

SUSTAINABLE WATER MANAGEMENT UNDER CLIMATE CHANGE IN THE SMALL ISLANDS STATES OF THE CARIBBEAN (WATER-aCCSIS)



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Contributing Organisations:

Caribbean Community Climate Change Centre (CCCCC)

Centre for Resource Management and Environmental Studies (CERMES) – UWI Cave Hill

Caribbean Institute for Meteorology and Hydrology (CIMH)

Climate Studies Group Mona – UWI Mona

Department of Life Sciences – UWI St Augustine

Mona GeoInformatixs - UWI Mona

Sir Arthur Lewis Institute for Social and Economic Studies (SALISES) –UWI St Augustine

Location of Study: Barbados, Trinidad & Tobago, Grenada, Jamaica

Prepared by: Dr Adrian Cashman University of the West Indies

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Abbreviations

Acronym	Meaning
CARICOM	Caribbean Community
CCCCC	Caribbean Community Climate Change Centre
CERMES	Centre for Resource Management and Environmental Studies
CIMH	Caribbean Institute for Meteorology and Hydrology
CSMG	Climate Studies Modelling Group
DAD	Direct Area Downscaling
GIS	Geographic Information System
HCV	High Conservation Value
IDRC	International Development Research Centre
MGI	Mona Geoinformatics Institute
PRECIS	P roviding RE gional C limates for Impacts S tudies
SALISES	Sir Arthur Lewis institute for Social and Economic Studies
SIDS	Small Island Developing States
SLF	Sustainable Livelihoods Framework
SRES	Special Report on Emissions Scenario
UN	United Nations
UWI	University of the West Indies
Water-aCCSIS	Sustainable W ater M anagement under C limate C hange in S mall Islands S tates of the Caribbean
WP	Work Package

1. EXECUTIVE SUMMARY

1.1 Introduction

In November 2012, The Centre for Resource Management and Environmental Studies (CERMES) at the Cave Hill Campus of the University of the West Indies were notified by the International Development Research Centre (IDRC) that it had been awarded a research grant. The research grant was to undertake the 'Sustainable Water Management under Climate Change in Small Island States of the Caribbean' Project, later to be known by the acronym Water-aCCSIS. The main focus of the Water-aCCSIS research project sought to understand the ways in which climate change might impact water availability at the catchment level. It also sought to investigate the linkages with the provisioning of environmental goods and services that contribute to the functioning of catchment areas as well as potential social impacts. To this end, Water-aCCSIS has work packages that investigate climate downscaling, vegetation modelling, environmental health, ecosystem services and livelihoods. The central focus that affects all of these is the hydrological functioning of catchments and the extent to which climate change and climate variability will affect the availability of water and the inter-connected effects on the environment.

Climate change and variability have the potential to impact the provision of ecosystem services and freshwater availability through biophysical changes as well as changing patterns of use and consumption. This interdisciplinary research project further investigates the linkages between livelihoods and ecosystem services, and how they might be affected under projected climate changes as well as how climate change and variability could affect water availability. Understanding these factors is vital to the formulation of robust adaptation strategies. The overall goal of this interdisciplinary research programme was to contribute to the improvement of water management and adaptation strategies of Caribbean Small Island Developing States (SIDS).

This goal was achieved via the fulfilment of the following objectives:

Objective 1: To downscale Global and Regional climate model outputs to local level using different downscaling techniques and the Representative Concentration Pathways (RCPs) of the IPCC.

Objective 2: To model landscape functionality through fieldwork and the use of models within an integrated modular systems-based approach.

Objective 3: To develop improved coupled landscape-hydrological modelling approaches that can accommodate sparse data availability, for selected pilot catchments as a means of assessing water demand, consumption and availability under different climatic regimes for the medium and long-term, considering possible feedback mechanisms.

Objective 4: To develop and evaluate adaptation strategies that consider water security, social vulnerability and impacts, valuation of environmental services and payment for ecosystem services instruments, societal norms and, socio-economic performance at local to national levels through the use of future Foresight Scenarios that describe possible future states of governance and societal values.

Objective 5: To provide evidence-based advice to national and regional institutions to assist in the development of robust water management plans that mainstream Climate Change into planning and adaptation process through improved channels of communication, advocacy and, policy coordination which is essential to the underpinning of sustainable development and, incorporate local perspectives and values into governance arrangements.

Objective 6: This objective is a cross-cutting theme and is embedded in each of the previous five objectives. This objective will increase the standing and research capacity of regional institutions through the development of networks between scientific, professional and community-based partners. Additionally, this objective allows for training in integrated water resources management and; the effective dissemination of the results of the work through engagement with national and regional policy makers, water sector practitioners, community partners and, the regional and international academic community.

The research programme extended current research by investigating new areas as well as linking natural and social science to better inform resource management and adaptation strategies. The approach enabled the investigation of the differentiated impacts on: water availability-scarcity; anthropogenic-ecosystem water requirements; vulnerable groups; droughts and; the contribution of ecosystem services.

The research work was carried out by a consortium of institutions located across the Caribbean. They included from the University of the West Indies; the Department of Physics and Mona Geoinformatics Institute in Jamaica, the Department of Computer Sciences and CERMES in Barbados, The Department of Life Sciences and SALISES in Trinidad. In addition, CIMH located in Barbados whilst the CCCCC located in Belize and has partnered with INSMET in Cuba to assist them.

The research work carried out by each of these institutions focused on four pilot sites located on the island of Carriacou in Grenada, Speightstown in Barbados; Rio Cobre in Jamaica, and Nariva in Trinidad. Coordination between sites and work packages was a major challenge for the project. Speightstown is located on the west coast of the island of Barbados. It is the smallest watershed out of the four being focused on for this project with an area of 8 square kilometres. Carriacou is a part of the Grenadine Islands located north east of its parent island of Grenada. The island is approximately 34 square kilometres. The Rio Cobre watershed is located in the parish of St. Catherine to the south coast of Jamaica. The watershed is approximately 1,250 square kilometres and contains the renowned Rio Cobre river. The Nariva watershed is located on the eastern coast of Trinidad and has the main feature of the Nariva Swamp. With the Nariva Swamp being a RAMSAR site, the majority of it comprises of Wetlands and swamps. The watershed is 495 square kilometres. **Table 1** indicates the pilot sites where research was carried out by a work package.

Table 1: Pilot Sites where research was carried out

	WP1	WP2 & 9	WP3	WP4	WP5	WP6&7	WP8	WP10	WP11	WP12	WP13
Barbados	X	X	X		X	X	X	X	X	X	
Grenada	X	X	X	X	X	X	X	X	X	X	
Jamaica	X		X	X			X		X		
Trinidad	X	X	X	X	X	X	X	X	X	X	

The outputs from the various work packages through this research included:

- The provision of regional scale climate variables at both 25 km and 10 km grid level at daily time steps up to 2100. These have contributed to the growing body of information on climate change scenarios in the Caribbean.
- Outputs from downscaled global and regional climate model were used to develop assessment of future vulnerabilities and water scarcity.
- An expanded Livelihood Vulnerability Framework and Index has been developed and applied to the pilot sites in Barbados, Grenada and Trinidad. and, capacity building on how to create and use the livelihood vulnerability indices.
- Training course in vulnerability assessment methodologies has been held with stakeholders in Trinidad.
- The development of land use maps and land use classification for pilot sites from local data and satellite imagery. The development of 17 land use classes used to determine the land cover of each watershed.
- The formulation of best case and worst-case land use scenarios using the development and zonation plans for each country.
- Water Poverty Index (WPI) was calculated for three of the pilot sites, based on detailed site surveys and questionnaires.
- Development of a rapid microbial water quality test.
- Identification of bacteriological contamination in water supplies at the Trinidad and Grenada pilot sites.
- Quantification of the value of ecosystem services in the Grenada and Jamaica pilot sites.
- Application of the WEAP water availability modelling approaches for all four pilot sites. Baseline runs for Barbados (Speightstown catchment) and Carriacou have been completed and then the impact of climate change on water availability in the near to medium term have been investigated.
- The creation of regional and national Foresight Scenarios. The scenarios were used to inform the development of water availability modelling.

The expected outcomes from this work were to be as shown in **Figure 1**.

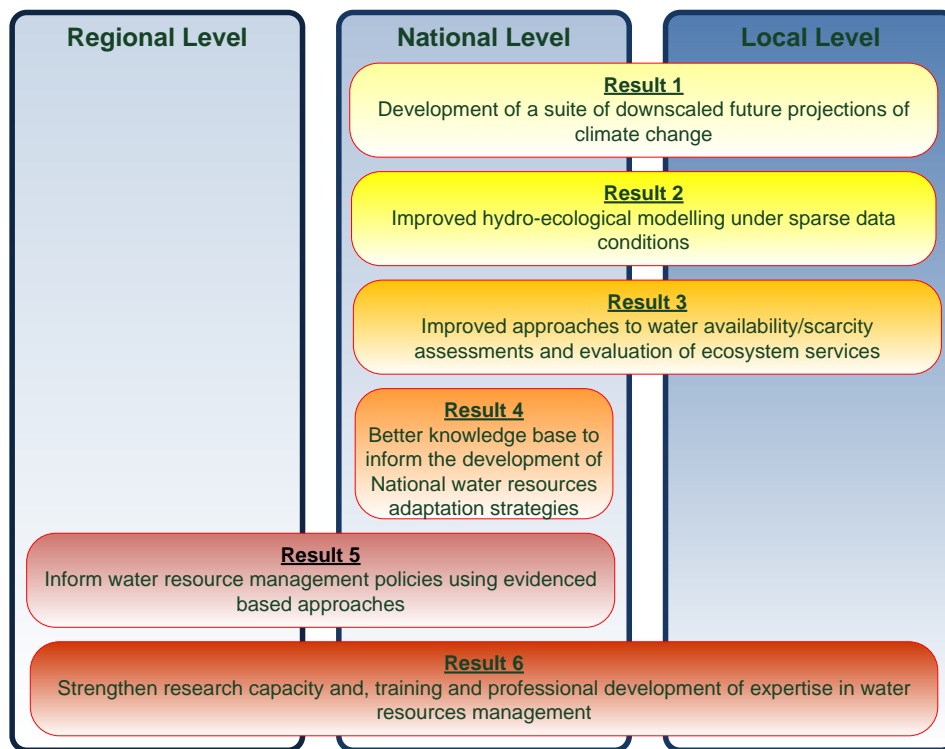


Figure 1: Proposed Results and Outcomes

Result 1: The Climate Studies Group Mona at UWI Mona did develop downscaled climate projections for the areas covering the pilot sites at 50km² and 25km² resolution.

Result 2: Hydrological modelling was completed for Carriacou – surface water hydrology and, Barbados, - groundwater model. Basic ecosystem models using InVEST of nutrient and sediment flows for Barbados and Trinidad were carried out. The expected outcome of improve hydro-ecological modelling was not fully achieved.

Result 3: The use and application of the WEAP modelling software to three sites, Rio Cobre was not undertaken, was successfully undertaken. A further development was the linking of WEAP software with hydrogeological modelling software MODFLOW. The evaluation of ecosystem goods and services was undertaken and include an assessment of forest vegetation species changes in Carriacou, Nariva Swamp and Rio Cobre, and valuation of ecosystem goods and services for Carriacou and Rio Cobre.

Result 4: The use of WEAP coupled with the outputs on future foresight scenarios has provided an improved base on which to develop water adaptation strategies.

Result 5: Not achieved.

Result 6: Research capacity has been strengthened particularly with respect to the following work packages; 1, 2, 3, 4, 5, 8, 9, 10 and 11. The expected training and professional development outcome has not generally been achieved.

Generally, dissemination in the form of published journal articles has not reached the expected level. This is could change as former work package persons begin to complete their studies and work on journal papers. However, much of the work undertaken has been presented at conferences through posters and papers, more than was originally intended.

