In any event, this process will take place at least during the wet seasons with increased rainfall. The long-term effect of this loss of soil fertility will have a debilitating effect on the soil. To correct this problem, other aspects of soil management to maintain soil fertility would have to be developed.

Increases in rainfall intensities and amounts and/or decreases in soil infiltration, directly or indirectly due to climate change, will influence **soil erosion** due to changes in runoff. Changes in soil structure will be
influential in the quantity and nature of runoff. Climate change is likely to increase both wind and water erosion in the future at many locations.

**Soil organic matter**, which is made up of partly decomposed plant and animal remains, plays a pivotal role in the formation and stability of soil structure; modifying the nature, size, shape and stability of soil aggregates. With its role in determining the physical structure of the soil and its other physiochemical properties, it influences the water-holding and other water transmission characteristics of the soil and indirectly controls soil processes such as leaching, runoff and erosion.

Temperature and precipitation dictate the rate of decomposition of plant and animal remains and therefore climate change will impact on the quality and quantity of soil organic matter, as would any change in land use patterns.

**Impact on water resources**

Caribbean water resources are likely to be significantly affected by the projected climate change in several ways. The supply could be reduced by a decrease in rainfall, while at the same time the demand is likely to be greatly increased from all users, particularly agriculture. Losses from evaporation due to higher temperatures and from runoff caused by higher intensity rainfall are likely to increase. The water quality would also be in serious danger of deteriorating by the rising sea level and consequent intrusion and pollution by saline water in estuaries, aquifers along river courses and even in irrigation systems. Coastal erosion would also become more important, leading to displacements and great economic loss by coastal communities and those in low-lying wetland and dryland areas.

The main environmental effects of the projected climate change and sea level rise could be the following:

- Direct inundation or submergence of low-lying wetland and dryland areas
- Increase in salinity of estuaries, aquifers and river courses in low-lying areas
- Higher coastal water tables

The greatest difficulty would be the protection of fresh water from pollution by saline water intrusion as the sea level keeps rising, of lowland areas such as in Guyana, Suriname and Belize. Throughout the region, but particularly in the small island states, a substantial proportion of the economic activity occurs within a few kilometres of the coast and therefore seawater intrusion, even to a small extent can be disastrous.

In order to ameliorate the full impact of these negative forces on the future supply of fresh water, it is necessary that corrective and preventative measures be taken when it is not too late. Measures to reduce waste and increase the efficiency of use will make more water available for other important uses, even with the present supply situation.

**Water availability and use in a drier Caribbean**

Rainfall is the primary and dominant source of water for the region. It is utilized directly as rainfall, stored and utilized as needed as groundwater, or stored in aquifers and utilized through wells and
pumping. The rainfall received is rapidly drained by the many rivers that exist caused by the steep terrain, especially so in the Leeward and Windward Islands with the result that the rivers can be dry soon after rainfall incidents. In a few instances, the rivers extend up to the central highlands and consequently, these have a better water supply. In the continental areas (Guyana, Suriname and Belize), there is much more flat lands, which result in more impeded surface drainage and flooding can occur. The result of fast drainage is that the water received as rainfall is rapidly lost unless it is stored, which is hardly being done at present.

Singh (1997) has pointed out that several models have indicated a general tendency towards more extreme rainfall conditions, that is, a decrease of rainfall during the dry season and increase during the wet season for the Caribbean region. A decrease in rainfall during the dry season will mean a decrease in the availability of fresh water supplies because of less runoff into rivers and less recharge to aquifers. This should necessitate a reduction in extraction rates, with the consequential negative impacts on domestic use and industrial and agricultural activities. A decrease in runoff to rivers and recharge to aquifers will induce further saline intrusion in both cases, resulting in even more damage to aquifers and contamination of fresh river water for longer distances upstream.

An increase in rainfall during the wet season can have both positive and negative effects. An increase during the wet season will mean rainfall of a higher intensity; as far as groundwater is concerned, higher intensity rainfall does not necessarily mean more availability for the aquifers, as the capacity and rate at which the aquifers can absorb recharge are both limited. This means there will be more direct runoff into rivers, which can result in flooding of important agricultural and residential areas. On the positive side, measures can be taken to store the excess rainfall during the wet season to be made available to supplement supplies during the dry season.

As a result of the Intertropical Convergence Zone and other atmospheric factors affecting weather, the rainfall is strongly seasonal with the first half of the year being dry and the rest of the year wet. The continental and equatorial areas of Guyana and Suriname, on the other hand, have two wet and two dry seasons, which at least gives a better distribution of the rainfall each year.

Most of the area is in the hurricane belt and hurricanes can occur from June to October each year. Storms and high winds are also more common with time. When they occur together, heavy rains are usually received, which are associated with disastrous landslides and floods.

Another important factor that affects the rainfall and its distribution throughout the region is the occurrence of most of the islands in a north-south orientation with central highlands. With a prevailing North-east Trade Wind, these factors lead to an exposed (eastern) side of the islands and a rain-shadow western side. A fairly well defined dry season occurs during the first half of the year, with the annual rainfall for St Vincent, for instance, ranging from about 3,750 mm in the Central Mountains to as low as 1,500 mm near the coast. This distribution superimposed upon the basic shape of the islands has resulted in a zonation of rainfall in concentric belts around the central mountain core (Ahmad 2011). The highest mountains and the wettest areas occur in Dominica, in which the central highlands have the highest peaks with annual rainfall in these areas exceeding 7,500 mm. Unlike islands such as Dominica and St Lucia, the western part of St Vincent is mountainous with steep slopes and the gentler, longer slopes are on the
eastern side. Thus, the western or leeward side of the island receives more rainfall than the windward or eastern side.

The total annual rainfall received for most of the territories in the region might indicate a good supply of water to support agriculture at current levels. Unfortunately, this rainfall is very unreliable in amount and in distribution and the projected climate changes for the future will add to these uncertainties. At present, only a small percentage of the water is used and, except for the calcareous countries, most of it is lost by runoff.

The attitude to water use in the Caribbean up to the present is that its supply is not limiting. However, it is projected that by 2020, due to natural increases in demand on the one hand and a decrease in supply on the other, there is likely to be a shortage of this essential commodity. It is important that these likely possibilities are highlighted as this would lead to a different outlook on the use and conservation of water.

Before considering the various measures that can be taken to increase water use efficiency in the region, it would be pertinent to briefly examine what happens to the water that falls as rain. This is determined also by the way the rainfall is received. Firstly, there is evapotranspiration from the bare soil surface and from vegetative cover.

Water also infiltrates and percolates and together, these processes are known as hydraulic conductivity. Evapotranspiration is important in maintaining turgidity in the plant system, which is necessary for growth and plant metabolic activity, and infiltration and percolation are important in replenishing stored water in the soil, thus providing the plant with a constant supply of water to avoid lack of turgidity and wilting.

The other important form of loss is by runoff and the greater the slope, the more profound is this loss. The norm at present is for runoff from elevated and sloping land to be uncontrolled and this is responsible for catastrophic soil erosion, along with indiscriminate land clearing for farming activity and for construction. This also leads to uncontrolled flooding at the lower elevations in river floodplains, pollution of water, destruction of crops and loss of property among other consequences. In the rainy season, the supply of water through rainfall can be overwhelming but in the dry season, there is very inadequate available water. Clearly, supply and demand of water throughout the year should be rationalized to alleviate wet season flooding and dry season drought. The real answer is storage of water in the wet season for use in the dry season and controlled disposal of runoff in the wet season.

The intensity of the rainfall is very important in determining its effectiveness in meeting water demand. High intensity rains reinforced by strong winds is almost the norm in the Caribbean. This type of rainfall is destructive to the soils if they are unprotected. It can also disrupt aggregates on the soil surface, which can lead to crust formation, decreasing infiltration and increasing erosion. On the other hand gentle rains, especially if intercepted by vegetation or soil mulch, will have maximum effect in increasing infiltration and replenishing available soil water.

At the present time, water storage in the region is largely confined to a few strategically located reservoirs, the water being used for domestic purposes. Hardly any stored water is used for irrigation except for Guyana and Suriname.
At present, probably as much as 80 per cent of rainfall is lost through uncontrolled runoff. The important question is, how much longer can the region so poorly utilize this valuable resource? For dynamic and prosperous agriculture—and in keeping with the stated goal of achieving food security—as soon as possible, production must become independent of the natural weather patterns. Good and effective water management is therefore an essential prerequisite for successful agriculture and this has to be improved and developed in every territory.

**Projections of future conditions affecting water use**

Among the factors limiting growth, the availability and use of fresh water is very likely to become one of the most important. The demand for water will come from all areas of human activity. In the domestic and municipal areas, the demand will increase rapidly as the population increases and the living standards keep rising. With tourist developments, this would also demand more and better water supplies. The industrial sector is likely to expand significantly at least in some territories and this would make demands on available water. However, it is in agriculture area that the greatest demand for water will come.

With the exception of Guyana, Belize and Suriname, the CARICOM region is a net importer of food, including very basic products. Even these three mainland countries import some food products, especially white potato, processed foods, beverages and wheat flour. Presently there is much interest in the region in achieving food security and there is some effort being made in increasing production through irrigation. However, this increase is occurring only in the area of vegetable production, employing high production technology systems utilizing growth houses (protected structures), drip irrigation and fertigation. In Guyana, Suriname, Belize, and to a lesser extent Jamaica, limited food crop production is being achieved through irrigation. There is some irrigation also being practised in the region for the production of banana and sugarcane. At the present time irrigation is little used in the Caribbean, with the exception of Cuba and the Dominican Republic, but the demands for it is likely to change drastically when the region fully embraces the task of achieving food security.

**Water availability and management**

In considering strategies for soil water management the following aspects of accessing and using the available water must be considered:

- Water harvesting
- Irrigation and water quality
- Water quality
- Caribbean experience in using and maintaining irrigation water quality
- Agronomic considerations in soil and water conservation and use
- Soil surface manipulations
- Soil erosion and conservation
- Protected agriculture
- Crop selection and other agricultural options
- Livestock production
- Aquaculture
• Policy for, and management of, water resources
• Water management systems
• Soil water management systems

Water harvesting

The term ‘water harvesting’ is used to describe situations in which surface water, in the form of dew or rain, is intercepted and stored in tanks and used for very restricted, life-saving irrigation, as done in the arid and semi-arid regions of India. Other forms of water harvesting can be seen in restricted areas in the Caribbean, where parts of hillsides are concreted and the water falling as rain is intercepted and stored in small reservoirs for use in irrigation or for domestic purposes. Another occurrence of water harvesting has been developed, again in the drier areas where the water that falls as rain on house roofs or on small hillsides is collected and stored in cisterns or small reservoirs, commonly constructed under the house. This is done in Antigua and the Cayman Islands and possibly elsewhere as well.