1.2 List of Work Packages

Table 2: Names of Work Packages and Responsibility

Work Package Number	Description	Responsibility
1	Climate change downscaling	Climate Studies Group, Dept. of Physics, Mona, UWI

2	Livelihoods modelling	SALISES, St Augustine, UWI
3	Remote sensing and GIS data acquisition	Mona Geoinformatics Institute, Mona, UWI
4	Vegetation Modelling	Dept. of Life Sciences, St Augustine, UWI
5	Environmental Health Modelling	Dept. of Life Sciences, St Augustine, UWI
6 & 7	Hydrological Modelling	Caribbean Institute for Meteorology and Hydrology Additional support by Depts. of Geography & Civil Engineering, St Augustine, UWI
8	Ecosystem Services Modelling	INSMET Cuba, through Caribbean Community Climate Change Centre and Dept. of Life Sciences, St Augustine, UWI
9	Vulnerability Impact Assessment	SALISES, St Augustine, UWI
10	Water Assessment	CERMES, Cave Hill, UWI
11	Future Foresight Scenario Modelling	CERMES, Cave Hill, UWI
12	Adaptation Generation and Evaluation	CERMES, Cave Hill, UWI
13	National Level Water Resources Adaptation Strategies	Caribbean Community Climate Change Centre

2. CONTRIBUTION OF THE PROJECT TO ADDRESSING THE RESEARCH PROBLEM

2.1 General

An accumulating body of observations has indicated that anthropogenic climate change is already impacting the natural world. It has also been well established, and most recently highlighted at the Paris Climate Change Conference in December 2015, that small island states across the world are already amongst the first nations experiencing the negative impacts of such changing climate conditions. The long list of projected and already experienced negative impacts for these islands such as those in the Caribbean include, but are not limited to: (i) decreased supply and access to freshwater supplies as a result of decreased rainfall, increased frequency and intensity of extreme weather events leading to large-scale damage and disruption, increasing temperatures as well as contamination of islands' freshwater lenses by salt water intrusion; and (ii) species extinctions as well as the shifting and general reduction of species distribution ranges – both within terrestrial and marine environments (Maharaj and New 2013).

There is a growing consensus that “the potential impact of climate change on society will, in many cases, be transmitted through the medium of water. If we are to live in a water secure world, water management is critical to adaptation.” (GWPO, 2010). The IPCC in its Synthesis Report (2008) noted that the Caribbean Region is likely to be particularly affected by climate change with rising numbers of people exposed to increased water stress. Furthermore, it has been suggested that “disruptions in rainfall and freshwater supply threaten the very existence of small island and low-lying coastal states of the Caribbean” (CCCCC, 2009). The impacts of climate change and the Caribbean Region have been detailed by the UNEP (2008) which stresses the need to develop vulnerability and adaptation assessments as well as the need for research into the effects of global environmental change on natural and anthropogenic systems.

The lack of empirical research linking what is known about the likely changes in climate to hydrological impacts and the interplay of responses between water, ecosystems and human activities at the catchment scale presents a major challenge. This is especially true in the Caribbean, where the few reported studies of the potential impact of Climate Change on hydrological systems have focused on stream flows (in Belize and Trinidad) or the impact on groundwater balance (Jamaica and Barbados). The main issue in catchment modelling is lack of data, especially when it comes to climate, flow and water quality data. Thus, one of the challenges is how to better understand the potential impacts and hence formulate adaptation strategies when data is sparse or missing, and providing meaningful results given these limitations.

Whilst water availability is likely to be impacted by climate change so too is water use by human activities and ecosystems. Whilst there is increasing interest in ecosystems approaches to water resources management (Doulgeris et al., 2012) to date this has relied on the use of existing hydrological models in which the influence of variables such as land cover is treated as a stationary input rather than being able to accommodate feedback. Future climate changes and their impacts on ecosystems will mean that greater attention will have to be paid to the maintenance of ecosystem functions, especially as current planning and management practices inhibit the ability of ecosystems to respond to climate change. Understanding the value of the goods and services that ecosystems provide will be a necessary step to motivating adaptation.

There is increasing interest in the interplay between natural and anthropogenic systems in formulating possible responses to climate change (Nilsson and Persson, 2012). Scenarios provide a means by which impacts, adaptations and vulnerabilities that arise from the interplay can be explored. Global climate change is seen as the most serious threat to sustainable development faced by CARICOM states (CCCCC, 2009) and in response the CARICOM Heads of State requested the preparation of a “Regional Framework for Achieving Development Resilient to Climate Change”. Under Strategic Element 2: promote the implementation of specific adaptation measures to address key vulnerabilities in the region, Goal 1 was to “promote the adoption of measures and disseminate information that would make water supply systems resilient to climate-induced damage”.

The aim of this research project was to investigate the ways in which future climate changes might affect a variety of interconnected aspects affecting water availability. The first step was to look at the individual components and then to seek to integrate them to form the basis of adaptation options. These adaptation options take into account the influence that socio-economic and political factors can play in shaping which adaptation options are considered relevant.

2.2 Reflections

2.2.1 Five most important results

The five most important outputs or outcomes from the project are as follows:

- 1 The development of the Sustainable Livelihoods Indices which incorporates factors associated with disasters and climate change. By incorporating the additional dimension, it takes into account the exposure of communities to the effects of disasters and climate change and in doing so provides decision-makers with a tool by which they can explore the potential effect and effectiveness of policy interventions. **Project Output**
- 2 The comparison of three alternative methods of investigating bacteriological water quality provides confidence in the use of the Compartmented Bag Test as a quick and effective method of testing. **Project Output**
- 3 Novel methods based on rDNA sequencing were used and applied to investigate the microbiology and pathogens as a means of identifying risks present in drinking water. **Project Output**
- 4 An innovative approach to developing future foresight scenarios at the regional level to inform the formulation of acceptable adaptation options. The approach can be applied to other circumstances and sectors. The outputs have been used in presentations to Caribbean Ministers, to inform the Barbados Water Authority of future trends in water resource availability and, further research to be conducted on macroeconomic modelling supported by the Stockholm Environment Institute. **Project Output**
- 5 A strong and supportive relationship has been developed with the people and government of the island of Carriacou. The relationship forms the basis for the support of further research and implementation projects. A spin-off has been to support applications from Carriacou to the Japan-Caribbean Climate Change Cooperation fund. **Project Outcome**

2.2.2 Most significant research outputs

1. The project has supported three PhD candidates, there was a fourth but they dropped out for personal reasons but did continue on to study at UNESCO IHE Delft, **the largest international graduate water education facility in the world.**
2. The project provided research employment opportunities for 10 postgraduate students. To this can be added a further six students, one of whom was a PhD candidate who have benefited by focusing their research projects around aspects of the research project and accessing project data. These students were not financially supported but received in-kind support. The original proposal indicated that 12 graduate students would be trained. One of the researchers employed is now planning to study for a PhD in Canada.

3. At the community level focus group discussions on the experience of disaster and climate change and how this shaped individual and community level adaptation were held in Carriacou, Nariva and Rio Cobre.

2.2.3 Research outputs

1. A list of research papers as outputs is provided in Appendix 1.
2. Training manual for GIS.
3. Videographic output from this project can found on the CERMES [Youtube](#) channel and [Twitter](#) account.

2.2.4 Outputs not completed

1. The development of a waterborne diseases index, coupled to the water poverty index was not developed as fieldwork and laboratory testing was first delayed and then was more extensive than anticipated. The work package ran out of time.
2. Vegetation modelling for Carriacou was not complete due to limited available resources in the Forestry Department.
3. The hydrological modelling of the Rio Cobre and Speightstown catchments were not completed. There were two main reasons. Firstly, the available data to build the models was incomplete. Secondly, and more importantly, the work package started late and did not put in sufficient human resources.
4. The hydrological model of Nariva started late due to the challenges encountered by CIMH. Field data required for the work was incomplete. To address this the project embarked upon field instrumentation and data collection. But this was insufficient to be able to calibrate and validate the model.
5. The development of adaptation options was hampered by the late start of other work packages and human resource limitations.
6. No work could be done on developing water resource adaptation strategies as the basic outputs from other work packages were not available when the project was drawing to an end.

2.2.5 Importance of funding this research

1. The research has made contributions to the understanding of the importance of understanding how the various different 'capitals' can be used to address livelihood vulnerability in the face of disasters and climate change through policy interventions.
2. The environmental health work on water quality has underlined that though there can be a wide range of pathogens present, not all are a risk to human health. It has highlighted the need to better understand the risks from water quality in the context of tropical environments.
3. Innovative ways are going to have to be developed to overcome the data limitations with respect to climate and hydrological data if catchment modelling is to play a role in understanding and managing the regions water resources. Reinforces the importance of basic environmental monitoring and data collection as well as the need for water resources modellers.
4. Highlighted the need for integrative modelling water resources and water demand. The research points the way in which they can be combined, though much more work needs to be undertaken.
5. The magnitude of future water resources shortfalls in supplying demand has begun to be quantified, indicating that the region is likely to face increasing water stress.
6. The foresight modelling, coupled with the adaptation options has begun to highlight the importance of understanding socio-political factors in developing acceptable adaptation options. This has focused attention on the importance of institutions and regulatory regimes; governance can shape adaptation as much as technical considerations.

2.2.6 What has happened as a result of the project

1. As a result of the Speightstown groundwater resources water availability work, funding for further research into groundwater modelling and future water demand projections for Barbados has been included in a recently awarded Green Climate Fund grant to the Barbados Water Authority, through the CCCCC.
2. Under the same Green Climate Fund grant, funding for research into a payment for ecosystem services scheme for enhancing groundwater recharge as an adaptation option has been included along with the installation of monitoring equipment.

3. The Stockholm Environment Institute has made funding available to continue with the development of macroeconomic model of island economies.
4. Development of hydro-economic models that integrate the impact of climate change on agriculture, domestic and tourism water demand and consumer welfare.
5. Continuation of work on developing a waterborne diseases index as part of a PhD study.

3. PROGRESS TOWARDS MILESTONES

Table 3: Research Findings

Work Package #	Description of Research Findings
WP1	The provision of regional scale climate variables at 25 km grid level at daily time steps up to 2100. The climate variables have been used as input into a Direct Area Downscaling model to produce further downscaled climate variables (temperature and precipitation) for three of the four pilot sites. These data are required as inputs into models being developed and used by other work packages. For example, using rainfall projections calculated for the time period 2065-2075 WP10 has used MODFLOW software to describe a 3-dimensional groundwater model for the Speightstown catchment to investigate the impact of climate change on water availability from the aquifer.
WP2	<p>Results of the Livelihood Vulnerability Index for Carriacou, Nariva and Speightstown have been produced. From the work in Nariva and follow up work after a major weather event, it was noted that community interactions have been changing significantly. Young people indicated that their willingness to collaborate was low and wanted to migrate out of the area as it was seen as becoming an increasingly marginalised place to live. Consequently, the older community members viewed them as un-participating and not keeping up with traditions. Nariva had good social capital scores, but this may not be for long and could be a potential source of vulnerability. Additionally, for Nariva the economic pillar has not impacted as expected.</p> <p>In Carriacou anecdotally and during discussion the community perceived themselves as close knit community, but the analysis of the field data suggested that social cohesion was not as strong as people perceived it to be. This is a counter-intuitive finding with potential implications for adaptation options.</p>
WP3	This primary concern was the provision and development of geographic information outputs that provide a platform and support for other work packages, particularly in respect of modelling. Based on the analysis of past land use changes over time three potential future land use change maps were developed. These were made available to other work packages
WP4	<p>The milestones achieved consist of the following:</p> <p>Rapid Botanical Surveys (RBS) of all vascular plants were conducted only within the Nariva watershed as limited resources did not allow for the same within Carriacou and Rio Cobre. Identification of vascular plants collected in RBS surveys to species level was completed for all the specimens collected within the Nariva watershed. List of High Conservation Value (HCV) species within the Nariva watershed was produced. HCV species were defined from a combination of (i) ecological analyses of the species data collected, (ii) a listing of globally rare species from specimens collected, (iii) a listing of species of local/regional conservation concern from specimens collected.</p> <p>Models of suitable environmental space of each species under present and future medium and long term climatic conditions were produced for the Nariva Watershed: species models of satisfactory strength were mapped. Models of majority of forest types for Rio Cobre were strong enough for validation. This allowed for the production of vegetation change maps showing areas of species range contraction, expansion and stable ones. Collective change maps – which integrates projected combined response (contraction, expansion and stable zones) of pre-selected groups of species within catchment - For the Nariva Watershed: change maps of individual species from 9 above were used to create collective change map for the group of species modelled. No change maps were created for Carriacou and Rio Cobre as forest types are distinct and do not occupy the same territory at any given point in time.</p>
WP5	A total of 607 surveys were completed and collected for the Water Poverty Index (WPI) from Barbados (206), Carriacou (188) and Nariva (213) and a WPI was calculated for each country. The calculated WPI values for Carriacou and Barbados for both wet and dry seasons are quite similar, a distinguishable trend was the