A form of water harvesting also occurring in dry climates and in areas with calcareous rocks, as in The Bahamas, the Cayman Islands and Belize, is the collection of water in solution cavities (cenotes) in the rocks from where it may be used either for agriculture or for domestic purposes. These means of water harvesting contribute to overall water supply and economic situation but their application and use must now be decreasing in the region in favour of more convenient means of obtaining fresh water.

The construction of farm ponds, preferably in association with mini-watershed protection projects, could be useful in collecting and storing water for small to medium size farm development. It is surprising that this form of water storage is not yet more developed in the region. In the early 1960s, farm ponds were established in many key locations in Central Antigua but these were not maintained and utilized at the necessary level and the ponds became silted and overgrown with weeds. Only few are still in use. In some cases, the water had too high a concentration of soluble salts and in such instances; the water was unsuitable for use. At this time, the Trinidad and Tobago Government is constructing strategically located farm ponds throughout the islands and it is expected that these will provide some irrigation water.

The major form of water harvesting is the creation of reservoirs in strategically located areas, selected on a watershed basis in which water will collect from drainage through particular river systems. Examples of such reservoirs are the Caroni-Arena, Valencia and Navet reservoirs in Trinidad, the Mona and Hermitage reservoir in Jamaica, the Roseau Dam in St Lucia, and the Postworks reservoir in Antigua. In Guyana and Suriname there are extensive reservoirs in the southern limits of the coastal plain, the water being impounded by earth embankments at the northern limits and along the river banks and by more elevated land at the southern bounds of the coastal plain. At the present time, the water stored in the reservoirs is mainly used for domestic purposes, except in Guyana where agriculture is probably the main user.

The construction and use of reservoirs for water storage in the Caribbean is not developed as much as it should be and there is now great emphasis being given to desalination of seawater as a quick solution for domestic use and even for wider applications. Apart from the economics involved in producing and distributing desalinated water, this is not addressing watershed protection problems in the region. The watersheds in the region are progressively degenerating due to land clearing and occupation of the land for housing and agriculture; increasing soil erosion follows these activities caused also by the high
intensity rainfall that is becoming the norm. The watersheds have to be protected from the impact of the rainfall by collection of the runoff in strategically located reservoirs and by structures to regulate the safe drainage of excess water from these areas. Watershed protection has to be done at all levels, from small to large, and this has to be the focal point of soil and water management in the Caribbean. If the drainage of water in the watersheds is regulated and the use of the land includes adequate conservation measures, the deterioration of the environment that is now occurring would be stopped and even reversed. Desalination is therefore not an alternative to water harvesting, although it may have applications in special circumstances.

**Irrigation and water quality**

Irrigation is the application of water to soil for the purpose of providing a favourable environment for plant growth. Up to the present, agriculture in the region is mainly rain fed with farmers being able to produce one crop per year, especially for the longer duration food crops such as cassava, sweet potato, yam, eddoe and dasheen. In order to enable farmers to be more productive and the consumer to be assured of a better distribution and supply of produce, agriculture must become weather independent as far as possible. Without this facility, the region may not be able to achieve food security.

So far, some irrigation is used for the production of the export crops, sugarcane and banana, and for rice in Guyana, Suriname and Belize. Recently there has been some interest and expansion in its use throughout the region, mainly for vegetable crops but irrigation has not been extended to production of other staple foods.

The existing conditions of soil permeability, the crop to be grown, topography, availability and quality of water, soluble salt content of the water and salinity status of the soil are all factors to be considered in deciding on the method of irrigation. The four principal methods used for the application of water are flooding, furrow, sprinkling and drip. The flood method is preferred if salinity is a serious problem, and there are variations to the design depending upon the crop and land layout. Furrow irrigation is well adapted to row crops and is suitable where the topography is too uneven or steep for other methods. Sprinkle irrigation is generally more costly but depending on the quality of the water, it may be difficult to apply enough water to achieve adequate leaching. The drip method is the most costly to install but it makes the most economic use of water, which can be applied directly to the roots of the crops. The water is kept away from the foliage thus discouraging the spread of plant pest and diseases. It does not allow for any appreciable leaching and therefore only the best quality water should be used to prevent salinity increase in the soil.

After deciding on the method of irrigation, the next important decision is the amount of water to apply to meet the needs of the plant and the soil. It is important to avoid using too much or too little water. Too much will cause a waterlogged root environment and would lead to a breakdown in soil structure; plant, pest and diseases will also be encouraged and in some instances it could lead to soil salinization and soil crust development. Too little water would not supply enough to the crop for its best growth and production and would lead to soil salinization.
For good irrigation control, water budgeting is necessary in which the requirements of the soil and the crop are met. The consumptive use of the crop and the leaching requirement of the soil must be met and allowance must also be made for rainfall during the period of crop growth.

**Water quality**

Since dissolved salts move with water (leaching), once water is added to soil as in irrigation, the dissolved salts can accumulate, as it is mainly the water that is taken up by plants. Irrigation, leaching and drainage should be considered collectively if maximum efficiency is to be obtained in irrigation use. In humid and sub-humid regions, when irrigation is provided salinity is usually of little concern because rainfall is sufficient to leach any accumulated salts. However, in semi-arid or arid regions, salinity is usually an ever-present hazard and must be taken into account at all stages of planning and operation. In the Caribbean, all these conditions are available and must be considered. The higher the salt content of the water, the greater the amount of water that must drain through the soil to keep soluble salt content at or below the acceptable level. For efficient irrigation, the soil must be free-draining otherwise the required leaching rate will not be achieved.

The concentration and composition of dissolved constituents in water determine its quality for irrigation use and a full understanding of this factor is necessary for successful irrigation. The characteristics of irrigation water that are most important in determining its quality are (United States Salinity Laboratory Staff 1954; Dargan et al. 1981):

- Total concentration of dissolved salts
- Relative proportion of sodium to other cations
- Concentration of boron or other elements, which may be toxic to plants
- The concentration of bicarbonate ion as related to the concentration of calcium and magnesium

The total concentration of soluble salts in waters can be adequately expressed in terms of electrical conductivity, which can be readily and precisely determined as micro-Siemens per cm (mS/cm) (formerly milli-mhos/cm). In general, all waters that have been traditionally used for irrigation have electrical conductivity values less than 2,250 mS/cm, (equivalent to 1440 parts per million). The higher the concentration of soluble salts, the greater the amount of water that is needed for leaching. For instance, if a sensitive crop like beans is being grown, 56 per cent additional water is needed for leaching plus the amount needed for the consumptive use of the crop but for a tolerant crop like cotton, only 14 per cent above the consumptive use of the crop is needed for leaching. The situation is that most of the food crops of the tropics are in the sensitive or moderately sensitive range of salinity tolerance but more information is needed on this aspect. The main conclusion is that the leaching requirement of the soil must be taken into account if irrigation is contemplated on a more permanent basis.

The relative concentration of sodium to other cations is important in determining the alkali hazard involved in the use of water for irrigation. If the proportion of sodium is high, this cation becomes more important in exchangeable form and this increases the alkali hazard. Conversely, if calcium and magnesium predominates, the hazard is low. To the extent that this occurs, the soils becomes alkaline and are often characterized by poor tilth and low permeability. The old expression, “hard water makes soft
land and soft water makes hard land” is applicable in this case. This property of the water is known as the sodium adsorption ratio.

Boron is a minor element that is highly toxic when it is present in the irrigation water above the tolerance limit. The element in toxic levels is commonly found in salt affected soils. The problem is that if boron is allowed to accumulate in soils, it is very difficult to remove by leaching since borates are insoluble in water. The occurrence of boron in toxic concentrations in some irrigation waters makes it necessary to consider this element in assessing the water quality.

The concentration of bicarbonate, as related to the concentration of calcium and magnesium, is an important aspect in determining the quality of the water for irrigation because there is a tendency for calcium and magnesium in solution to precipitate as carbonates as the soil solution becomes more concentrated. This reaction does not go to completion under ordinary circumstances but in as much as it does proceed, the concentration of calcium and magnesium are reduced and the relative proportion of sodium is increased, leading to alkalization of the soil.

In order to assess any water for its suitability for irrigation, the following properties must be routinely assessed:

- pH
- electrical conductivity
- calcium, magnesium, sodium and potassium
- carbonate and bicarbonate, sulphate, chloride and nitrate
- boron

Caribbean experience in using and maintaining irrigation water quality

GUYANA AND SURINAME: The water stored in coastal reservoirs that is collected during the wet seasons is of excellent quality for irrigation, having very low contents of dissolved salts. However, during dry seasons, and depending upon their severity and amount of water stored, salt water can encroach along rivers from the ocean and pollute the water in the rivers as well as in irrigation channels. In very bad years this pollution can be very serious, making the water unusable. Rice and sugarcane crops are largely affected. The varieties of rice that are popular are sensitive to salinity and this has made farmers very vigilant. Once salt affected water floods a field, it will take at least two years before the decreasing effects on crop performance are not evident.

TRINIDAD AND TOBAGO: With cessation of sugarcane cultivation, irrigation for other crops is only now becoming important. Surface water in small reservoirs and in some restricted cases, domestic water, is used with trickle irrigation. The water used so far is of good quality with respect to salinity.

BARBADOS: Groundwater is utilized for irrigation; this is the same source for domestic and municipal water supply. There are two potential hazards in this situation, one being over-pumping of groundwater leading to saline water intrusion and the other is pollution of the groundwater from pollutants on the soil surface. Investigations show that neither of these occur at the present time (Wood 2006). The water
economy in Barbados is very good since surface drainage is directed underground through wells and losses by runoff are minimal. About 30 per cent of the precipitation is stored as groundwater.

**Windward Islands:** Surface water is used for irrigation, usually from constant-flowing streams. The water is of excellent quality but its supply is not constant and is unreliable. With increasing irrigation, some storage would be necessary.

**Leeward Islands:** Surface water and domestic water are used. In Antigua, some use is made of small reservoirs (farm ponds). With the exception of Antigua, very little irrigation is practised. The quality of surface water in Antigua should be regularly checked because there is some salt-water pollution already occurring.

**Jamaica:** Groundwater from springs and wells and surface water from constant-flowing streams are used. The water originating from the central limestone plateau of the island is usually of good quality. There is one significant spring at Caymanas, which yields brackish water not suitable for irrigation. The water at lower elevations obtained by pumping, supply much of the water for both domestic and agricultural use. Unfortunately, some time in the relatively recent pest, the water was over-pumped and was used for growing of sugarcane and other crops in the Clarendon Plains and St Catherine. For some time it was also used for production of banana. Considerable salinization of the soils resulted and in the present situation of water availability in this part of Jamaica, the satisfactory reclamation of these soils may never be achieved. About 9,000 ha of land have been salinized in this way and are now out of production. At least this should serve as a reminder to the region that if irrigation is being used, proper monitoring and management of the water resources must be employed.