	<p>high access and capacity components for both countries.</p> <p>A total of 365 samples for Microbial Water Quality were collected. Three different analysis and testing procedures were developed including a novel rDNA approach to the identification of pathogens. The risk assessment indicated that the water quality was different by country as was expected given that sources of domestic water varied by country. Carriacou had the highest level of risk followed by Nariva and then Barbados.</p>
WP6/7	<p>A groundwater model for Barbados was developed which allowed the impact of climate change on groundwater to be investigated and from this a sub-model of the Speightstown catchment was developed. Rainfall-runoff modelling for the same catchment was made available from another project. For Carriacou a SWAT based hydrological model of water was developed that looked at the effect of climate change on run-off. A similar approach was attempted for the Nariva Swamp catchment but due to data limitations was not completed.</p>
WP8	<p>This WP is concerned with the future impacts of climate change and human activities on ecosystem goods and services both now and for 2035 and 2050 time periods. Research outputs from Carriacou suggest that the maintenance of soil quality provides the highest valued ecosystem services. In the Rio Cobre the impact of future changes in climate on hydrological functioning could result in significant loss of value in ecosystem services through the loss of forest. Preliminary modelling work in Barbados has highlighted the role of natural vegetation in retaining sediments on the land and preventing soil erosion. This has provided preliminary estimates as to how much sediment is retained and prevented from smothering the near shore coral reef systems, even over a small area of coastline.</p>
WP9	<p>This work package builds on WP2. Using the vulnerability index the potential impacts of different policy interventions were explored. For Nariva this indicates that policy interventions that improve knowledge and level of education have the biggest impact in reducing vulnerability. In contrast on Carriacou interventions that promote better social cohesion would reduce the vulnerability of communities, which runs counter to initial impressions.</p>
WP10	<p>Two complementary water availability modelling approaches were explored but only one was adopted; this used the Water Evaluation and Planning software (WEAP). It was used for the Carriacou, Nariva Swamp and Speightstown catchments. Sparse input data meant that simplified approaches had to be used in order to get outputs. It compares the different medium term future scenarios against a Baseline run for each catchment. The runs have highlighted the high vulnerability and significant reductions in monthly available water at all three pilot sites under climate change. In the case of Barbados, aquifer depletion is a serious threat, even assuming conservative development scenarios. For Nariva crop production would be severely curtailed without significant adaptation measures and, in Carriacou drought-like conditions will compromise agricultural production.</p>
WP11	<p>The e-Delphi consultation process was initiated, which not been attempted before in the Caribbean and this has provided experience in how this technique could be further developed. The outputs from the e-Delphi were transformed using a cross-impact approach to identify key areas and these were then linked with global Shared Socio-economic Pathways (SSPs) using conditional Bayesian probabilities. The result is a series of five future regional scenarios coupled with 16 story-lines, four for each country included in the project. These form the basis for guiding potential future adaptation strategies..</p>

4. SYNTHESIS OF RESEARCH RESULTS

Figure 2 shows the proposed relationship between the objectives of the research and the anticipated results. During the course of the project changes were made to the work carried out by the various work packages, see section 6.

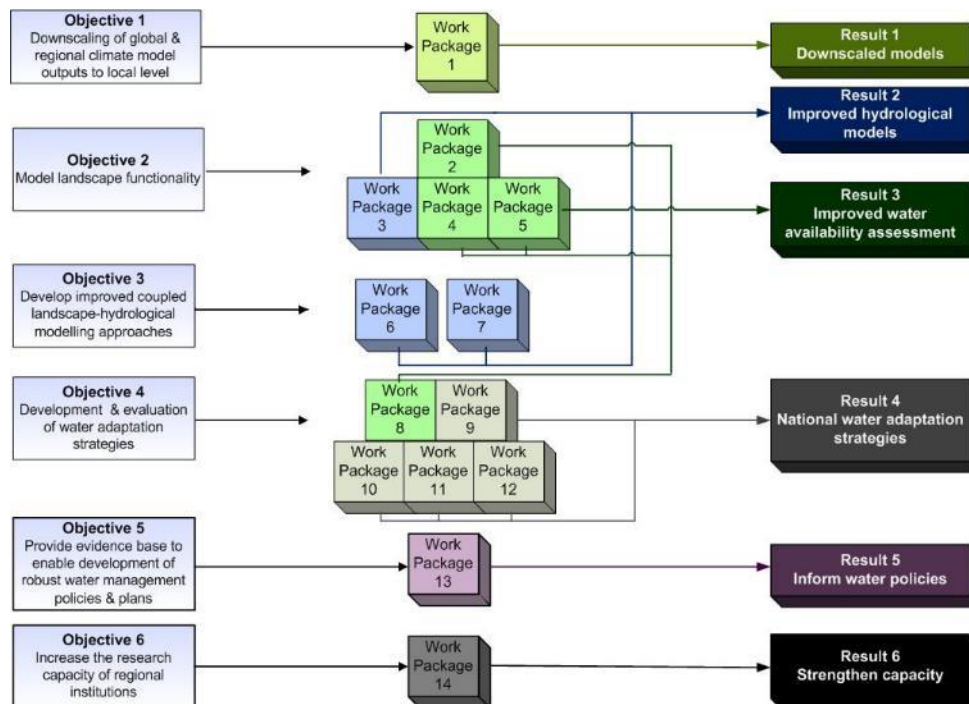


Figure 2: Relationship between Objectives, Work Packages and Results

The overall goal of the research programme was to contribute to the improvement of water management and climate change adaptation of Caribbean states through a better understanding of the potential effects of climate change on water resources and ecosystems. The Project set 6 overall objectives as reflected in **Figure 1**. For each of these the work packages involved will be highlighted, the methodologies adopted, the challenges and outputs will be described.

4.1 Objective 1: Downscale global and regional climate model outputs to local level

Work package 1 was the sole contributor to this objective.

4.1.1 Methodology

The objective of work package 1 was to downscale global and regional climate model outputs to local level.

The project activities were split between the Climate Studies Group Mona in the Department of Physics at UWI Mona under the leadership of Professor Michael Taylor and Computer Science at UWI Cave Hill with Dr John Charlery. The Climate Studies Group Mona is responsible for producing downscaled reanalysis, baseline and future climate data from regional climate models to two scales; 50 km² and 25 km² for the Caribbean Region and for two time slices. The IPCC Special Report on Emission Scenarios (SRES) was used to force the models as the data for the Representative Concentration Pathways were not available at the time. The PRECIS model utilizes boundary conditions from the HadCM3 coupled ocean-atmosphere global circulation model (GCM) for the Special Report on Emissions Scenarios (SRES) A1B scenario. Boundary conditions for five (5) members of the sixteen (16) member perturbed physics HadCM3Q ensemble along with the standard unperturbed output were used to provide “high resolution” outputs from PRECIS.

On the UWI Cave Hill Campus Dr John Charlery was to be responsible for the Direct Area Downscaling (DAD) of the output data from the regional downscaling. The DAD technique was developed by Charley and Nurse (2010) to generate further downscaled data appropriate to the catchment scale. In order to do this adequate geographical and temporal data coverage is required. This presented a challenge for the project. The following models were used to generate downscaled climate change models for the Caribbean Region:

Global Climate Models

HadCM3 (U.K. Hadley Centre)

ECHAM5 (Max Planck Institute)

Downscaling Models	Direct Area Downscaling Model (DAD)- regional to local	PRECIS Model	Regional	Downscaling
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4.1.2 Challenges

This work package was the source of the most significant delay to the project. Work packages 2, 3, 4, 5, 6&7 and 8 were dependent on receiving outputs from the climate modelling – it was one of two activities that were on the critical path for the project. The work was carried out by the Dept. of Physics Climate Studies Group Mona, the only group in the Caribbean capable of doing this work. However, this also meant that the Group had multiple calls on its time and resources and the person allocated to work on this project was overstretched which compromised progress. It also emerged at the start of the project that the Climate Studies Group Mona did not have the necessary computing storage capacity to process the climate runs. Resolving this contributed to the delays.

Apart from the personnel there were technical issues. Due to the specialised nature of climate modelling and regional downscaling the type and nature of the outputs from the climate modelling were only understood by other climate modellers but there were none in the other work packages. This led to not only misunderstandings but more important that the format of the climate outputs were not immediately compatible with the requirements of the other work packages. Resolving these issues involved much additional consultation.

The original timeline for completion of the downscaled reanalysis of climate variables was by the end of the first 12 months of the project. The Direct Area Downscaling (DAD) would follow from there for completion by month 18 with results available for the other work packages. Difficulties associated with not having sufficient resources, indicated above, had the effect of delaying the delivery of the first set of results to March 2014. As indicated above, even when the outputs started to become available the reliability of the data and its formatting was problematic and additional work had to be undertaken. Only then could a start be made on the DAD work. This too has been delayed for two main reasons. In order to undertake the DAD, time series data from a good coverage of existing weather stations is required. Sourcing and obtaining this data were a huge challenge and even then, a lot was of poor quality or gave insufficient coverage. Secondly, the person who was to undertake the work was over committed and did not give this work priority. As a result, this work has only been completed for Barbados and Trinidad in August 2015. Overall there was a delay of 18 months with all the consequent knock-on effects. Other work packages tried as best they could to accommodate the delays.

Because of the lack of historical climate data, the Carriacou spatial distributions of downscaled elements were not possible for that domain, leading to a major problem for modelling. The quality of data produced for Trinidad has been such that there was a spatial mismatch between temperature and rainfall data rendering much of the work unusable by other work packages.

The work package was on the critical path affecting particularly work packages 4, 6/7, 8 and 10 with the result these work packages have had to spend time and effort in looking and processing alternative approaches, such as the use of WorldClim data sets in one case and the generation of alternative downscaled data in another (i.e. WP6/7). It is important to note that at recent IPCC meetings the limits to downscaling have been considered and there is an emerging body of opinion that downscaling below 10km² is problematic, particularly for islands.

The slow progress with this work package and the lack of outputs, being on the critical path has delayed the whole project by at least 12 months. Coupled with this are the difficulties that have been experienced with the quality and usability of the DAD data for Trinidad and Carriacou. This too has had a knock-on effect.

The lack of reliable downscaled climate data for use by the other work packages has had the effect of discouraging them from publishing the results of their research.

Lessons Learnt

Climate modelling and downscaling should be treated as a separate research project and not included as a part of a larger project. Use existing available regional model outputs and apply appropriate area downscaling techniques.

4.1.3 Progress

The provision of regional scale climate variables at 25 km grid level at daily time steps up to 2100 was completed. The climate variables have been used as input into a Direct Area Downscaling model to produce further downscaled climate variables (temperature and precipitation) for three of the four pilot sites. These data are required as inputs into models being developed and used by other work packages. For example, using rainfall projections calculated for the time period 2065-2075 WP10 has used MODFLOW software to describe a 3-dimensional groundwater model for the Speightstown catchment to investigate the impact of climate change on water availability from the aquifer.