**Cuba and the Dominican Republic:** In both countries, there are examples of soils salinized by faulty irrigation. In Cuba, about 600,000 ha and in the Dominican Republic about 25,000 ha have been made saline. Especially in Cuba, strict monitoring and control measures are now being followed. There has also been extensive salinization of groundwater in the southern parts of the country. The Dominican Republic has much water resources from constant-flowing streams and the water is of good quality. About 90 per cent of the water used is surface in origin and 10 per cent ground. In both these territories, irrigation is very important. In Cuba, for example, half of the water used is for irrigation and in the Dominican Republic almost 400,000 ha is irrigated.

**Haiti:** Some irrigation is achieved using surface water but this is done on a limited basis.

**The Bahamas and the Cayman Islands:** The Bahamas has considerable groundwater resources especially in the larger islands of Andros and Abaco. This water has hardly been exploited for agriculture but due to the low elevation of the islands, the freshwater aquifers can become polluted and therefore exploitation should be carefully monitored to prevent saline intrusion. The same applies to the Cayman Islands, where seawater intrusion is a more common occurrence due to exploitation of the groundwater for domestic and municipal purposes as well. Recharge of groundwater has been tried in the Cayman Islands with some success.

In the Caribbean as a whole, the use of wastewater for irrigation is hardly being done, which leaves a significant source of water for irrigation not being fully used.
Agronomic considerations in soil and water conservation and use

Soil surface manipulations

Since the loss of water from the soil takes place from the soil surface or along the surfaces of soil cracks, any manipulations that will reduce the exposure of these surfaces will reduce soil moisture loss. The material used to do this, usually straw, wood chips or any vegetable residues is called a mulch and the process of using it is called mulching i.e. spreading the material thinly on the soil surface. Its other benefits are to protect the roots of plants from heat or cold, or to keep fruit and vegetable clean. Other important functions of mulch are to control weed growth, reduce runoff, and to protect the soil surface from the direct impact of rainfall. A covering of the soil surface of about 3cm with the mulch is usually enough. Mulching is very effective in reducing moisture loss from the soil but the availability, handling and spreading of this bulky material is a problem. For this reason, the use of plastic sheets spread over the soil surface i.e. plastic mulch is gaining in popularity. The plastic material is usually black in colour to prevent weeds from growing. The sheets are also made with spaced holes for the planting of seedlings or seed. While plastic mulches are not nearly as beneficial as vegetable mulches for soil protection and preservation, its role in reducing water loss from the soil is quite good.

Yet another form of soil surface manipulation to reduce soil water loss is called dust mulching. This technique is used particularly in cracking clay soils and it consists of tilling the surface of the soil to a medium tilth at the beginning of the dry season. This tilled layer causes a discontinuity of the porosity of the deeper soil, so although the surface can become desiccated as the dry season progresses, the moisture in the subsoil is stored for future use. The surface dust mulch also prevents the soil from cracking and this further reduces evaporation loses. This technique is used in semi-arid and arid climates in countries such as India, Australia, Sudan and Southern Africa.

Live mulches can be very beneficial in saving soil water and in providing soil protection at the same time. Leguminous plants are commonly used as live mulches, either as a complete ground cover or in alley cropping. Live mulches have the added advantage in cracking clay soils of greatly reducing the incidence of cracking and thus also reducing evaporation losses.

Another form of soil water storage is known as stubble mulching. This technique has been developed in more temperate countries involving cereal crops such as wheat, oats, barley and maize. In this case, the straw from the harvest of these crops in the autumn is left on the land surface at harvest. In the spring, weedicides can be applied to destroy weeds if necessary and then the succeeding crop is sown on zonally tilled soil using a seed drill. In this case, disturbance of the soil is minimal thus also reducing soil erosion. In the Caribbean this farming system could be tried in Belize, for instance in the cowpea crop, and it could be used in the future if field cropping of row crops become widespread.

Soil erosion and conservation

Unlike water, soil is not a renewable resource and it has been lost by mismanagement for hundreds of years. The main form of soil loss in the region is in runoff and so it is closely associated with water loss as well. Madramootoo (2002) listed a number of measures that can be taken to prevent soil erosion and runoff losses of water, all of which are applicable to the Caribbean.
Soil erosion and associated runoff and water loss have been a serious problem throughout the long history of agricultural activity in the Caribbean, leading to loss of top soil, downstream pollution and soil compaction. The overall importance of steep slopes was always a major factor in aiding soil loss. Fortunately many of the soils, especially in the volcanic islands, have relatively stable soil structure and high permeability and therefore resist normal erosion and degradation. Where this is not the case, as in Haiti, the results have been disastrous. Another important factor is the historical cultivation of plantation crops in the region, which provides some soil protection as typically occurs in Grenada. The present overall status of soil erosion in the region is that while the impact is variable, it is a serious problem that requires an immediate solution.

Many instances of serious soil erosion are related to the method used in land clearing. Manual land clearing is the most protective of the methods but it has many disadvantages, since it is too slow, laborious and time consuming. There is always a great temptation to use mechanical land clearing without regard to the damage that can be done to the soil through the initiation of accelerated erosion after removal of the vegetative cover. In this process, there can be too much soil disturbance, soil loosening and destruction of the surface soil layer, thus exposing the more compact and less permeable subsoil and increasing runoff. Too often, windrowing of the uprooted vegetation in barriers along the natural contour of the land is not done and this adds to the erosion hazard. Burning can be useful in reducing the biomass resulting from land clearing but this can be overdone as a clean burn will overexpose the soil to erosion. If this process is necessary, controlled burning should be done, the main component of which is burning when the uprooted vegetation is not too desiccated. This is sometimes achieved in the ‘milpa’ farming system done in Belize.

Over the years, there has been awareness of the soil erosion problem and attempts have been made to correct it. Yet today, there is little or no evidence of any activity in this regard. Traditionally, two categories of soil conservation methods have been used to protect the soil against erosion and these are biological or agronomic methods and engineering methods. Gumbs (2001) outlined the various techniques that can be used in each category. For instance, good soil management—to aid plant establishment, crop and root growth—and rapid ground cover. Tillage systems that minimize the use of implements and soil disturbance are preferred. Minimum tillage should be emphasized.

On sloping land, contour cultivation should always be practised and care should be taken to have the crop actively growing through good agronomic practices to achieve optimum ground cover. Live or dead vegetation can form effective barriers for controlling or reducing soil erosion. Mulching over the soil surface is always effective in conserving the soil and reducing weed growth and water loss.

Crop selection can also be important in soil conservation. For slopes up to 10 degrees, there is considerable flexibility in crop selection but as the slopes get steeper, small annual crops should be avoided and larger plants preferred. With slopes greater than 20 degrees, tree crops should be grown. In this way, the ground surface will get maximum protection. In formulating recommendations and ways of developing and managing the soils, not only the slope but the depth of soil and nature of the soil parent material should be taken into account and a treatment oriented recommendation should be made as was proposed for St Lucia (Ahmad and Sheng 1988). Other techniques such as multiple cropping, intercropping, and relay cropping, some elements of which are endemic in West Indian agriculture, are all useful in providing protection to the soil and reducing water loss. Forms of agroforestry systems, in which
trees are utilized in various combinations and arrangements to facilitate the cultivation of crops and food

trees in combination, are also good strategies in soil and water conservation.

There are four types of engineering structures that are relevant to farmers in the Caribbean and these are

contour or cut-off drains, downslope waterways, mini-terraces, eyebrow terraces and gully control

structures. Gumbs (1987) gave specification for the constructing of these. Stone barriers have been tried

in parts of the Caribbean but they are very labour demanding and should be attempted where stones are

plentiful. These were tried in the Leeward Islands of Montserrat, St Kitts and Nevis and more recently in

Cuba.

All these measures will not only reduce the rate of runoff of water from the soils but will facilitate greater

infiltration and percolation, hence their role in water conservation while at the same time protecting the

soil.

There is no doubt that the above listed methods, both agronomic and engineering, are effective in

controlling soil erosion if they are well applied and managed. Yet presently, there is very little evidence

that they are being applied and used in spite of the fact that there are some cash incentives paid by

governments in some instances. There are several reasons for failure in this most important activity. Lack

of land ownership is important because most of the farmers involved do not own the land and they are

therefore hesitant to invest labour, time and financial resources to establish the particular structures. For

terraces, drains and contour beds, not all the farmers cooperate to construct and maintain these structures.

Since the holdings are generally small, farmers find it difficult to utilize parts of the land area to construct

soil conservation structures and in many cases, the plants used to establish barriers have little or no

commercial value. In Jamaica, large areas of land were terraced and small farmers settled on such land.

As soon as the areas reverted to management by the farmers, the terraces deteriorated. Today there are no

remnants of these terraces at Smithfield, Christiana or any other area where they were constructed in

Jamaica (Ahmad 2011). About the only example in the Caribbean where soil conservation measures are

still successful is the Scotland District of Barbados where some measures of Governmental control still

exists.

The methods that are likely to be more successful are the agronomic ones that the individual farmer can

apply and manage. Nevertheless, there are instances such as the control of gullies, stream bank erosion

and land slippage where governmental intervention and the use of heavy earth-moving equipment would

be necessary. To some extent, this is the present approach—in St Vincent for instance.

While land degradation and unrestricted water loss is a continuous process in the region, the rehabilitation

of the degraded land is receiving little or no attention. Only in Cuba is there a programme based on

regeneration of natural vegetation and the replanting of forest. For the fifty-year period 1950–2000, the

forested area increased from 13.4 per cent to 21.8 per cent. Presently, there are about 500,000 ha of

plantation forests in the country. It was found that on sloping lands five to seven year regrowth of the

vegetation was already very effective in reducing runoff and soil erosion.

The retention of water by the soil is an important way of increasing its supply to growing crops. Caribbean soils have been largely degraded by erosion over many years of misuse. Many of the soils on sloping terrain are now very shallow and they are underlain by solid volcanic rock. Any attempt to use
these soils in a food production drive will face the problem of water supply, since the soils in their present degraded state are able to store very little. Any programme of soil rehabilitation should include the building up of the organic matter content, since this component will not only absorb and store more water but will also retain more plant nutrients. In this process the use of mulches, including live mulches, would be very beneficial. Farming systems to keep the soil protected at all times would be needed. Such systems will include multiple cropping, intercropping, relay-cropping and the use of trees for overall production in agroforestry systems, in which case food producing and fruit trees would be incorporated into the system.

There is now international interest in the use of powdered charcoal as an additive to degraded tropical soils to increase their water and fertility retention capacities and research should be done in the region to investigate this claim. There is a new product called ‘Biochar’, which should be tested for its efficacy in this respect (Simpson 2011).

**Protected agriculture**

In the Caribbean, there are often strong winds charged with marine salts. Water use for agriculture and availability of land for crop production can be significantly influenced by protection from such winds through wind breaks, shelter belts and overhead shade. These measures modify the microclimate in the crop environment, making it more suitable for crop growth and reducing soil water loss by evaporation. With efficient protection, crops are saved from physical damage by high winds and from leaf scorch by salt spray and other physical damage. There are many examples in the region that show the beneficial effects of protection as well as the reverse. Unfortunately, it seems that farmers are now no longer keenly aware of the beneficial effects with the results that new windbreaks are not being established and the existing ones are also not being maintained.

In the region, the natural agro-ecological zones are fairly clearly defined and this is followed in agricultural land use and crop zonation, which is good for efficient water use. Additional protection from adverse climatic factors would add to the efficiency of agricultural production.

**Crop selection and other agricultural options**

In the context of a drier Caribbean, the cultivation of the same crops now being grown for food production is likely to experience serious problems, since they do not have much known drought or salt tolerance. Additionally, it would be difficult to change the food preferences of the population as experience has shown in other parts of the world. Research would have to be done to assess the water stress and salt tolerances within crop varieties. Clearly, cultural practices and crop production techniques may have to be modified to fit into the changing patterns of climate. On the whole, it may be more advantageous to increase water use efficiency rather than to change the crops, hopefully, for more drought tolerant ones.

Some aspects of the projected climate change may actually facilitate crop production. For instance, the increase in CO$_2$ in the environment could lead to earlier maturity of some crops, better root development and increase in biological nitrogen fixation. Also, there may be the possibility of introducing new crops into the region.
Livestock production

A drier climate may be advantageous for livestock production since among forage species, drought and salt tolerance are well known and other forage species may be introduced into the region that may be adaptable to local conditions. However, other factors in a changing climate, such as increased temperature and evaporation, could have negative impacts on the livestock themselves.

Aquaculture

In future strategies for water use and management, aquaculture as an integrated aspect of the agriculture of the region should be included. In areas where various forms of flood irrigation is being used, the waste or drainage water from irrigated land may well be suitable for some aspects of aquaculture, as done in Israel for example. In this instance, water is used to irrigate a succession of crops with increasing tolerance to salinity, until it has a concentration of dissolved salts that would make it unsuitable for the irrigation of any crop that is being cultivated. At this stage, the water is collected in fish farms producing tilapia. After harvesting the fish, the salt-polluted water is drained away and discarded. In this way, the maximum benefit is obtained from the water. However, this level of use of water requires careful monitoring of the water quality, as it is used from one crop to another, as well as suitable infrastructure for the conductance of the water from stage to stage. It is obvious that in a drive to achieve self-sufficiency in food, more fish and fish products, among other commodities, would have to be produced. Tilapia may not be the only species that can be produced in this way.

Policy for and management of water resources:

Concerns over the status of freshwater availability in the Caribbean region have been expressed for at least the past 30 years (Cashman et al. 2009). If the expected increase in use and subsequent efficiency of use of water is to be achieved in a drier Caribbean, greater attention is needed in water policy and management reform. At present, especially in the southern Caribbean, there is little regulation in the use of water and there does not appear to be any central infrastructure for its distribution—other than for domestic water use—this is the reason for the large-scale use of domestic water for irrigation. The use of irrigation cannot expand on this basis. In Trinidad and Tobago, there is as yet no organized system for collection of water or its distribution for irrigation. The Government is only now involved in establishing small reservoirs (farm ponds) but there is no information on how the stored water is to be distributed for irrigation. The Water and Sewerage Authority in the territory has ownership of all water, whether surface or ground in origin, and in theory, fees are collectable for the use of the water for irrigation. There is a conflict of interest in this arrangement.

Since irrigation is little developed in the region, it follows that infrastructure for the conveyance of water would be minimal. In Cuba, the Dominican Republic and Jamaica there are some old conveyance channels but these are mainly in poor condition and need to be improved and maintained. In Guyana and Suriname there are distribution systems but they need maintenance. Most of the new irrigation areas receive pipe-borne water from the domestic supply or water pumped from nearby streams. The overall efficiency of conveyance at present is probably less than 50 per cent. By comparison, in Israel where
water is transported for long distances in pipes or conduits, the loss can be less than 10 per cent. Major loss occurs through evaporation, seepage and theft.

In the Gezira Irrigation Project in the Sudan, about two million hectares of clay soils are irrigated for the production of cotton, mainly. Water distributory systems are kept filled with water when not in use, so the soils on the embankment remain saturated so there is no shrinkage and cracking of the soil and loss of water is accordingly greatly reduced.

In any future developments in irrigation in the region, conveyance of the water should be well planned to reduce loss so that maximum benefit can be derived from the water.

Solar energy can probably be used to transport water to the farm gate and then within the farm. This would be a highly desirable innovation (Simon 2010).

In Jamaica, irrigation has been in use for a long time, especially in the Parishes of Clarendon and St Catherine, and some infrastructure exists. This, however, needs maintenance to reduce loss and increase efficiency. Recently, the management of the resource has improved with a functioning National Irrigation Commission and there is much better control of the quality of irrigation water following the salinization of large areas of agricultural land in these Parishes. In the Dominican Republic and Cuba, there is satisfactory management of irrigation but maintenance of the infrastructure needs to be improved.

In Guyana and Suriname, irrigation of the main crops—rice and sugarcane—is well organized and managed although the system in place allows for the overuse of water. Arrangements for the irrigation of market-garden crops, on the other hand, is not organized and it is likely that the main source of water is the domestic supply, which cannot be the basis for an increase in area in these crops.

The question of payment for the water used for irrigation is a questionable aspect throughout the region, probably due to the traditional non-payment or token payment for water in the past. In Guyana for rice and sugarcane production, farmers are assessed by the area of land being farmed and not by the amount of water used. In Jamaica, this was also the system for payment but recently the basis was changed to the volume of water used. In the Dominican Republic, farmers pay for the amount of water used but the rate is very low, ranging from 0.05 to 0.08 per cent of the actual cost of providing the water.

From the above, therefore, it is obvious that much progress has to be made in developing and improving all aspects of irrigation in the region.

**Soil water management systems**

While at high governmental levels in the region there has been much concern expressed about increasing the amount of water available for use, the implementation of measures to achieve this has been slow. The philosophical thinking up to now, with respect to water use, has been directed to providing water for domestic and municipal use and not so much for agriculture. This is not so for Guyana and Suriname, or for the Dominican Republic and Cuba, however in the first case, engineering projects are mainly involved, such as construction of reservoirs and establishing distributory networks. For agricultural use, there are many other considerations that are important, the more difficult ones being the interaction of water with the environment and the consequences. If agricultural production is to become independent of
the weather, water must be provided in the form of irrigation, so that food production can be a continuous process. Water must also be available for the production of all staple food crops and not only for vegetable crops.

In order to make a significant impact on agricultural production, much more water would have to be made available for irrigation from both surface and groundwater sources. Emphasis should be given to utilizing surface water because of its relationship to soil erosion and conservation in all its forms. Water must be accessed on a watershed basis, so as to influence its disposal and consequent effect on soil conservation. So important is the reduction of the erosive capacity of water in a drainage basin, that the water that is won may even be regarded as secondary to the soil that is saved. Watershed protection, such as developed by the Tennessee Valley Authority in the United States and St Lawrence River Action Plan (Madramootoo 2002), are models to follow. In these examples, the drainage water is led away safely and can be used for irrigation, while at the same time, the watershed is protected and soil erosion is checked.

The exploitation and use of groundwater is simpler and less costly, especially if the water is used close to where it is available since the construction cost would be less. The main danger in using groundwater for irrigation is contamination of the aquifers with saline water and the continued inadvertent use of the polluted water for irrigation until the soils become salinized. It is a fact that all the lands that were made saline by irrigation in Jamaica, the Dominican Republic and Cuba were from groundwater use. In the particular environments the reclamation of these lands is simply not possible due to the quantity and quality of water that would be needed for leaching of the salts so that crops can be successfully grown again.

In developing soil water management systems, especially for a drier Caribbean, an integrated approach involving good soil water, crop and environmental management should be used. Increased water use alone would not solve the problem but might probably create others. Madramootoo (2002) listed 20 measures that are appropriate in controlling soil and water loss, and all of them are applicable to the region. A few more can be added for the Caribbean to cater for specific environmental factors, such as high winds and hurricanes and the many agro-ecological zones that are characteristic of the islands due to orientation of land mass, slope, aspect, and variability in the soil. It is up to the farmer and the technical adviser to develop production systems employing the particular conservation measures suitable to the environment, which would include the use of irrigation. The land resources are available to achieve food security, although the region is not generously endowed in this if Guyana, Suriname and Belize are excluded. While much of the land is already degraded, much of it can be rehabilitated and made manageable. Compared to many other parts of the world, the Caribbean has good water resources, which need to be properly developed and used. The climate is amenable but will pose problems in the future with changes that are taking place and predicted. It is expected that with needed changes in crop production techniques, the region will continue to produce a range of high quality products. With all these attributes and with an enlightened population, what has to be done is to bring all these attributes together and develop integrated production systems to provide the food we need.
Conclusions

The following are the main conclusions from this study:

- Climate change in the Caribbean seems inevitable, unless measures are taken to reduce atmospheric pollution by greenhouse gases. If the current trend continues, global temperatures will increase and for the Caribbean, there will be reduced rainfall and the rainy season will become shorter and rainfall incidents heavier. This will cause greater losses of water from runoff and associated loss of soil through erosion.

- Global warming will result in a rise in sea level, which could lead to salt-water intrusion in coastal irrigation systems and groundwater pollution.

- The changes in climate will affect many soil properties, which together will make the soils more difficult to manage.

- The climate change will have effects on the crops that are normally cultivated in the Caribbean. The new agronomic conditions will expose the crops to water stress, increase in soil and water salinity, higher temperatures and increased atmospheric CO$_2$. Crops are likely to have shorter growing periods with decreased yields. Some of the current crops may be unable to be productive but on the other hand different crops may be introduced.

- At present, the region as a whole has a good supply of water through rainfall but the use that is made of it can be greatly improved. Most of it is lost by runoff and only a small amount is intercepted and used.

- It is projected that the demand for water in the region will greatly increase in the medium and long term, particularly in agriculture, as the region strives to achieve food security. Irrigation, which is as yet little used in most of the region, would be more developed and more widely applied and will extend to the production of the staple food crops. Storage of surface water through the use of water harvesting techniques and reservoirs from farm ponds to large water storage structures would have to be used. The interception of runoff will have to be done on a watershed basis as a soil conservation measure as well. Distributory systems would have to be developed and improved, especially to reduce losses. For this reason, the use of groundwater should take precedence over the use of desalinized water.

- Where groundwater is available, its careful exploitation and use would be the most convenient source of increased water supply. Monitoring the quality of the water for salt-water intrusion and other pollution would have to be carefully, thoroughly and routinely done.

- For effective use of surface water for irrigation, storage is necessary, except in cases in which the water is supplied from constant-flowing streams. The water harvesting must be done on a watershed basis varying from mini to large watersheds; at the same time soil conservation and watershed protection measures should be incorporated.