4.1.4 Findings and Outputs

Production of downscaled regional climate data:

- PRECIS – daily climate variables covering all four pilot sites at 50 km² and 25 km² resolution
- Three CMG Technical Reports

The results from this work feed into the wider work undertaken by the Climate Studies Group.

4.2 Objective 2: Describe landscape functionality and social-ecological systems

Work packages 2, 3, 4 and 5 all contribute to this objective.

4.2.1 Methodology

4.2.1.1 Work Package 2 – Livelihoods Modelling Methodology

The objective of work package 2 was to generate a framework for modelling sustainable livelihood vulnerability, which uses data on assets, socio-economic status, demographics, and land use and resource management strategies.

A sustainable livelihood framework (SLF) (DFID, 2000), was used to guide the collection of information on factors such as population demographics, access to natural capital, land use and resource management strategies, poverty and employment, economic activities, and cultural practices. To the traditional 5 Capitals approach to SLF, a sixth was added to take account of natural disasters and climate variability. A detailed questionnaire was developed for primary data collection required to populate the 6 capital pillars. Site survey work has been carried out in four communities in Nariva, 14 communities in Carriacou, and 4 in Speightstown. In addition to this, at the suggestion of the IDRC Project Office, additional fieldwork was carried out at all four pilot sites in the form of focus group discussions, although in the case of Speightstown there was zero response from the persons in the catchment area. The group discussions focused on elicitation of additional information on community experiences of extreme events and climate change and how they had and would adapt. The quantitative data were entered into a software analysis package which has produced a series of composite index scores. This information is used to investigate the vulnerability facets and the impact of different policies on the vulnerability indices.

Work package 2 generated data on the human activities that influence ecological dynamics at the scale of the catchment level, including intrinsic and extrinsic influences. Using a sustainable livelihood framework (SLF), which considers various capitals (which shape human's vulnerability context), policies, institutions processes and data (quantitative and qualitative) on factors such as population demographics, access to natural capital, land use and resource management strategies, poverty and employment, economic activities, and cultural practices was collected.

Indicators for the six (6) pillars were identified and developed with each pillar defined as a function of a series of attributes, which determined by its nature, its importance and how it can be quantified and measured. The vulnerability index comprised; environmental, physical, social, human, economic and natural disaster and climate variability pillars. Primary data collection was necessary to obtain the information required to populate the pillars. The quantitative data was complemented with key informants' interviews that provided a greater insight into the 'why' and 'how' questions. Additionally, the interviews allowed triangulation to the data sources and methods of collection.

The data was employed to construct sustainable livelihood indices to assess vulnerability and determine the impact of climate change on water availability in the chosen catchments. The indices were required by work package nine (9) to complete assigned tasks.

4.2.1.2 Work Package 3 - Remote Sensing & GIS Data Acquisition Methodology

The objective of work package 3 was to obtain the remote sensed and GIS data necessary for the modelling components of the project and to make this information available to the other work packages.

GIS data was sourced from a range of agencies in any available format for processing into a common database. To do this partners were asked to identify sources of information known to them. The agencies identified were approached and requested to release data. Often, the data had to be reformatted and in other cases, classifications used differed from one country to another and from one agency to another. Data were then integrated with satellite imagery data for different periods to categorize and evaluate land use changes, as well as secondary data from online sources regarding weather and climate information.

Seventeen (17) land use classes were developed to determine the land cover of each watershed. Each watershed displayed a different combination of land use classes, not all seventeen classes may have been present. Land cover classes were derived from satellite imagery using remote sensing methodologies. Spectral signatures were developed based on the reflectance values and properties of the imagery. From the signatures, the imagery was classified using the supervised classification tool in the ArcGIS software. Training samples were used to influence the supervised classification method by identifying characteristics specific to each class within the Area of Interest. Results from the supervised classification were then used to generate validation sample sets (Ground Control Points – GCP's) for field validation, in all four catchments. GPS units were used to identify these sampled points during the field reconnaissance. Where discrepancies were found between the modelled results and the sampled data, algorithms were changed to match the sampled data. The output was a series of land use and classification maps in ArcGIS available to work packages.

Three future scenarios were used for each watershed for the year 2050; as-is, best case and worst case. Scenarios were adapted from the methodology employed by *Caribbean Coastal Scenarios Project* developed by the Inter-American Institute for Global Change Research. To perform the change analysis, the land cover classification results for all years were used. Net losses and gains for each class could then be geometrically calculated using ESRI's ArcMap for each cross comparison period. To factor in the effects of climate change, the factors of rainfall and temperature were taken into account while doing the change analysis to generate the new land use. This was done only for the Rio Cobre watershed due to the availability of data which provides the required resolution to perform the change analysis.

4.2.1.3 Work Package 4 - Forest and Vegetation Species Modelling Methodology

The objective of work package 4 was to generate data on areas within selected watersheds that may support forests/key vegetation species within a future, changed climate. The literature was reviewed to determine criteria for the selection of High Conservation Value (HCV) species for water conservation for each of the study sites. A Rapid Botanical Survey (Hawthorne & Marshall, 2016) methodology was used to determine the vegetation and distribution of the HCV species for Carriacou and Nariva. This included the random generation of sampling of vegetation plots, processing and identification of samples and spatial analyses of species locational data. Due to the nature of forest and vegetation cover in Barbados – it is limited to ribbon-like gully features, it was decided that this approach was not suitable. In the case of Rio Cobre, the geographic extent of the area meant that it was beyond the budget to use this approach. In the case of Carriacou and Rio Cobre GIS analysis based on historic land coverage data of forest cover changes has been carried out. The next step was to use Environmental Niche modelling (MaxEnt) to carry out ecological analyses of key species looking at historic changes and using climate data modelling responses of forests to possible future changes under climate change. This enabled the generation of change maps for groups of species showing projected areas of species range contraction, expansion and stable zones.

The conducting of a vegetation survey and subsequent identification and data-basing of collected samples was carried out and completed for the Nariva Watershed without significant problems.

4.2.1.4 Work Package 5 - Environmental Health Modelling Methodology

The objective of work package 5 was to examine the interrelationship between the effects of climate change on human health by focusing on water quality and vector ecology and management of water-related diseases.

Fieldwork forms an integral part of this work package as it was necessary to collect water samples for laboratory analysis and DNA extraction during both wet and dry seasons. At the same time questionnaire surveys were conducted to be able

to construct water poverty indices for each of the sites. The questionnaire survey investigated the linkages between water resources and, water storage and use practices in three study sites – Carriacou, Grenada, Nariva, Trinidad and Speightstown, Barbados. From all three sites 340 questionnaires were completed and collected. The data collection provided the information for the calculation of a water poverty and environmental health index for each of the study sites. A Water Poverty Index (WPI) integrates physical estimates of water availability with socioeconomic variables to summarize poverty issues from a water resources perspective (Sullivan 2002). To calculate the WPI, the standard WPI survey instrument was used but modified to factor in the various social conditions for the countries. Care was taken to ensure the same data was collected for each country.

In the water samples, levels of microbial water quality and contamination were measured using three methods – traditional culturing approach, a modern rapid method (compartmented bag test, CBT). The third approach used a non-culture-based MiSeq next-gen 16s rRNA gene sequencing approach and parasite analysis using *Cryptosporidium*. Microbiological agents are an important indicator of quality. In this study *E. coli*, a common water quality indicator was used to determine the water quality in the catchments of interest. While the previous two methods only screened for one indicator organism, this method has the potential to screen for thousands of organism in small volumes of water using high-throughput sequencing of 16S rRNA gene amplicons (Roeselers et al. 2015). Sequencing analysis was carried out at the Genomic Medicine Laboratory J. Craig Venter Institute (JCVI) in California USA. This data will be used to develop risk scores for the water samples based on the organisms identified in the samples. This would be used to expand the microbial water quality and human health risk data collected. It was anticipated to be a more sensitive indicator of water contaminants for the three sites. Computer modelling was used to examine the effects of climate change on the spread and management of diseases such as dengue and gastroenteritis. DNA samples was extracted from any insects/microbes present to develop an environmental situation analysis and risk factor profile for each community.

Traditional methods have a long turnaround time for results and therefore have been the development of several rapid methods in recent years. One such method is the Compartment Bag Test (CBT). These methods are designed to given results in 24 hours and are easy to use and involve the potential for use by the non-skilled persons which is particularly relevant for disaster situations (Stauber, Miller et al. 2014).

Overall, this study demonstrated that 1) there remains a high reliance on rainwater harvesting in rural communities with varying levels of risk due to various water use practices, 2) testing for faecal contamination using traditional methods such as the CBT and mFC, while widespread and valuable, has its limitations in tropical environments 3) the dataset generated using Illumina MiSeq showed the high microbial diversity and detected a range of pathogenic and opportunistic organisms that exist in drinking water and 4) drinking water in the Southern Caribbean has a high prevalence of the *Cryptosporidium* parasite. These findings suggest a human health risk from drinking water which should be validated and can contribute to revising microbial water quality guidelines in the Southern Caribbean.

A waterborne disease index (WBDI) was to be developed by combining a standard Water Poverty Index (WPI) with a range of measured disease pathogens. The Waterborne Disease Index (WBDI) was planned but could not be completed as the project was wrapped up before this could be done.

4.2.2 Challenges

4.2.2.1 Work Package 2

The main challenges for this work package were associated with research personnel. The original project programme indicated that this work package would be completed within the first 18 months of the project. There were initial problems experienced in recruiting research staff with the recruited PhD candidate resigning in August 2014. Eventually, research assistants from existing projects were used, commencing in November 2014. The development of the survey instruments was slow for other internal reasons in SALISES and completed in February 2014. Training of field enumerators in Carriacou took place in July 2014 and fieldwork commenced in November 2014 and was completed by December. In Nariva fieldwork commenced in August 2014 and was completed in November. Work in Barbados commenced in March 2015. No work was carried out in Jamaica due to logistical and budgetary constraints.

There was an overrun of approximately six months and had a knock-on effect on work package 9 which uses the outputs from the fieldwork.

4.2.2.2 Work Package 3

In order to share the data with other work packages a computer server had to be installed and it wasn't until October 2014 that the server host was operational, resulting in delays in making information available. This was not anticipated during the development of the research proposal and it was only post-commencement that this matter was brought up.

It was anticipated that sourcing the necessary geographic information required by the project in electronic format would be challenging. However, due to the number of different agencies involved from across the region this proved to be more complicated and challenging than anticipated. One of the biggest difficulties has been identifying who holds data and the processes of applying for it to be released. In some cases, data was either not been available in electronic format but in paper copy or it was not available at all. This has been a source of delay.

Satellite imagery were received with inconsistent alignment and this affected the ground-truthing work. As a result ground-truthing was not completed for Rio Cobre until June 2015. This has had a knock-on effect on the completion of the land use classification, evaluation of land use changes and land use change modelling. The original programme had a completion date of September 2014, this work ended up being 12 months behind schedule.

As this work packages outputs became available to other work packages problems with the spatial alignment of the data was experienced by a number of work packages e.g. 4 and 8. Resolution of these had an adverse impact on the work of these work packages which were eventually resolved.

4.2.2.3 Work Package 4

Following a site visit the Barbados study area was found to be unsuitable for the Rapid Botanical Survey technique proposed by the work package team. There is little forested area in Barbados and what there is, is confined to linear gully drainage systems. The Rio Cobre catchment in Jamaica (1,250 square kilometres) was too large to be accommodated the application of the Rapid Botanical Survey technique within the work package budget, timescale and personnel resources available. In Jamaica an alternative approach based on available time series historical data of forest cover and climatic data coupled with downscaled regional climate modelling was used to model changes in forest composition over time and by climate scenario, see below. Only the Nariva Swamp and Carriacou catchments were deemed suitable for the Rapid Botanical Survey technique.

Fieldwork for this work package was heavily dependent on the support of the national Forestry Divisions and without their support could not be undertaken. Although there was initial support in Carriacou, part of the way through the fieldwork, support was withdrawn over issues resource limitations and of payment to Forestry Division personnel. As a result, fieldwork was only successfully carried out only in Nariva. In order to overcome these challenges, an alternative approach for forest and vegetation modelling for Carriacou and Rio Cobre had to be developed, based on available forest cover mapping. This change in approach introduced additional work and time spent.

Two major issues adversely affected this work package. The first was the production of the downscaled climate data, as previously noted. In addition to the delays in having access to data, the quality of the downscaled data was such that it is not useable for Carriacou and Nariva, necessitating the investigation of other more suitable sources of data. These were eventually made available. The second issue was the accuracy of the land use mapping. The accuracy was such that coverage in some cases has been very coarse and in others additional ground truthing has revealed errors at the local scale- important for this study.

Another main problem encountered was the unavailability of adequately downscaled climate data to support the vegetation modelling analyses. Local climate variations play a large role in the response of vegetation species to changing climate. With the current state of development and knowledge, it is unlikely that this can be addressed.

Significant delays were encountered by the non-communication and non-availability of colleagues from the Climate Studies Group Mona, responsible for providing the climate data. There was very little engagement by them with this work package for the initial two years; any work package dependent on climate data were left with little or no information as to the details of the data being provided and when these data would be provided,

The original timeline was for this work to have been completed by month 24, i.e. February 2015. The work was not completed until late 2016.

4.2.2.4 Work Package 5

This work package struggled with HR issues which have taken a considerable time to resolve; the original PhD student was appointed in September 2014 but resigned at the end of July 2014 and a replacement had to be found to take over the work. Part way through the work package leader had a heart attack and sadly died. As a result, there was a loss of leadership.

The original proposal for work to be carried out under this work package was to look at the effects of climate change on human health by focusing on vector ecology and management of water-related diseases. This would have included purchasing and using software (DENSIM) to model the spread and management of vector borne diseases. Prior to the start of this project, the software had been purchased under a different grant and was therefore not required. The work package leader requested that the funds be re-allocated, still within Research Expenses, to the purchase of water quality sampling and testing equipment, required to carry out fieldwork into the presence and distribution of water related diseases. Delays were encountered in sourcing and obtaining field testing kits.

The change in approach away from epidemiology to water quality collection and testing necessitated work to be carried out in both wet and dry seasons. Samples had to be sent away for DNA sequencing whilst others were analysed either in situ or back at the university laboratory. The work done in this work package involved a considerable amount of laboratory work, which could not have been completed without the assistance from persons from the Parasitology and Mycology labs that volunteered their time for collection and processing of samples. The work was completed at the end of 2016.

Lessons Learnt

Allow more time for recruitment of research personnel. Develop requirement checklists. Change of scope and the associated changes to a work package implied by this should have been documented and discussed with the Project Officer. If fieldwork intensive research is intended, make adequate budgetary provision.

4.2.3 Progress

Results of the Livelihood Vulnerability Index for Carriacou, Nariva and Speightstown have been produced. From the work in Nariva and follow up work after a major weather event, it was noted that community interactions have been changing significantly. Young people indicated that their willingness to collaborate was low and wanted to migrate out of the area as it was seen as becoming an increasingly marginalised place to live. Consequently, the older community members viewed them as un-participating and not keeping up with traditions. Nariva had good social capital scores, but this may not be for long and could be a potential source of vulnerability. Additionally, for Nariva the economic pillar has not impacted as expected.

In Carriacou anecdotally and during discussion the community perceived themselves as close knit community, but the analysis of the field data suggested that social cohesion was not as strong as people perceived it to be. This is a counter-intuitive finding with potential implications for adaptation options.

This primary concern was the provision and development of geographic information outputs that provide a platform and support for other work packages, particularly in respect of modelling. Based on the analysis of past land use changes over time three potential future land use change maps were developed. These were made available to other work packages.

The milestones achieved in work package 4 consist of the following:

Rapid Botanical Surveys (RBS) of all vascular plants were conducted only within the Nariva watershed as limited resources did not allow for the same within Carriacou and Rio Cobre. Identification of vascular plants collected in RBS surveys to species level was completed for all the specimens collected within the Nariva watershed. List of High Conservation Value (HCV) species within the Nariva watershed was produced. HCV species were defined from a combination of (i) ecological analyses of the species data collected, (ii) a listing of globally rare species from specimens collected, (iii) a listing of species of local/regional conservation concern from specimens collected.

Models of suitable environmental space of each species under present and future medium and long term climatic conditions were produced for the Nariva Watershed: species models of satisfactory strength were mapped. Models of majority of forest types for Rio Cobre were strong enough for validation. This allowed for the production of vegetation change maps showing areas of species range contraction, expansion and stable ones. Collective change maps – which

integrates projected combined response (contraction, expansion and stable zones) of pre-selected groups of species within catchment - For the Nariva Watershed: change maps of individual species from 9 above were used to create collective change map for the group of species modelled. No change maps were created for Carriacou and Rio Cobre as forest types are distinct and do not occupy the same territory at any given point in time.

A total of 607 surveys were completed and collected for the Water Poverty Index (WPI) from Barbados (206), Carriacou (188) and Nariva (213) and a WPI was calculated for each country. The calculated WPI values for Carriacou and Barbados for both wet and dry seasons are quite similar, a distinguishable trend was the high access and capacity components for both countries.

A total of 365 samples for Microbial Water Quality were collected. Three different analysis and testing procedures were developed including a novel rDNA approach to the identification of pathogens. The risk assessment indicated that the water quality was different by country as was expected given that sources of domestic water varied by country. Carriacou had the highest level of risk followed by Nariva and then Barbados.

4.2.4 Outputs

Under work package 3, the following outputs were achieved:

- GIS data acquired and collated
- Field sampling for validation of spatial models.
- Land use classification and changes for the pilot site catchments.
- Terrestrial ecosystem spatial characterization and scenarios created.

Land use changes for the four territories through to 2050 showed changes to 2 main land use categories – agricultural and primary/secondary forests. Some locations showed increases in agricultural land use, while others showed declines. Climate change-based land use conversions, whether in as-is, best-case or worst-case scenarios, have specific impacts on certain classes more than others, especially natural land use categories such as primary and secondary forests, wetlands and swamps, and scrublands. Climate change may also affect agricultural and field land uses, but these may also be anthropogenically influenced through artificial irrigation, as well as economic demands, neither of which are assessed here. This complemented the work of WP4;

Completion of sampling, identification and databasing of species within Nariva watershed. Carriacou was started but due to logistical issues this had to be shelved.

- Processing of species location data within Nariva watershed.
- Spatial analyses of species location data for modelling analyses.
- GIS analysis of Forest cover change within Rio Cobre and Carriacou.
- Ecological analyses to reveal key species within major plant communities within the Nariva Watershed.
- Generation of a list of HCV species (Nariva) catchment.

Preliminary analysis and results of presence of potential microbial and bacteriological contaminants.

The outputs from WP2 can be summarised as follows:

- Review of country reports
- Formulation of questionnaires and interview schedule
- Determine sample size and survey administration
- Questionnaires returned, and data entry completed
- Construction of livelihood indices
- Focus group discussions impact and adaptation to natural hazards

For Rio Cobre only, the focus group discussions were carried out in 17 communities involving over 140 persons.

Work package two produced: i) Livelihood Vulnerability Framework; and ii) Questionnaire. The Livelihood Vulnerability Framework examined questions that utilised to calculate the livelihood Vulnerability Index Scores. The Questionnaire comprised of 6 sections: General Environmental, Change of Climate, Benefits from Nature, Access to Water and Quality of Life, Family and Community Ties and Socio-Demographic Information.

The 'Creation and Use of Livelihood Vulnerability Indices' Workshop was held on 22nd September 2015 and various

stakeholders from Ministry Permanent Secretaries, Trinidad and Tobago representatives from the Food and Agriculture Organization (FAO), Inter-American Institute for Cooperation on Agriculture (IICA), the Cropper Foundation and the United Nations Development Programme (UNDP), Graduate Students from SALISES, the Faculty of Food and Agriculture as well as to the Marketing and Communications Office of the UWI, St. Augustine were in attendance.

Some of the outputs from WP5 complement the work carried out by WP2 above, in that household questionnaires were also administered, avoiding duplication of households where questionnaires had already been administered. The outputs include:

- WPI for all three sites
- West and Dry season fieldwork including sample collection and questionnaires at all three sites.
- West and Dry season laboratory analyses and DNA extraction for all sites.
- Characterisation of viruses and pathogens found in water samples.
- Comparison of the effectiveness of three identification measures.

4.3 Objective 3: Develop coupled landscape socio-ecological - hydrological modelling approaches

Work package 6 & 7 contribute to this objective.

4.3.1 Methodology

The objective of work package 6&7 was to provide hydrological models of the pilot catchments to enable the investigation of the response of the catchments to future changes in climate and conditions in the catchment with respect to water availability.

The implementation of work packages six and seven required the characterisation of surface water and groundwater flows. The intended approach was to separate the surface water and groundwater simulations to ease the complexity of the modelling and the computational resources required. The surface water flow simulations for the pilot watersheds were to use using the open source Hydrologic Modelling System (HEC-HMS) software package designed to simulate the complete hydrological cycle. HEC-HMS was chosen as the rainfall-runoff model because it is (i) freely available, (ii) computationally inexpensive and (iii) capable of continuous simulation. During the project implementation phase, model development for the four catchments was not completed by CIMH. CIMH produced an outline surface water flow model for the Speightstown catchment, based on previous work using HEC-HMS.

CIMH began work on the development of a geological framework model for the Rio Cobre catchment. The development of the framework model was outsourced to the Southwest Research Institute located in San Antonio, Texas but was not completed. Data sets that were used included Shuttle Radar Topography Mission (SRTM) 30 m data set for Digital Elevation Models (DEMs). Existing land use/cover information was obtained from satellite imagery. Hydro-meteorological data for model calibration and validation were obtained from the Water Resources Authority (WRA) of Jamaica for the Rio Cobre watershed. Limited data were available from the archives at CIMH for the Speightstown watershed. The climate data required for projecting the impact of climate change on the hydrological flows, were obtained through work package one. Work package one output provided downscaled climate data with climate outputs from their PRECIS model.

The outputs from the PRECIS model were shared with the project team via a FTP server managed by CERMES. The data consisted of daily text files for a 360-day calendar year at each computational grid point for the simulation period 1961 to 2098. The climate data of interest for long term hydrological simulations were limited to precipitation, short wave flux, air temperature, wind speed and relative humidity. These data were to be pre-processed and used as inputs to the hydrological model. During pre-processing it was realized that rainfall outputs from the PRECIS model were missing from the data provided for a few years. Data from the previous year were used to complete the time series on these occasions.

Hydrological models require data at spatial and temporal resolutions that are relevant to the scale of the investigation. The PRECIS outputs provided by the CSGM were at a spatial resolution of twenty-five (25) km and a temporal resolution of one (1) day.

Given the difficulties encountered by CIMH the decision, late in the day, was taken to outsource the hydrological modelling for Nariva Swamp, Carriacou and the Speightstown groundwater modelling. The Nariva and Carriacou hydrological

models were developed by persons from the St Augustine Depts. Of Geography and Civil Engineering. For the Nariva Swamp Catchment the study developed and utilised the HEC-HMS model of catchment hydrology, which was driven by daily downscaled climate model outputs for the A1B SRES scenario, at a spatial grid resolution of 25 x 25 km. For this study, the model simulations provided were AENWH (which represents the standard, unperturbed model with original parameter settings) and AEXSA and AEXSK (which provide two variations in parameters, based on AENWH). Minimum and maximum daily temperatures and daily large-scale precipitation were provided.