- Appropriate irrigation systems must be compatible with the particular farming systems and water quality. The amount of water applied must allow for the consumptive use of the crop and the leaching requirement of the soil to avoid soil salinization. Water quality must be carefully monitored, the main parameters being pH, electrical conductivity, relative proportion of sodium to other cations, concentration of boron and other elements that may be toxic to plants, and the concentration of bicarbonate ion as related to the concentration of calcium and magnesium.
• Agronomic measures known to be beneficial in soil and water conservation, such as mulching (vegetable, live and dust), windbreaks, overhead shade where applicable and shelter belts should be incorporated in the farming systems as soil and water conservation measures.

• Soil erosion is an important hazard in the region, resulting from the predominance of steep slopes and high intensity rainfalls. Soil and water conservation measures based on watershed protection principles are of great urgency.

• In a policy to maximize the use of water, opportunities may be created for the development of inland aquaculture as the final use of the water when it has become too saline for crop irrigation. If environmental conditions become too marginal for crop production, more livestock production may become possible, since forage species exist with greater salt and drought tolerance.

• With some exceptions, i.e. Cuba, the Dominican Republic, Guyana, Suriname and Jamaica to some extent, irrigation is little used and inadequately managed. Management systems are needed to ensure that farmers have access to irrigation and that water is used in the right amounts and appropriately applied. A system of fees for water use would have to be developed.

• Soil water management systems should be designed by the farmer and relevant scientist, taking into consideration all the factors that are involved and important for successful water use in agriculture.

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Case study:
A Jamaican Case Study - Innovative On-Farm Water Management

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Introduction

Small island states are more vulnerable to the disastrous effect of climate change and Jamaica is no exception. All the climatic parameters have shown that storm surges, drought, hurricanes and floods are regular occurrences.

Since 2001, climate related events resulted in damages estimated at J$111.8 billion (approximately 2% of GDP) and each event affected an average of 250,000 persons; 58 lives have been lost over the period.

It is projected for Jamaica that by 2050 there will be a decrease in the length of the rainy season by 7–8 per cent and an increase in the length of the dry season by 6–8 per cent.

Given this scenario, a case study was done for Flagaman in St Elizabeth to see how small farmers were coping and adapting to climate change.

Description of Area of Study

Flagaman district is part of an elevated plateau in southern St Elizabeth, which lies in the rain-shadow area of the island. The Northeast Trade Winds deposit their moisture in the interior mountainous range. When the Trades reach the southern plain they are devoid of moisture and hence southern St Elizabeth lies in the drier coastal plain of Jamaica. The district of Flagaman borders Pedro Cross to the east, Beacon Little Park to the north and Treasure Beach on the Caribbean Sea to the south.

The area consists of rolling topography with a deep layer of red bauxitic soil that is low in nutrients, especially in nitrogen and fixed phosphate. It is important to note that the soil is not tilled. If the soil were ploughed, most of the moisture would be lost due to evaporation. The soil is deep and friable and allows for rapid root development.

Flagaman is a productive agricultural district that is highly fragmented, ranging from less than one acre to ten acres. This is due to the culture of landowners sub-dividing their holdings for the next generation. The crops cultivated are high value vegetables, including tomatoes, escallions, thyme, onions, and cantaloupe. Although, Flagaman is located in the rain shadow area of the parish, it still receives approximately 1,000 mm (40 inches) of rainfall per annum. There are two main rainy months; they are May and October. Other factors leading to its high productive include:

1. The climate of the area is cool in the nights.
2. The soil has a good moisture holding capacity and it is deep and friable in many areas.

3. The water management techniques (dry farming) developed over the years has ensured a reliable yield and good quality high value products.

The unique climate and soil creates the proper environment for the successful growth and development of high value agricultural crops.

**A Study on a Family in Flagaman District – The Ebanks Family**

The Ebanks family has had a long history of farming in Flagaman of over 50 years. A parcel of land of approximately three acres was bequeathed to three family members:

- Nolford Campbell
- Mernel Ebanks
- Nicholos Ebanks

**Nolford Campbell**
Mr Nolford Campbell is 41 years old. He has been farming for 15 years. He has reported that up to five years ago, the area had been without electricity. There is still no domestic water supply in some homes.

Mr Campbell has noted the improvement in living conditions today. The installation of an electricity supply has improved living conditions. Improvement in water management and crop production has resulted in a higher income. The improvement in income has resulted in home improvement and better sanitation and in the acquisition of a radio, a television, a motorcycle and cell phones.

**Mernel Ebanks**

Ms Mernel Ebanks is 80 years old and has been farming for nearly sixty years. Her main cultivated crop is cantaloupe and she normally grows three squares\(^3\) (1,112 m\(^2\)). She noted the improvement in the quality of life for her and other persons in the district. She remembers that donkey and mule carts were the main form of transportation. At that time, there was no electricity, no television and shortwave, battery-operated radio was the only means of entertainment. At present, everybody has an electricity supply and some persons in the district have a domestic water supply.

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\(^3\) 10 squares = 1 acre = 0.405 ha
Ms Mernel Ebanks recalls that the rainfall was more reliable and predictable; the land was more fertile and produced a reliable crop. Fertilizer was used in limited amounts. She explained that with the help of extension officers providing guidance, significant improvement in crop yield was realized.

She now lives a better quality of life and has made significant improvements to her home. The kitchen and bathroom are now inside her house instead of being on the outside.

Electricity is available and this allowed her to acquire and use a number of electrical appliances. She noted that many farmers in the district have pickup trucks and motorcycles and are able to move around independently. They can bring in farm supplies, e.g. fertilizer, and they can take their farm produce to the markets.

Flagaman land settlement was without a pipe-borne supply of water for many years and the main source of water, both for domestic and agriculture use, was from rainfall and rainwater harvested from roof catchments. It is suggested that the continuous use of rainwater with no fluoride has cause dental problems for some farmers in the district.

Nicholos Ebanks

Mr Nicholos Ebanks was born in 1944 and he has been farming for over forty years. He has four children, all of whom are living overseas.

His account of the social and cultural farming practices in the early days was similar to that of his sister, Ms Mernel Ebanks. He is currently cultivating 2.3 acres (9,307.77 m²) of land, of which three squares (1,112 m²) of land was bequeathed to him, while the rest is leased.

Without irrigation and grass mulching, he has suffered from frequent crop failure. He emphasized that the following are required to have a reliable and successful production of crops:

- No tilling of the soil
- Application of grass mulching
- Adequate fertilizer
- Rainwater harvesting
- Additional water from trucks
- Proper crop care

A Historic Perspective of the Farming Practices

First Phase

The development of the area for agriculture dates back to over 100 years ago, when the first settlers removed the natural vegetation and started agricultural production. The farming practice of the early settlers was slash and burn: the area would be cleared, the land allowed to dry then burnt, after which the seeds would be planted, with planting coinciding with the rainy seasons of May or October. Once the crop
was growing, a struggle ensued to ensure that the crop was watered. It would mean that the domestic water supply would be shared with the plants to ensure a successful crop.

In periods of severe drought, the crop would fail and the water would be sparingly used for domestic purposes.

The Ebanks family realized that if the water from rainfall has to serve for domestic use as well as for agriculture, water conservation measures must be introduced. The measures implemented were the following:

1. Leaking of water from the water storage system was prevented.
2. Water was carefully transported from the house tank to the field in buckets.
3. A 170 litre drum was used to store water in the field.
4. A small watering can was used to dispense the water to the root of each plant.

Although in the end a successful crop was realized, the process was time consuming and laborious.

Second Phase

After a number of crop failures, it was discovered that if grass was cut and used to cover the area before planting, the amount of water required from the tank was drastically reduced. This meant that more water would be available for domestic purposes. This method is commonly known as dry farming.

Dry Farming

The act of covering the ground with Guinea grass (*Panicum maximum*) is called mulching. Mulching is the traditional backbone of dry farming in parishes such as St Elizabeth. Guinea grass is cultivated as a cash crop for mulching purposes. The soil is not tilled; instead, land preparation includes weeding (using both chemical and manual labour) and digging holes for the specific crop.
The Guinea grass covering the land has the following beneficial effects:

1. Soil temperature is reduced.

2. Water conservation, which is the most beneficial purpose of the grass mulch. The grass reduces evaporation from the soil; the lower soil temperature created by the grass mulch allows the soil to retain its moisture for longer periods.

3. During a rain event, the water penetrates the soil, since the grass mulch reduces runoff and erosion, and allows the water to be stored and available in the root zone of the plant. When a small can of water is applied to the root, the mulch allows for maximum utilization by the plant.

4. There is grass mulch decay, especially at the interface between the soil and the grass cover. This means that organic matter is slowly released to the soil. Organic matter from the grass mulch provides valuable nutrient to the plant, improves the moisture holding capacity and reduces phosphate fixation.

However, harmful insects and other pests may inhabit the grass mulch and, as such, care must be taken to ensure that they are eliminated.

With the advent of grass mulching, crop yield became more reliable and less water was required. Better quality and yield of crops were obtained. The importance of grass mulch was well recognized and the
benefits were demonstrated. It became necessary for the farmer to allocate a section of his farm holding to cultivating Guinea grass for mulching. With little or no care, Guinea grass grows quickly and profusely during the rainy season and is available for mulching during the dry season.

Once a crop is reaped from the mulched area, a herbicide is used to kill the remaining plants and a new crop is planted on the same field. This entire cycle is called dry farming.
However, it was noted that the level of success of the dry farming systems is also dependent on water: the source of the water and application of the water system. Traditionally, water for crops (in semi-arid areas in Jamaica) has been supplied through water stored in drums in the field.
Some farmers, however, have devised innovative water harvesting and application methods. One example is the construction of a water tank roof catchment, which collects rainwater. A submersible water pump is suspended in the tank and used to deliver the water for the crops through a water hose.
Rainwater Harvesting and Storage

With the success derived from dry farming, more money became available to the family, better houses were built, a pickup truck and motorcycle were bought and the general standard of living improved. The farming area expanded and required more water than that was available from rainfall. The additional water was purchased from 'water trucks'. The present cost for a 15,000 litre truckload of water (4000 gallons) is between eight and nine thousand Jamaican dollars. Water from the truck is stored in the house
tank where it is available for use on the farm or in the house. Sometimes some of the water is conveyed directly to the field for irrigation.

The farming system remains the same: grass mulch is applied, some fertilizer is used, proper crop care is practiced and water conservation and management are carried out. The entire farming system requires major labour input. The laborious task of drawing water from the house tank by bucket and transporting it to the field to fill a 170 litre drum and applying the water to every plant root persisted; this was time consuming.

As the cropping area expanded and the demand for water increased, the cost of trucked water became a concern, especially in times of severe drought when a crop was in the field. Sometimes, the water demand was very high and it became too expensive to purchase, so the crop growth would be retarded or fail.