Analysis of the climate model outputs indicated a clear upward trend in temperature, but no apparent trend in precipitation. Intensity-duration-frequency curves of rainfall showed both decreases (for AENWH) and increases (for AEXSA and AEXSK) in intensity for most event durations. Consequently, the models presented a mixed picture in which the reductions in more frequent events shown by AENWH indicate a likely negative water balance; however, AEXSA and AEXSK both show increases for these events. For more extreme events, AENWH and AEXSK show a decrease, with a possible reduction in flood risk; however, AEXSA shows an increase for these events. For annualised water distribution, HEC-HMS model results indicate there appears to be (i) no significant trend in precipitation for any of the three models; (ii) a significant positive trend in potential evaporation for all models; (iii) no clear trend in canopy evaporation, with only AEXSK showing a significant positive trend; and (iv) for AENWH only, significant positive trends in baseflow, surface runoff and groundwater flow, indicating a negative pressure on the catchment water balance. When analysing water distribution seasonally and the difference between future projections and the baseline period, some additional patterns were found. For example, surface runoff either had moderate negative differences (for AENWH) or strong positive differences in the wet season (AEXSA).

For Carriacou a SWAT hydrological model was developed and implemented. Downscaled climate model outputs were provided by the Climate Studies Group Mona (CSGM) of the University of the West Indies, Mona, Jamaica for the period 1961 to 2098 from the PRECIS model driven by HadCM3 for four model parameter set perturbations. Daily climate model data were provided, for the A1B SRES scenario, at a spatial grid resolution of 25 x 25 km. The variables provided and used in the SWAT model were daily precipitation, minimum and maximum temperatures, wind speed and relative humidity. These were converted and processed to allow them to be included in SWAT. Climate model outputs show (i) a clear upward trend in temperature; (ii) small increases in average wind speeds in later months of the year for late in the 21st century; (iii) slight increases and less variation in relative humidity for August to November; and (iv) variability in the response of precipitation under climate change, with increases in intensity of smaller, more frequent events for two models, but reductions in the intensity for the other two. A limited model verification was completed against available monthly rainfall data and generally showed some over-prediction. Insufficient data were available for climate model bias correction.

Model results demonstrate an increasingly negative water balance for Carriacou, driven by declines in rainfall of between 4 and 16% when compared to a 1966 to 1999 baseline average, and increases in potential evaporation of between 5 and 10%. The increases in potential evaporation are likely to be as a result of the increases temperatures of around 3 °C throughout the period. Although actual evaporation does not appear to have a strong trend, this is likely to be due to the reduced availability of water for evaporation in the catchment. As a result of decreases in rainfall and increases in potential evaporation, the total water yield decreases by between 7 and 53%. The water yield represents the total available water in rivers in the basin and is comprised mainly of surface water runoff and ground water contributions to stream flow. In addition, the total annual shallow aquifer recharge shows a decrease of between 13 and 45%. Annual trends in total annual rainfall, potential evaporation, water yield and aquifer recharge are weakly negative respectively, and a strong positive trend in annual potential evaporation.

Seasonally, for all scenarios, water yield generally decreases towards mid- to late century, but this is particularly pronounced during September to November for the AENWH scenario, with daily mean water yield decreasing by between 58% and 72%. Water yield appears to be highest for the Mount Pleasant catchment. Variability in water yield also decreases towards the end of the century, which may indicate a consistent reduction in water yields, rather than some years having surplus. For groundwater percolation, all models indicate greater groundwater percolation during September-November, with declines towards the end of century. Return period analysis of daily water yields indicates a decline in the annual maximum rainfall event, although since extreme flow events may be short-duration and spatially small in extent, it is possible that the scale of representation of rainfall within the climate model is insufficient to represent them. For 7-day low-flow events, return periods display a shift downwards for the mid- and late-21st century, meaning that the low-flow

events are projected to become more extreme. This may indicate that periods of drought become more frequent.

4.3.2 Challenges

These two work package were the responsibility of the Caribbean Institute for Meteorology and Hydrology (CIMH) and, at their request the two were combined into one. CIMH took over a year to sign a contract to undertake the work and assigned a person to lead it. That person spent from the signing of the contract in April 2014 until the end of 2014 trying to derive climate data which could be used in the hydrological models and as a result no progress was made on developing hydrological models. In January 2015 the work package lead resigned, was not replaced but this was not communicated by CIMH. Eventually, CIMH withdrew from the project early in 2017, though they did provide two reports on work carried out in Speightstown, Barbados and Rio Cobre Jamaica. But these came too late to be used by other work packages.

In the light of the difficulties encountered with CIMH and, after discussions with the Project Officer the decision was taken to independently commission two consultants to carry out hydrological modelling for Carriacou and Nariva Swamp respectively.

Lessons Learnt

Risk analysis of the impact of non-performance of partners could be undertaken by the PI in consultation with the Project officer and 'red lines' agreed upon.

4.3.3 Progress

Hydrological models for Carriacou, Nariva Swamp and Speightstown were developed. A start was made on modelling the Rio Cobre catchment but was not completed due a) not being able to characterise the geology of the catchment which controlled flows and b) CIMH running out of time and c) lack of technical resources on the part of CIMH. A groundwater model for Barbados was developed which allowed the impact of climate change on groundwater to be investigated and from this a sub-model of the Speightstown catchment was developed. Rainfall-runoff modelling for the same catchment was made available from another project. For Carriacou a SWAT based hydrological model of water was developed that looked at the effect of climate change on run-off. A similar approach was applied for the Nariva Swamp catchment but using HEC-HMS.

4.3.4 Outputs

- Development of a general and downscaled hydrogeological model for Barbados and the Speightstown catchment
- Development of a SWAT based hydrological model for Carriacou
- Development of HEC-HMS based hydrological model of the Nariva Swamp and Speightstown catchments.

4.4 Objective 4: Develop adaptation strategies for ensuring water security

Work packages 8, 9, 10, 11 and 12 all contribute towards the achievement of this objective.

4.4.1 Methodology

4.4.1.1 Work Package 8 - Ecosystem Services Modelling Methodology

The objective of work package 8 was to investigate and understand the role and value of ecosystem services in maintaining the quality of the environment as well as how climate change and anthropogenic activities impact those services.

The activities in this work package were split between the (CCCCC) and the Department of Life Sciences of UWI St Augustine (DLS). The CCCCC worked in conjunction with Meteorological Institute (INSMET) in Cuba addressing the ecosystem services in Carriacou and Rio Cobre. The UWI DLS at St Augustine was responsible for addressing ecosystems services in Barbados and Nariva. Identifying and describing the ecosystems services of the pilot catchments requires the identification of what ecosystem services are being provided and gathering data on which parts of the environment are providing the services, their extent, the values being attached to each of them and how they are interrelated.

The approach adopted by DLS differs from the INSMET adopted approach in that it is based on the use of the InVEST and RIOS models. InVEST (Integrated Valuation of Ecosystem Services and Trade-offs) is a suite of software models

used to map and value the goods and services from nature, developed by the Natural Capital Project. It incorporates biophysical and economic sub-models as well as scenarios. In the case of Speightstown and Nariva InVEST was used to investigate nutrient and sediment retention as well as run-off estimations. RIOS (Resource Investment Optimisation System) was also developed by Natural Capital Project and is meant to complement InVEST. It combines biophysical, social, and economic data to identify locations for protection and restoration activities. The land use changes developed out of work package 3; As-Is, Worst Case and, Best Case were used to investigate the changes in sediment and nutrient flows under different climate change scenarios. Whilst this approach did not produce values (nor was it intended to), it was of value in that it highlighted how particular ecosystem services (nutrient and sediment retention) can be explored.

The approach utilised in Carriacou and Rio Cobre was the identification and quantification of the four elements of ecosystem services; provisioning, supporting, regulating, and cultural services. These services were valued based on their direct use and the range of indirect uses and values. Direct use can be valued through the use of market-based data whilst non-market approaches have to be used for the non-direct uses. Having established the services provided and the associated value and estimation was made as to how the services would change under an altered climate and then using the same methods the change in value was estimated. Given the sparsity of data many assumptions have had to be made. In order to obtain values a benefit transfer approach was used, whereby the value of benefits from similar ecosystems from literature were used as proxy values.

The methodological work procedures in conducting valuation of ecosystem services for the island of Carriacou included:

- Island Characterization was undertaken to establish a baseline with the aim of describing the environmental, economic and social characteristics on the island.
- Economic estimates of the selected ecosystem goods and services provided by the island through methods such as Avoided Cost; Cost of restoration; Transfer of per hectare economic benefits and, Opportunity Costs.
- Estimated changes in selected services provoked by climate change and human activity in the medium and long term -Climate scenarios were developed in work package 1 using the ECHAM and Hadley, they are nested models in the PRECIS Regional Climate Model. For analysis of the impact of climate change on water availability and the water environmental services, changes in temperature and precipitation determined with the climate models for the future scenarios. To model the impacts of climate change on water supply and estimate changes in ecosystem services and their value to economic sectors in the medium and long term (2035 and 2050) two future climate scenarios were considered. The cost of adaptation and mitigation, based on the estimated losses of the economic benefit of production systems; the pricing of technologies for adaptation investments and evaluate potential adaptation and mitigation were investigated.

The approach developed could be used as a tool for decision-making, where the local government, as administrator, manages funding sources for the management and conservation of environmental goods and services in order to address the climate change process as an opportunity for sustainable community development. In other words it can be used to motivate investment in adaptation measures.

4.4.1.2 Work Package 9 - Vulnerability Assessment Methodology

The objective of work package 9 was to assess the dimensions of environmental and socio-economic vulnerability at the catchment level. The work package utilised the sustainable livelihood indices constructed in work package 2 and survey data to assess the extent of vulnerability of the population. The calculated vulnerability used a modified version of the methodology described by Hahn et al (2009). The vulnerability indices and sub-components of the pillars were used to determine the potential impact of different policies to reduce vulnerability. Additionally, the value obtained from each of the pillars of the index can be used as a tool to communicate the extent of vulnerability in the population to various stakeholders and as a means of suggesting measures that can be adopted to reduce the impact of climate change on water availability in the various communities.

4.4.1.3 Work Package 10 - Water Availability Assessment Methodology

The objective of work package 10 was to conduct a water availability assessment which integrates meteorological, hydrological, economic and social dimensions to explore the impact of different future scenarios on water availability. Inputs from other work packages were needed; WPs 1, 3, 4, 6/7 and 9. However, as only outputs from work packages 1 and 3 were availability for the modelling. As a result, assumptions had to be made and the approach simplified. Originally

it was intended to use the VENSIM systems dynamics software as the modelling platform. However, as simplifications had to be made, the Water Evaluation and Assessment Programme (WEAP) developed by the Stockholm Environment Institute was used in its place. WEAP is a fully configured modelling platform in which the type of data required, and the modelling algorithms are already specified and as such requires the full complement of data in a particular format. For each of three pilot the schematic models were developed, first the basic configuration and then additions based on adaptation options incorporated into the model to respond to future climates. As part of the work on developing the Speightstown WEAP model a hydrogeological groundwater model (using MODFLOW) was coupled to WEAP to explore the impact on groundwater. The Nariva WEAP model was developed as part of a student research project and then developed further by the same person who also developed the Carriacou WEAP model.

In the case of Speightstown the modelling indicates that meeting the future expected levels of demand would result in severe aquifer depletion, if it were not for the fact that the area imports water from other parts of the island. In the case of Carriacou the modelling indicates that there will be significant unmet demand during the dry season which will adversely affect agriculture and tourism on the island, across all future scenarios, differing only in the magnitude of the unmet demand. A similar pattern also emerges for Nariva but here the primary effect is on agricultural production. The situation is aggravated by the operation of the Navet Dam which releases water into the catchment. Under future climate scenarios, less water will be released and this will exacerbate the level of unmet demand from agriculture.