Third Phase

In 2003, the government introduced an irrigation system call ‘gravity drip system’. This system consists of an elevated platform, about 1.22 metres (4 feet) above ground level, on which a 3,750 litre (1,000 gallon) plastic tank is accommodated. The plastic tank is connected to a pipe that conveys the water to the field, which is located at a slightly lower elevation. Water truck fills the 3,750 litre plastic tank on a regular basis.
Gravity Drip System

The water flows from the tank by gravity through a main 3.8 cm (1 ½ inch) leader pipe to the crop in the field. Drip tubes are connected to the header pipe and carry the water to the root of the crop that is in the field. This farming system using the gravity drip method, which eliminates the laborious task of drawing water from the house tank, transporting it to the field to fill a 170 litre drum, using a can to dip the water from the 170 litre drum and placing it at the root of each plant, and repeating that cycle until all the plants are watered.

This farming system is less difficult and allows the farmer more time to do other chores. However, it is more capital intensive. It requires the capital cost for the tank, pipe and drip tubes as well as the cost for the water.

The task of moving water from the house to the 3,750 litre plastic tank has many challenges:

1. The tank must be placed at a higher elevation in order for the drip system to work.

2. The proper operation of the drip system dictates the location of the tank.
3. Filling of the tank with water requires that it is accessible to the water truck or by the use of a pump.

The pump needed is a small, small volume model with a capacity of 15.14 litres (4 gallons) per minute. Such pumping activity can be achieved by the use of 0.25 horsepower solar pump with a 200 watt solar panel.

In 2009, the Food and Agricultural Organization (FAO) project ‘Promoting rainwater harvesting and small scale irrigation in South Saint Elizabeth’ chose the Ebanks family to demonstrate the use of solar pumps along with the gravity drip system and to improve water management and water use efficiency.

Two solar pumping systems were installed:

- 1 for Ms. Mernel Ebanks
- 1 for Nicholas Ebanks and Nolford Campbell
Gravity Drip System with Solar Panels

The shared solar pumping system for Nicholas Ebanks and Nolford Campbell consists of individual house water catchments that go to the house tanks and a 418 m² barbeque catchment\(^4\) (18.29 m x 22.86 m). Water from each catchment is collected and stored in a shared 200,000 litre (54,000 gallon) covered concrete storage tank (9.14 m x 9.14 m x 3.05m).

The solar pump is connected to the 200,000 litre tank. The purpose of the solar pump is to transfer water from the holding tank to two 3,750 litre tanks, one owned by Nicholas Ebanks and the other by Nolford Campbell.

Each tank supplies water to approximately 0.2 ha (0.5 acre) of land. Crop cultivation includes beet, watermelon, escallion and thyme.

Positives

- The new solar pumping system provides enough energy to move the water from the 200,000 litre storage tank to two elevated 3,750 litre plastic tanks. Each of these is connected to a drip irrigation system, which serves approximately a 0.2 ha of vegetable cultivation.

- The elimination of the laborious task of drawing water from the house tank using a small bucket and transporting it to a 170 litre drum in the field and watering each plant individually using a small can.

- The cost of energy is no longer a factor as the sun provides the solar power to energize the pump.

- The water catchment system connected to a storage tank provides an avenue to harvest rainfall whenever there is a rain event.

Negatives

The maintenance of the catchment, pump, pipe, tank and gravity drip system is very important. Any one area of weakness can cause failure.

This system has to be inspected regularly to ensure that:

1. There is no blockage of the pump and suction hose.
2. There is no breakage of the pipes. This has to be repaired quickly to reduce water loss.
3. The 3,750 litre plastic water tank base is maintained to ensure its integrity.
4. The tank float valve mechanism is serviced to ensure that it closes once the tank is filled.
5. The tank outlet valve and pipes are free of all leaks and blockages.

---

\(^4\) A barbeque catchment is a concreted area used for drying crops such as rice and pimento, and for harvesting rainwater.
6. The drip tubes are maintained to ensure an even distribution of water.

7. Any breakage of drip tubes are mended promptly.

8. The solar pump is serviced. This is critical as failure of the pump adversely affects the agricultural production that can be carried out by the two farms.

Evidence of this last point was seen when the solar pump for Nicholas Ebanks and Nolford Campbell malfunctioned. Due to communication problems and a slow response time from the supplier, the pump was out of service for six weeks. This caused severe moisture stress for the crops in the ground, resulting in retarded growth and low production.

The introduction of drip irrigation has had its teething pains. It was demonstrated that the acquisition and installation of the first set of drip tubes were done without proper consultation with the farmers. The crop being cultivated was cantaloupe and seeds were planted five feet apart along the row, however, the drip tube supplied has holes set at one foot apart. The farmer observed that the four drippers located between two plants in the row were wasting valuable water.

The time to run the drip hose is critical. In the beginning, the farmer was not sure how long one watering session should take, he discovered that the 3,750 litre plastic tank would be out of water before the expected crop area to be irrigated was achieved. The farmer then put a small sausage can under one dripper and calculated the time it took to fill the can. He was therefore able to determine how long it took to water each plant root with the equivalent of one can of water, and therefore how many minutes it would take to carry out the irrigation cycle.

These are important considerations in introducing new technology to farmers. Care must be taken to train and demonstrate how the system operates before it is turned over to the farmer.
The cost of production and revenue for 1,112 m² (3 squares) of cantaloupe

<table>
<thead>
<tr>
<th>ITEMS</th>
<th>Cost (J$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Seed cost for 1,112 m²</td>
<td>5,000</td>
</tr>
<tr>
<td>2. Fertilizer (one 50 kg bag)</td>
<td>4,300</td>
</tr>
<tr>
<td>3. Trucked water - 3 truckloads (15,000 litres each) @ J$9000 per truckload</td>
<td>27,000</td>
</tr>
<tr>
<td>4. Chemicals (Manozeb and Silicron)</td>
<td>10,000</td>
</tr>
<tr>
<td>5. Labour J$1,500/day for 6 days</td>
<td>9000</td>
</tr>
<tr>
<td>6. Grass Mulch</td>
<td>6000</td>
</tr>
<tr>
<td><strong>Total Cost Of Production</strong></td>
<td><strong>J$61,300</strong></td>
</tr>
</tbody>
</table>

US$1 = J$86.00

Production (yield): 1,133 kg per 404 m²

Crop loss in the field: 453 kg per 404 m²

\[= 1,586 \text{ kg gross production from 404 m² (1 square)}\]

Cantaloupe price ranges from J$55 per kg to J$77 per kg.

At J$55 per kg + yield of 1,133 kg, gross revenue = J$62,300 per 404 m² (1 square)

At J$77 per kg, gross revenue = J$87,240 per 404 m² (1 square)

Cost of Production of 1112 m² (3 squares) of cantaloupe = J$61,300

Cost of Production for 404 m² (1 square) = J$20,400

Cantaloupe yield - 1133 kg from 404 m² (1 square)

Gross Revenue from 404 m² @ J$55 per kg = J$62,300

Gross Revenue from 404 m² @ J$77 per kg = J$87,240

Average Gross Revenue from 404 m² (1 square) = J$77,770

The Average Gross Revenue of J$77,770 includes the cost of the farmer’s labour over a four-month period.
A yield of 1,133 kg per 404 m² (1 square) occurred when all the input stated above were applied. If the land is not mulched and the crop is planted out of the rainy season, there is a high probability of crop failure.

If the crop is planted in the rainy season, there is a possibility of crop failure as the rain events can be two weeks apart. The grass mulch ensures a reliable crop.

With irrigation and mulching, fertilizing and crop care, a yield of 1,134 kg (2,500 lbs) is a good expectation.

The efficient use of water through the drip system and grass mulching ensures a reliable and profitable yield.

**Fourth Phase - Future Developments**

Fertigation is the practice of dissolving fertilizer in a liquid medium and applying it to the crops. The fertilizer in a liquid state can move quickly to the root zone of the crop where it is absorbed. This technology has resulted in an increase in yield of many crops in the irrigated district.

It is proposed to use fertigation as the next level of innovation in the farming system in south St Elizabeth.

The fertilizer, suitable for fertigation, will be dissolved in water, the mixture will be added to the black plastic tank where it will be discharged by gravity to the drip tubes to the field. This is expected to increase crop production by 20-25 per cent.

Care will be exercised to ensure that the tanks are properly marked, so that persons will know that the content of the tank is unsuitable for human consumption.

**Conclusion**

Climate change is real. Extreme weather events are regular occurrences and adaptive strategies are necessary if we are to mitigate the possible disasters that can occur. Agriculture is vulnerable to these events, which threaten food security. Therefore, integrated water resource management (IWRM) and water use efficiently are of utmost importance for sustainable agriculture.

The Ebanks family and their innovative farming practices have demonstrated the evolution of a farming system that has shown that rainwater harvesting, efficient irrigation, crop mulching and erosion control can be achieved. These innovations have resulted in higher yield, the efficient use of water and energy, and a sustainable agricultural production and a better standard of living.

Fertigation will be the next level of innovation in this farming system.
E-Discussion Synthesis Report

Question 3: Are the recommended and/or currently implemented soil management practices appropriate for a drier Caribbean?

Thread builders:

➢ Is there enough regard for water conservation?
➢ Is soil-water management only an agriculture issue?
➢ Is the rainfall pattern so unpredictable as to cause disruption of cropping cycles?

Moderator’s Comment:

This iteration of the e-discussion focused on soil management as the overall rubric within which water resources are managed. Management of water resources in this context involved collection, storage, conservation and effective use. There were 11 posts around the questions posed in this thread.

E-Discussion:

One of the earliest posts was a request for a collation of recommended and implemented soil and water management practices in the Caribbean for the participants to decide if they were appropriate. A subsequent listing gave examples of land management protocols using excerpts from various documents cited by CTA in Spore No. 139 - February 2009: FAO 2001 on soil fertility management, Alliance for a Green Revolution in Africa (AGRA) and TerrAfrica (a partnership that aims to address land degradation in Sub-Saharan Africa). The World Overview of Conservation Approaches and Technologies (WOCAT) ‘Best practices in soil and water conservation’, was a useful addition to the listing. However it was the respondent’s ‘On-Farm Research’ that was most useful. The shared document highlighted an integrated soil management programme incorporating tillage and limestone application to ameliorate an acidic heavy clay soil and a water management programme including a micro-irrigation system with ‘fertigation’ capability.

Another noteworthy referral of soil and water conservation methods for the Caribbean was that produced by the late Professor Frank Gumbs of the University of the West Indies (UWI), St Augustine in 1987, titled, “Soil and water Conservation Methods for the Caribbean” and published by the Department of Agricultural Extension, UWI. Unfortunately, as with many asynchronous e-discussions, this wealth of information being devoid of controversy did not generate extensive dialogue.