4.4.1.4 Work Package 11 - Future Foresight Scenario Modelling Methodology

The objective of work package 11 was to generate quantitative and qualitative descriptions of up to four possible future socioeconomic and political scenarios for each of the pilot countries that reflect different possible developmental trajectories that would influence adaptation options.

This WP commenced with a detailed literature review to identify the approaches to scenario building that have been developed and what similar work, pertaining to water management, climate change and the Caribbean has previously been conducted. The next activity was to conduct interviews with key informants and to hold a scenario development workshop attended by external key informants (e.g. CARICOM Secretariat), in Trinidad. This was to explore views on future key factors affecting economic development in the Caribbean. The data was used in a cross-impact matrix to develop consistent scenario kernels at the regional level. The next stage was the development of macro-economic models for each of the pilot countries used to inform the developed scenarios. In parallel to this work a web-based platform was developed through which to conduct an e-Delphi facilitated dialogue process. E-Delphi is a web based forecasting process framework based on the results of several rounds of questionnaires sent to a panel of experts. Several rounds of questionnaires are sent out, and the anonymous responses are aggregated and shared with the group after each round. In this process a cross-section of informants, drawn from across the Caribbean region, were invited by the moderator to respond to the qualitative descriptions of the scenarios developed. On the basis of the shared feedback the scenarios were refined and reposted. After several rounds the emerging consensus was used to define future regional development scenarios for the Caribbean. The Regional Future Scenarios were then used to develop four quantitative and qualitative storylines, focusing on water management, for each of the four countries, corresponding to each of the four regional scenarios. The purpose was to inform the development of adaptation options.

Given the complexity of this process, a macro-economic modeller has been recruited from outside of the project to assist with the economic modelling.

4.4.1.5 Work Package 12 - Adaptation Generation and Evaluation Methodology

The objective of work package 12 was to develop and apply alternative adaptation strategies, related to the possible future states.

The development of this work package was contingent on outputs from WP 4, 6/7, 8, 9, 10 and 11, although work commenced in the absence of their outputs. It entails the evaluating the institutional and governance regimes as well as the nature of the impacts of climate change on water associated goods and services. These taken together with the anticipated impacts can be used to develop potential adaptation strategies that 'fit' with the scenarios and expected circumstances.

A Research Associate was recruited in April 2015 and commenced work on this package working on a literature review and developing possible approaches – without the concrete outputs from other work packages. However, for personal family reasons she resigned as of the beginning of September 2015. Some further work was conducted but not completed. This included the development of a preliminary paper outline adaptation options for Carriacou using outputs from work package 6&7, 10 and 11.

4.4.2 Challenges

4.4.2.1 Work Package 8

The major challenge for this work package was the availability and completeness of data required for the modelling approaches adopted. As noted for work package 3 identifying sources of data and negotiating access to it were time consuming. In some cases, the necessary data did not exist e.g. hydrological data for Nariva Swamp, Trinidad and, climate data for Carriacou and Rio Cobre.

Lessons Learnt

If there is going to be a reliance on the use of external data, not generated by the project then more upfront effort needs to be made in ensuring that the necessary data is available and accessible.

4.4.2.2 Work Package 9

This work package was a continuant of work package 2.

4.4.2.3 Work Package 10

The major issue for this work package was the availability and accuracy of the data needed to run the models as well as outputs from other work packages and it was time consuming to address them, causing delays in progressing the work. As it turned out this work package had to move forward almost independently of the other work packages, it was particularly affected by the delays in work package 6&7. It was proposed to use two complementary modelling approaches. This though added additional burden and caused some uncertainty with respect to model outputs. In addition, there were personnel issues, the person working on this had to relocate and then accepted an offer of a scholarship, which curtailed their work on the project.

Lessons Learnt

Adopt one modelling approach, which will ensure consistency and aid understanding of outputs.

4.4.2.4 Work Package 11

There were no major issues with this work package. Additional human resources were provided by another project in order to complete the work. It should be noted that there was almost no regional expertise available in this area and globally there was little expertise in the e-Delphi methodology.

Lessons Learnt

More time should have been allocated to this work package and more resources for the engagement with stakeholders and informants.

4.4.2.5 Work Package 12

The work package experienced a turn-over in personnel which adversely affected the outcomes which could be produced. This was on top of the delays caused by the knock-on effects on earlier work packages.

4.4.3 Progress

Work package 8 is concerned with the future impacts of climate change and human activities on ecosystem goods and services both now and for 2035 and 2050 time periods. Research outputs from Carriacou suggest that the maintenance of soil quality provides the highest valued ecosystem services. In the Rio Cobre the impact of future changes in climate on hydrological functioning could result in significant loss of value in ecosystem services through the loss of forest. Preliminary modelling work in Barbados has highlighted the role of natural vegetation in retaining sediments on the land and preventing soil erosion. This has provided preliminary estimates as to how much sediment is retained and prevented from smothering the near shore coral reef systems, even over a small area of coastline.

Work package 9 builds on WP2. Using the vulnerability index the potential impacts of different policy interventions were explored. For Nariva this indicates that policy interventions that improvement in knowledge and level of education have the biggest impact in reducing vulnerability. In contrast on Carriacou interventions that promote better social cohesion

would reduce the vulnerability of communities, which runs counter to initial impressions.

For work package 10 two complementary water availability modelling approaches were explored but only one was adopted; this used the Water Evaluation and Planning software (WEAP). It was used for the Carriacou, Nariva Swamp and Speightstown catchments. Sparse input data meant that simplified approaches had to be used in order to get outputs. It compares the different medium term future scenarios against a Baseline run for each catchment. The runs have highlighted the high vulnerability and significant reductions in monthly available water at all three pilot sites under climate change. In the case of Barbados, aquifer depletion is a serious threat, even assuming conservative development scenarios. For Nariva crop production would be severely curtained without significant adaptation measures and, in Carriacou drought-like conditions will compromise agricultural production.

A core part of work package 11 was the e-Delphi consultation process was initiated as, which not been attempted before in the Caribbean and this has provided experience in how this technique could be further developed. The outputs from the e-Delphi were transformed using a cross-impact approach to identify key areas and these were then linked with global Shared Socio-economic Pathways (SSPs) using conditional Bayesian probabilities. The result is a series of five future regional scenarios coupled with 16 story-lines, four for each country included in the project. These form the basis for guiding potential future adaptation strategies.

4.4.4 Outputs

Basic InVEST models for Nariva and Speightstown developed and model runs undertaken. These have been used to identify deficiencies in the modelling. Completed first stage of ecosystem services modelling for run-off estimation, sediment, phosphorus, and nitrogen retention for Speightstown and Nariva.

For the Carriacou and Rio Cobre catchments the identification of goods and services completed and this was used to undertake the valuation of environmental goods and services was completed. Following this the impact of climate change on the value of environmental goods and services was completed.

The outputs from WP8 indicated that the total value of ecosystem goods and services selected in the Carriacou Island are estimated in US \$258 million. The total benefit over 2012 – 2014 ranges from US \$27 to \$39 million. When examining the economic sectors value of 2014, the highest value is tertiary sector (\$24,5 million) followed by the primary sector (\$7,4 million) and secondary sector (\$6,9 million). The total economic benefit losses for the simulated scenarios estimate a value of US \$2,205 and \$3,053 million for 2035 and 2050, respectively. The total economic benefit losses for the simulated scenarios were estimated considering agriculture as subsistence farming, fishing and tourism. The agriculture shows the highest loss with US \$ 828 thousand (2035) and \$1,147 million (2050), followed by tourism with US \$1 and \$1,4 million and fishing with US \$368 and \$510 thousand (2035 and 2050, respectively). The total cost associated to ecosystem goods and services (EGS) losses and conservation were estimated considering the economic social and environmental benefit loss and the financial need to execute adaptation and mitigation measures and technical studies for the EGS conservation. This cost reached a value of US \$21,2 million.

The Total Economic Value of ecosystem services of Rio Cobre watershed was performed using the transfer method from results of different case studies, corresponding to the classification of ecosystem functions reaching an estimated value of \$J 103632,9 million. The Value of the Hydrological Services of the watershed (VHES) at J\$ 4354,7 million was estimated, it was held from representing the water supply to this ecosystem, for it is considered the sum of value capture (\$J832,6 million), the recovery value (\$J2513,0 million) and the value management (J \$1009,1million). Losses due to the water reduction in A2 scenario 2035 are \$590,5 million and for 2050 are J\$1706,7 million. The losses due to water reduction in B2 scenario 2035 are J\$90,3 million and for 2050 are J\$ 1177,7 million.

Under work package 9 the following have been completed for Nariva and Carriacou:

- Calculation of the vulnerability indices,
- Analysis and incorporation of outputs from focus group discussions,
- Report on the work.

Generated three outputs: (i) LVIs for each catchment for 2015 as well as for: (2021-240, 2041-2060 and 2061-2080) for A1B, A2 and B2 scenarios; ii) LVI scores for each sub-component; and iii) Index Sensitivity Analysis for key areas such as: water storage and access; education; climate knowledge; and perceived changes in water quality and quantity.

Index results demonstrated that overall, Nariva (0.538) was the most vulnerable catchment, while Speightstown (0.412) was the least vulnerable catchment. Carriacou's LVI score was 0.456. The Environmental Capitals for Nariva (0.630) and Speightstown (0.597), were the most vulnerable pillar whereas, the Social Capital was the most vulnerable pillar for Carriacou (0.651). The Physical Capitals, for Carriacou (0.343) and Nariva (0.351), were the least vulnerable pillar and the Natural Disasters and Climate Variability Capital was the least vulnerable pillar for Speightstown (0.279).

In terms of the water availability modelling:

- WEAP models for Speightstown and Carriacou have been develop and run for both baseline scenarios and under two future climate change time horizons, near and medium term.
- A groundwater model of Speightstown has been set up, calibrated and incorporated into the WEAP model.
- A SEAWAT model for seawater intrusion has been set up for Speightstown but not calibrated yet.

A WEAP model for Nariva completed and the impact of different climate scenarios completed.

For the Future Foresight Scenarios the following have been completed:

- Literature review,
- Key informant interviews and regional scenarios workshop,
- Development of macro-economic models of economies of Jamaica, Trinidad and Barbados,
- Development and analysis of regional scenario kernels,
- Development of a web-based e-Delphi platform and implementation of the web-based Delphi elicitation exercise,
- Using the outputs from the macro-economic models, e-Delphi, cross-impact analysis four future foresight regional scenarios have been developed.

From the four regional scenarios, 16 national storylines, four for each country, which outline the impact on water have been developed.

4.5 Objective 5: Provide evidence-based adaptation strategies for national water management policies

This objective was to be met by Work Package 13.

4.5.1 Methodology

The objective pf work package 13 was to utilise data and lessons from the pilot sites to inform outputs that can be scaled up to the national level to inform water resources management planning and adaptation. No work was undertaken on this work package

4.5.2 Challenges

This work package did not happen. If it had it is anticipated that it would have encountered problems in translating the research outputs into a format which could be used to communicate with decision and policy makers.

4.5.3 Progress

No progress

4.5.4 Outputs

No outputs

4.6 Objective 6: Expand regional research capacity, collaboration and improve training opportunities

4.6.1 Methodology

The following capacity building activities have taken place:

- Development of a GIS and Geonode Training manual.
- Forestry staff in Trinidad and Carriacou were trained in Rapid Botanical Survey technique.
- A training workshop on The Creation and Use of Livelihood Vulnerability Indices was conducted.