The unpredictability of rainfall patterns rather than any drying trend, which is not yet evident, was seen as a major issue to be addressed. For a very long time, perhaps even before temperatures began their slow rise, rainfall has been unpredictable both in amount and in timing. The idea was floated that soil management practices should be adapted to "prepare for the worst case", there being no reason not to "expect" 20-year events. There are several types of extreme events that may each be expected to occur once every 20 years, whereas the actual frequency of one or the other happening is much more than once every 20 years.
Another contributor added that there are also the El Niño and La Niña effects, and opined that efforts should be directed at anticipating the events that are cyclical and taking measures that mitigate the adverse effects. She acknowledged the stellar work of agro-meteorologist, Adrian Trotman, and his department and expressed the view that more should be done, in terms of using available information, to better manage water resources in agriculture.

One respondent, a soil scientist, reminded the group that soil management, although the most economical means of storage, is limited. The antecedent soil moisture, soil depth, the relief, vegetative cover and soil management can all modify the water holding capacity. The soil has a finite capacity for moisture retention but organic matter and mulch can substantially improve the moisture storage. He advocated that focusing on a holistic, integrated approach at the sub-watershed level could assist, along with considering mechanisms for aquifer recharging.

The Moderator, being privy to parallel discussions taking place with non-agricultural members of the group, offered the following on soil management versus land management, in the context of water availability.

*Recent discussions with an experienced engineer reinforced my belief that land management on a national level requires multi-disciplinary teams. It was agreed that engineers will often “see” engineering solutions to land management issues. Civil Engineers, for example, concerned with infrastructure protection (by dint of their training, exposure and areas of interest) would most likely decide on retaining walls or gabion baskets. Several professions view land as “something to be stabilized, graded or drained”. Those in professions where land is seen as soil, often have different views; in that it is viewed in terms of its fertility, possible protection and improvement as a precursor to irreversibly covering it with concrete.*

*The so-called soft engineering solutions for “soil stabilization”, such as grassing with Vetiver spp. are often not considered when land is seen as a “base for building”. Soil is an entity with inherent capacity to provide solutions and products, or regulate natural cycles including the water cycle. In our discussions on land use policies we must constantly interject that soil use is equally important. Land use policies require multi-disciplinary teams to add to the range of tools brought to the task.*

There were posted and privately e-mailed responses to those observations. One discussant concurred that there is a dire need for a holistic interdisciplinary approach. Where land is steep and abuts roads, buildings and streams, then engineering solutions may be the only way out. He agreed that one might have to look at cheaper structures, such as gabion baskets for agricultural lands, especially where stones are readily available. However, he was adamant that appropriate contour structures with vegetation and agroforestry approaches might help to manage some of the challenges. He concluded his observations by sharing that there had been discussions, at the national level, on the concept of land husbandry in which a number of practices to fit different scenarios had been proposed.
Panel Discussion: Technical session III

CHAIRPERSON:

Dr Leslie A. Simpson (Natural Resources Management Specialist, CARDI)

RAPPORTEURS:

Tristan Alvarez and Ipha Miguel

PANEL MEMBERS:

Dr Michael Taylor (The University of the West Indies)

Dr Matthew Wilson (The University of the West Indies)

Professor Nazeer Ahmad (Professor Emeritus, Soil Science, University of the West Indies)

Mr Stanley Rampair (National Irrigation Commission, Jamaica)

Mr Gregg Marshall (Consultant Irrigation Engineer)

Opening Panel Comments Discussion Notes and Speakers

Dr Matthew Wilson (UWI, St Augustine): There must be a push towards Integrated Water Resource Management (IWRM) especially as it relates to agriculture, where it can give agriculture that voice as it pertains to water management. There is a lot agriculture can do independently of the central system at the local scale e.g. water harvesting. On the wider scale however, there is the need for IWRM, allowing for equitable distribution of resources.

Mr Stanley Rampair (National Irrigation Commission, Jamaica): We have to look at the efficient use of water, emphasizing the call for water management, fertigation and proper extension services. Part of the blame lies with extension. It is critical however to now use science and technology to solve our problems.

Mr Gregg Marshall (Consultant, Barbados): We have the data; we just need to communicate it effectively. There is the need to put the information into an effective form so that the end users can make practical use of it. There is the example of farmers receiving information from a website (which may not be an effective communication method) verses receiving the same information via a voice message on their phones. An effective communication approach is critical in the overall strategy.

Professor Nazeer Ahmad (UWI, St Augustine): It is unfortunate that decisions makers are not present at the workshop. The problem lies in getting decisions from the decision makers so that things can move forward. If not, we will remain stifled. There is also the need to command more water and a suitable body to manage it. Thus Government intervention is necessary.
Dr Leslie Simpson (CARDI, Jamaica): IWRM is the way to go but there is the remaining problem of effectively implementing this action. On-farm Water Management (OFWM) is also critical for the more efficient use of water but the question remains, how do we implement?

Dr Michael Taylor (UWI, Mona): Communication action is key for farmers and policy makers. Communication to the relevant end users must be simple, comprehensive, directed as well as contextual. There is the need to note Caribbean case studies as well.

Dr Lystra Fletcher Paul (FAO, Guyana): An FAO-driven project determined the feasibility of the expansion of small-scale irrigation in Grenada. The project identified areas where irrigation was feasible and did studies for different size farms. Grenada had a good information system. Since EU funding required a water management policy, Grenada was able to develop the policy got the loan for irrigation infrastructure. The importance of data and there is a critical need for a water information system. Feasibility studies as well as a water management policy were developed in order to get funding to carry out the project and is another key step. In Jamaica, water deficit maps determined where rainwater harvesting was possible and pilots were set up. Training in irrigation scheduling was done and suitable crops were identified. Data and information is essential to working with farmers. This relates to a good extension service where farmers can learn what crops can be grown in extended periods, storage of water, etc.

Mr. Vincent Sweeny (UNEP): A lot of work has been done throughout the region but how to operationalize it? IWRM plans have been developed for countries; however, there is the need to move towards implementation. A CARICOM consortium, if operational, can advance supportive policy decisions. Also, in terms of communication, there is need for the development of a media tool kit for better interaction between the media and the various interests to create understanding. There is need to highlight the important role of the media

Mr Adrian Trottman (CIMH): Along with the Caribbean Agrometeorological Initiative (CAMI) communication plan, there should be collaboration among all the agencies in the region that communicate technical information. There is need to develop a comprehensive plan for the region with an initial workshop to operationalize the communication strategy. With respect to FAO’s work in Grenada, there is also need for climate information. That climatic information on an operational basis can assist with the water information system that Dr Fletcher-Paul alluded to. The Caribbean Disaster Emergency Management Agency (CDEMA) is embarking on a new initiative to develop a drought monitoring and management programme in Caribbean countries, including Grenada. This will lead to a drought and water information system, which can be used by policy makers to assist farmers. I hope that there can be a coming together of those in the fields of climate change, agriculture and meteorology. There is also the need to further the effectiveness of communication.

Ms Jewel Forde (Media, Barbados): I endorse and recognize the involvement and importance of media in terms of advocacy however, it should be noted that media are not involved in the issues. They only receive press releases or get notification in the event that a minister is present. Thus, the media is aware on a superficial level but exposure on a more in-depth basis is needed. The media needs to part of the process instead of receiving handed down data. Also, the experts need to be willing to come forward and give information.
Mr Byron Buckley (Media, Jamaica): The media and its relation to agriculture is changing in Jamaica. There are three senior journalists here. Media and its relation to agriculture is changing in Jamaica. There was the re-launch of the Agri Gleaner three months ago. Journalists have to take the reins. It is a journalist’s job to take the information and break it down.

Ms Keeley Holder (BSTA/BAS, Barbados): There is a need to utilize the scientists who are farmer leaders and who interact with farmers on a day-to-day basis. In terms of packaging the information, it should be tailored to the farmers. The information should be able to inform as to whether money will be made and/or saved and how much. The workshop failed to touch on certain issues that farmers need to know, such as irrigation scheduling, using a class A pan to measure evapotranspiration, the use of GIS application in water management and also well measuring: that is done in New Zealand, to remove water in times of flood events and decrease flooding in farming areas. There is also the use of plastic mulch in IPM strategies. The workshop has not touched on these issues. There is also the need to provide calculations for farmers in terms of rainfall needed for an acre of a particular crop and the storage needed, as this will allow for effective planning. The information needs to be more targeted to those on the ground.

Dr Lystra Flechter Paul: There is a water system in Antigua to capture water. There is also a hydromet station in Grenada.

Dr Leslie Simpson: CARDI has on-farm weather stations. In terms of the information produced for farmers, scientist do not speak in absolute terms but can only provide guidelines for farmers to make informed decisions.

Mr Stanley Rampair: We have set up research and demonstration plots, doing on-farm research to identify and solve the problems, packaging it and then educating the farmers. They know that is the way to go but time is the critical factor.

Mr Adrian Trottman: It is not only important to provide the information to the farmers but it is critical to teach them how to use the information to make informed decisions. Work is being done but a more collaborative approach is needed. Statistics are needed to develop weather-related pest and disease models that are country specific and pest specific. We must work with farmers to conduct validation trials in the field. It is process that will take time because there are only a few persons doing the type of work in the region.

Ms Keeley Holder: Farmers need the information. There is documented information out there. Why isn’t it being made available? We need to have workable data and, if not, make them workable. There is a disconnect between information and dissemination of vital information from Ministries of Agriculture.

Mr Ramgopaul Roop (TTABA): What do we do with all the case studies we have? How do we get these case studies to benefit other farmers? We have to fix the soil or we will be wasting water. I inherited a heavy clay soil with a pH of 3.5. Through water management, drainage and irrigation, I have achieved success. We need to fix the soil or we will wastewater.
TECHNICAL SESSION IV
TECHNICAL SESSION IV

Adaptation Strategy For Agriculture In The Caribbean In Relation To Declining Water Resources As A Result Of Climate Change

FACILITATOR: MR STEVE MAXIMAY

Presentations on the findings by the Working Groups (Parallel)

Group Presentation 1

The WHY: The Formulation of the persuasive policy argument

Overarching Framework

Considerations

- Urgency
- Contextualizing issues
- Mainstreaming climate variability and change in development issues
• Cost of Inaction/Opportunities from Action

1. Conveying the urgency of the message
   • Using historical and present experiences
     o Show where development is impacted by water related disasters (flooding/drought)
     o Speak to the economic values of disasters
     o Link disasters to other development issues
     o Identify specific threats
   • Need to show how inaction now can exacerbate issues in the future
     o Using scenarios to describe future impacts
     o Using examples to show changes in the scale and frequency of problems

2. Contextualizing Issues
   • Addressing policy-makers and politicians in the relevant context
     o Short terms 4-5 years = Variability
     o Impacts on their constituents
     o Linking experiences and impacts to development frameworks
   • Recognize vulnerable groups in society
     o Convey how climate variability and change adds another layer, which could increase vulnerability

3. Mainstreaming into development issues
   • Framing the message is important
     o Making the issue more than climate variability and change and tacking onto development issues
     o Identify opportunities and taking advantage of funds from climate change pools, which can be used for development

4. Cost of Inaction/Opportunities from action
   • What are the real costs of inaction?
     o Left behind the pack, becoming disadvantaged as a result
     o Present these using scenarios (examples available)
• Explore opportunities from action
  o International accreditation
  o Meeting Millennium Development Goals
  o Food security- reducing food import bill

**Group Presentation 2**

**The HOW: Policy Recommendations**

**Elements of the Policy**

• Purpose of the policy and its intended audience (Decision makers and Ministers)
• Steps towards policy development
• The issues which need to be addressed
• Implementation

**Purpose of the Policy**

• To draw the attention of the policy makers to the importance of their action
  o NO ACTION IS NOT AN OPTION
  o ADOPT A NO REGRETS STRATEGY

**Steps towards Policy Development**

• Situation Analysis
  o Pull from “The Why”
  o Existing Policies
    - Caribbean Water Policies – Spanning the Spectrum (FAO publication)
    - Other policy documents (Climate change adaptation plans, Initial National Communications, IWRM Roadmaps, other relevant sector plans, etc)
  o Development of a framework document, which identifies the key elements that should be included in the regional policy document (generic)

**Main Elements/Issues**

• Water allocation for agriculture
• Communication and outreach
• Capacity building
• Research and development
• Data management and National Water Information Systems

Main Elements/Issues

• Private sector involvement
• Participation and stakeholder engagement
• Institutional Arrangements – Inter-Sectoral Water Committee (e.g. WRA in Jamaica, Water Council in Guyana)
• Infrastructure Development (Rainwater harvesting systems, water storage facilities, drainage)
• Incentives (Rainwater harvesting systems, groundwater recharge, reduction of losses, water recycling etc.)

Main Elements/Issues

• Cultural context
• Traditional knowledge (from indigenous peoples who have been using coping mechanisms for centuries)

Capacity Building

• Training (start from small, involving the primary schools)
• Needs assessment to identify gaps and human resource requirements, as well as to assist in developing the training plans
• Data analysis, interpretation and dissemination (the message and the medium, etc.)

Research and Development

• Modelling of groundwater
• Assessment of groundwater availability
• Modelling of the socio-economic impacts of climate change, with specific reference to the agriculture sector (to help make the case for the consequences of inaction)

Implementation

• Development of an Action Plan for Implementation so that the policy takes life and becomes more than just a document on a shelf or a dust collector
Group Presentation 3

The WHAT: What are the practical on-farm measures to encourage IWRM in the face of climate variability?

*Water alone is not sufficient, it is water combined with all the other technological advances…*

Prof. Madramootoo

Oct. 9th, 2011

**CAMI Initiative:**

- Weather forecasts for farmers
  - Daily, weekly, decadal;
  - Micro-climates
  - 2 week dry spells etc…

- Communication
  - Train meteorology staff
  - Train farmers on how to use the information
  - Bulk text messaging pay service
  - Mobile application

**Soil Water Monitoring**

Geographic Information System
Land Slippage

- Land management / hillside management for soil conservation
  - Earth barriers (banks that break water velocity)
  - Economic crops (fruit trees etc)
  - Contour planting
  - Individual basin for tree cropping
  - Strategic clearing of crops
  - Terracing
    - Caution: Maintenance is KEY, Must be properly implemented

Land Slippage

- WHO?
  - Farmers
    - Installation, maintenance
  - Extension Officers
    - Training

- 179 -
Government (Conservation Authority)
- Installation, maintenance
- Demonstration / research plots
- Agricultural Policies (crop selection, land practices)

**Land Slippage: Examples**

- Barbados, Scotland District
  - Terracing and subsurface drainage removes water and stores in pond for irrigation
- St Lucia
  - Farmers trained on how to install and maintain terraces

**Drought**

- Mulching (plastic and organic)
- Irrigation scheduling
- Using drip irrigation
- Drought tolerant crops
- Geographic Information Systems (GIS), early warning
- Cover crops
  - Tropical kudzu, water grasses etc.
  - Root crops
- Intercropping and alley-cropping (guinea grass)

**Flooding**

- Plastic mulch
  - Equipment
- Tile drainage (farm or district level?)
- Trenches and canals (e.g. Trinidad)
- Ponds
  - Proper installation to reduce leakage
- Row covers to lessen wind and heavy rain

- 180 -
• Water tolerant crops
  o Dasheen, rice
• Fertilizer management
  o Slow release fertilizers, fertigation
• Geographic Information Systems

Pest and Diseases
• Integrated pest management
• Early warning system (CAMI)
  o Similar to SEC in USA
• Row covers
• Plastic mulch

Irrigation Support Systems
• Private Sector Professional
  o Farmers as sole knowledge worker, problem
  o Offer technical support to farmers
• Water Users Association (WUA)
  o District of farmers practicing a particular irrigation method
  o Registered association with laws governing it

Irrigation Support Systems
• Set up of Irrigation Authority
  o E.g. National Irrigation Commission in Jamaica
  o Data collection, monitoring and responding
  o Groundwater monitor to prevent salinity
  o Irrigation Master Plan (e.g. Jamaica)

Other Agricultural Uses
• Postharvest handling
• Livestock feeding
- Wastewater recycling

PRESENTATION TO THE ALLIANCE
PRESENTATION TO THE ALLIANCE

Climate Change Adaptation in Caribbean Agriculture: Enhancing Water Resources Management

BACKGROUND

Scientists, Representatives of Farmers Organizations, Climate Specialists, Water Authority Executives, Engineers, Researchers and Media-workers were amongst the participants at a three-day workshop that officially launched the Caribbean Week of Agriculture (CWA) on Sunday October 9, 2011, in Dominica. This workshop provided the scientific and rational bases for implementable Water Management Policy directives in response to climate variability and change.

Synthesizing of these policy briefs is in keeping with CARDI’s responsibility to provide the technical and socio-economic framework for consideration by the Region’s Policymakers. CARDI is part of the Consortium of CARICOM Institutions on Water Management, which is expected to assist Member States in coordinated consultation with national, regional and international partners in the formulation of Integrated Water Resources Management (IWRM) and Water Use Efficiency (WUE). This consortium also includes the CARICOM Secretariat, Caribbean Disaster Emergency Management (CDEMA), The Caribbean Environmental Health Institute (CEHI), CCCCC, CIMH, UWI, University of Guyana and University of Surinam.

CONTEXT

- Agriculture has played, in the past and continues to play a significant role in the socio-economic development of the Caribbean region.

- For some countries within the Region, agriculture contributes more than 20% of the GDP and is seen as a major economic driver.

- Climate variability and change will impact the water availability via changes in temperature, rainfall, intensity of storms and rising sea levels.

- The emerging picture for the Caribbean is one of reduced available water due primarily to increased variability of rainfall patterns and also due to the long-term drying trend that is anticipated under global warming.

- The trends have serious implications for agriculture within the Region, as production systems are predominantly rain fed; more than 50% of agricultural operations rely solely on rainfall.

- Agriculture in the Caribbean is sensitive to these variations in rainfall; therefore, “rainfall is king”.

- Not responding to this vulnerability is not an option, as it will have serious implications for Food and Nutrition Security goals, reducing poverty and hunger and economic development.
CONCLUSIONS (POLICY INFLUENCING ISSUES/POINTS)

- Access to water is essential for sustainable economic development and achieving Millennium Development Goals relating to a reduction in poverty and hunger.
- The current fragmented approach to water management needs (allocation) a focused response.
- An Integrated Water Resource Management approach is critical for sustainability.
- Collection and storage of reliable data pertaining to the water sector is imperative for the development of evidence-based policies.
- A science-based approach towards the development of policies that relate to water management for agriculture is necessary.
- The enhancement of current farming operations to improve the efficiency of collection, storage and use of water should be aggressively pursued e.g. water harvesting, crop mulching, soil erosion control, drought tolerant crops, water recycling.
- New and innovative technologies that improve the efficiency of water management practices should be pursued (e.g. GIS).
- Capacity building among technocrats as it relates to water management and climate change should be given high priority.

RECOMMENDATIONS (MOVING FORWARD)

- Development and strengthening of policies from which programmes and projects are developed and implemented.
  - Some of the elements and issues that are essential for the policy:
    - Water allocation for agriculture
    - Data collection and management
    - Research and development (scientific and socio-economic)
    - Capacity building
    - Information systems, communication and outreach (engagement – approach, timing)
- Scale up the implementation of current successful sustainable water management programmes and projects so as to increase the number of stakeholders/produces adopting these practices.

*Our vulnerability due to the variability of rainfall can affect our viability if our water management systems are not enhanced and therefore demands immediate action*
Agriculture plays a significant role in the socio-economic development of SIS. For some countries agriculture contributes >20% of the GDP and seen as a major economic driver. Climate variability and change will impact water availability – productivity of agricultural systems. Climate change impacts water availability via changes in temperature, rainfall, intensity of storms and sea levels.

Less water available water due primarily to:
- Increased variability in rainfall patterns
- the long term drying (drought)
- Drought may become more frequent and be more severe.

Based on the heavy reliance on rainfall, we are very Vulnerable to vagaries of climate. Not responding to this vulnerability is not an option.

Serious implications for Food and Nutrition Security, economic development and the livelihoods.
CONCLUSIONS
POLICY INFLUENCING ISSUES
for the efficient management and use of water in agriculture

Access to water - essential for sustainable economic development and achieving MDG (poverty and hunger)
Current fragmented approach to water allocation - focused response required.

CONCLUSIONS
POLICY INFLUENCING ISSUES
New and innovative technologies to improve water use efficiency must be pursued.
Capacity building of technical personnel is imperative (agriculture, climate change)

RECOMMENDATIONS
Develop/strengthen policies from which programmes and projects are developed and implemented
Essential elements:
- Water allocation for agriculture
- Data collection and management
- Research and Development (scientific and socio-economic)
- Capacity Building
- Information systems, communication and outreach
- Scale up the implementation of current successful sustainable water management programmes and projects.

Our vulnerability due to the variability of rainfall can affect our viability if our water management systems are not enhanced and therefore demands immediate action.
APPENDICES
# Appendix 1

## Climate Change Adaptation Contact List

**DOMINICA - 2011**

<table>
<thead>
<tr>
<th>No.</th>
<th>Name/Designation</th>
<th>Organization/Address</th>
<th>Tel/Fax/Mobile/E-mail</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Prof. Nazeer Ahmad Emeritus Professor</td>
<td>UWI, St Augustine, TRINIDAD AND TOBAGO</td>
<td>Tel: 868-645-5274 <a href="mailto:nazeer.ahmad@sta.uwi.edu">nazeer.ahmad@sta.uwi.edu</a></td>
</tr>
<tr>
<td>2.</td>
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