- Attended a conference and workshop at the University of Manchester on Foresight: Exploring the Future, Shaping the Present.
- Training sessions on InVEST were held.
- On-line training course on the use and application of WEAP
- Enumerators carrying out field data collection for WP2, 4 and 5 in Barbados, Grenada (Carriacou), and Trinidad were trained.
- Attended a Workshop in Cape Town organised by IDRC
- Ecosystem goods and services valuation workshop for regional participants held in Grenada

The following Outreach and Dissemination activities have taken place:

- A focus group discussion on climate change and water availability was held with local communities in Rio Cobre, Carriacou, Nariva and Speightstown
- Presentations on the Future Foresight Scenarios to an annual meeting of Caribbean Ministers with responsibility for water.
- Presentations on the project were made at an international climate change held in Trinidad, sponsored by the Caribbean Development Bank, among others.
- Short videos were produced and were made available through the CERMES Youtube channel.
- Papers were presented at conferences in France, Spain, The Bahamas, South Africa, Miami New York and Philadelphia USA, and Trinidad.

4.6.2 Challenges

The delay in completing almost all of the work packages limited the ability of the project to develop teaching and learning materials to the extent originally envisaged, with one or two exceptions.

4.6.3 Progress

The project has produce a number of conference papers and presentations. The development of some of these into peer-reviewed journal articles is hampered by having incomplete baseline data which would make it problematic to have the papers accepted. However, publications from work packages, 2 & 9, 5, 1 and 11 are expected as draft papers have been worked on and in some cases submitted fro review.

4.6.4 Findings and Outputs

Details of papers and publications are included in the Appendix.

5. GENERAL PROBLEMS AND CHALLENGES

5.1 Overview

The fundamental challenge of the research was that it was too ambitious in scope and scale. It was ambitious in terms of scope; trying to link together, climate modelling and downscaling through to the generation and evaluation of adaptation options. One of the effects was that the research lacked a coherent focus, there was too much going on and too much to be considered. Following from this was the vulnerability of the whole process to the knock-on effect of any difficulties encountered in one work package on subsequent or dependent work packages. This was in fact the case with the first work package, climate modelling and downscaling, upon which work packages 2 through to 8 were dependent, noting though that his was not the only example. Another facet of the ambitious scope, the bringing together of many and different partners and disciplines. In all there were 9 partners in the project, spread across the Caribbean in different geographic locations. This contributed to the difficulties in coordinating and being able to properly manage the activities of the work packages. In fact, it proved difficult at times to get the level of response, feedback and reporting that was expected. This was in spite of the efforts of the project manager. The other aspect was the scale of the project, being spread across locations in four countries. This made establishing contact on the ground, liaison with local officials, knowledge of local conditions problematic. It was challenging, with different work packages active in different locations to keep adequate track of activities, progress and more importantly, outcomes.

In addition to the above, almost all of the participating parties had little experience of working on a large multi-disciplinary and inter-dependent research project. There was not a culture of coordination and cooperation and for many this was their first experience. This had negative influence on the overall management of the project. Partners were unclear what their technical and financial record keeping and reporting responsibilities were and in particular the IDRC requirements. Reporting was a continual problem, a matter that was discussed with the Project Officer. Initially teleconference meetings were held on a regular basis but attendance was often poor. Later, the format was changed and catchment focused teleconference meetings were initiated, but with a similar response. Whilst some Work Packages have presented incomplete forms of reports on the technical aspects of the work they carried out none has presented a final Technical or Financial Report. The responsibility has to be shared between the work packages and the Principal Investigator and project manager. The project manager was often not responded to by work packages and on a regular basis had to ask the PI to intervene, which devalued the role of the project manager and added to the work load of the PI. The net effect is that although a lot of research work has been undertaken it has not been properly recorded and documented. In addition, the UWI Bursary had not fully developed their administrative procedures to support research projects. The effect was that reconciling expenditures in the project format was undertaken by the PI.

Changes in research personnel was a particular problem in the early stages of the research. Virtually all the work packages were affected; 2&9, 3, 4, 5, 6&7, 8, 10 and 12. In addition the leader of work package 5 died in the course of the research. The changes had an effect on continuity and familiarity with the project and its objectives. One work package did not engage at all in spite of strenuous efforts to bring them to the table. In the end they effectively withdrew from the project having given rise to major delays. In hindsight they should have been removed much earlier in the project.

As the project developed more of a focus was placed on the Grenadian pilot site of Carriacou. This was partly in response to it being a smaller island which facilitated working and also because of the particular circumstances of the island. The island has in the recent past experienced the impact of severe weather events i.e. droughts and there is very little physical data available. It therefore was seen as a place where, given the challenges, the possibilities of research having an impact could be explored.

5.1.1 Lessons Learnt

Persons involved in the management of a research contract should undergo training and sensitisation around the technical and financial management requirements. This could include the sharing of best practices for administration and reporting.

5.2 Project Output and Outcome indicators

Output	Indicators	Sub-indicators
Output 1: Gender sensitive climate knowledge (i.e. adaptation options, barriers, finance tools/mechanisms, etc.), made accessible to communities, governments and private sector, to support planning, investment, policy and/or practice	# of publicly available climate knowledge outputs; authorship disaggregated by gender and membership in a southern institution.	(1) # of peer-reviewed journal articles published; Total 8 - 7(m) & 1(f)
		(2) # of research outputs published other than journal articles: Total 23 - 7(m) & 16(f)
Output 2: Tested examples of applicable, scalable, bankable adaptation/mitigation solutions	Number of pilot interventions to apply solutions, systematically documented	Not applicable
Output 3: Trained individuals/institutions	# of Graduate students (within project lead and partner organisations) who benefit from IDRC supported fellowships and awards programs to pursue Masters and PhD. Disaggregated by gender.	Total 17 - 5(m) and 12(f)
	# of individuals who benefit from IDRC supported fellowships and awards programs to do Post-doc, Internships, or professional development activities. Disaggregated by gender.	Total 4 - 4(f)
	# of Institutions that received organizational or technical support through participation in the project	Not applicable
Immediate outcomes		

Outcome 1: National and international climate decision making (at public and civil society level) has been informed by the supported researchers/thought leaders (>50% women?)	# of CC researchers/leaders (gender differentiated) directly involved (part of specific bodies/platforms) with decision making processes for adaptation plans/policies/actions at national and international levels.	1. Participation in Annual Ministerial High Level Forum 2016 at which the outputs from WP11 Future Foresight Scenarios were share and discussed by Ministers with responsibility for Water. Meeting involved 1 female researcher presenting the work. 2. Participation at the International Climate Change Conference for the Caribbean. The meeting was attended by decision makers from across the Caribbean plus representatives from the Caribbean Development Bank, UNDP, European Union, Global Climate Change Alliance + Initiative and the Govt. of Japan. Presentations were made by 7 Researchers of whom 6 were female. 3. Outputs from the climate modelling and downscaling have been used by the Climate Modelling Group to inform decision-makers through meetings and presentations by Professor Michael Taylor and Mr Jayaka Campbell. The work has been used to inform publications such as a recent on the differential impact of a 1.5° versus a 2.0°C rise in temperature on the Caribbean. This information is used to inform the Caribbean Region's negotiating position at COP.
	# of decision making processes that have been influenced by the research at national; municipal-local; and international levels.	(1) # of decision making processes at MUNICIPAL level that have been influenced by the research; Most decision-making in the Caribbean takes place at the national level.;
		(2) # of decision making processes at INTERNATIONAL level that have been influenced by the research – It is difficult to pinpoint how much the research work carried out has influenced decision-making. However, the work presented at the Interational Conference in Trinidad in 2017 was noted by the Caribbean Community Climate Change Centre which has lead responsibility to CARICOM for the development of the regional climate change response and action plan.
		(3) # of decision making processes at NATIONAL that have been influenced by the research. There is no hard evidence that can be cited.
Outcome 3: Public (governments at adequate levels) and private (companies and civil societies) stakeholders have developed policies and plans to apply evidence based, gender sensitive adaptation and mitigation solutions	# of adaptation and mitigation plans and policies developed or informed on the basis of research, at subnational, national or international level.	(1) # of SUBNATIONAL LEVEL adaptation and mitigation plans and policies developed or informed on the basis of the research. (2) # of NATIONAL adaptation and mitigation plans and policies developed or informed on the basis of the research. (3) # of INTERNATIONAL adaptation and mitigation plans and policies developed or informed on the basis of the research. There is no available substantive evidence for this at any of the three levels.
Intermediate outcomes		
Outcome 1: Public and private policies and plans to promote climate action (application of and investments in adaptation and mitigation innovations at scale) , are implemented at adequate scales (entire hotspots, watersheds, cities)	# of public and private adaptation/mitigation plans and policies implemented at adequate scale	There is no available substantive evidence that ca be offered for this.

Outcome 2: Key stakeholders including actors from planning, policy, research and communities have the capacities to make evidence-based choices for coping with current variability and potential future impacts of climate on development.	# of examples of key stakeholders, not directly supported by the research, make choices for coping with climate change in development, based on evidence generated by the supported research	Ministry of Carriacou and Petit Martinique, Grenada and Carriacou Farmers Association. The research on the island of Carriacou has highlighted the need to include the potential impacts of climate change on agriculture and water availability in planning. This has contributed to the refurbishment of communal rainwater tanks and supporting agriculture activities. 2. In Barbados, outcomes from the research have been used to sensitise the Barbados Water Authority who are now seeking funding to carry out more work on assessing the sensivity of water resources to climate change and to look at adaptation options.
Outcome 3: New flows of (public and private) investment for the application and scaling of adaptation and mitigation solutions in vulnerability hotspots.	New public and private funds invested for the application and scaling of adaptation and mitigation solutions in vulnerability hotspots	(1) New PUBLIC funds invested for the application/scaling of adaptation/mitigation solutions; (2) New PRIVATE funds invested for the application/scaling of adaptation/mitigation solutions. No evidence can be provided for this Indicator.

6. ADMINISTRATIVE REFLECTIONS AND RECOMMENDATIONS

6.1 Administrative Reflections

6.1.1 Changes to Work Packages

Originally the research proposal suggested that five pilot sites would be covered. However, after discussions at the Inception Meeting it was decided not to include a Guyanese pilot site and to continue with the others; Barbados (Speightstown), Grenada (Carriacou), Jamaica (Rio Cobre) and, Trinidad (Nariva Swamp).

The study was divided into 13 work packages, the changes that have been made to the original proposal are as follows:

- WP6 and WP7 have been combined into one, at the request of the work package leader, Dr Farrell of CIMH,
- Due to the poor performance of CIMH and with the agreement of CIMH in WP6/7 the hydrological modelling for Carriacou, Grenada and Nariva Swamp, Trinidad was undertaken by persons from UWI St Augustine Campus,
- In WP8 the work was originally to be all undertaken by CCCCC. Following discussions regarding the challenges faced by CCCCC it was agreed that part of the work would be reassigned. The work was divided between CCCCC undertaking the work at Carriacou and Rio Cobre and a consultant, working with Dept. of Life Sciences, UWI St Augustine taking the lead on Nariva and Speightstown, Barbados.
- In WP11 additional human resources are being provided to the project from other sources.

6.1.2 Project Management

The project was managed by a part-time Project Manager assisted by a Communications Officer. Because of the complexity of the project the Principal Investigator has spent more time assisting the Project Manager and Communications Officer than had been anticipated.

Following the Inception Meeting in March 2013 the Water-aCCSIS collaborative group has met face to face in Carriacou (10th March 2014). Due to the costs involved and as per the proposal project meetings have been held via video conferencing. Video conference meetings have been held November 2013, March 2014, June 2014, August 2014 and May 2015. A full project meeting was held with all partners and the Project Manager in Barbados on 15 & 16 February 2016. Catchment progress meetings were held on 14, 17 and 22 March 2016, 18 and 20 April, 201, 9 and 26 May 2016 and, 22 and 27 June 2016.

A stakeholder engagement meeting was held in Carriacou in March 2014.

A feature of the project management and of the meetings has been the difficulty in achieving full participation of all the project partners, in spite of extreme efforts on the part of the Project Manager and Communications Officer to ensure attendance. This was a grave concern as it compromised the effective management and coordination of the work. Coupled with the poor level of participation were the difficulties experienced in getting work packages to provide progress reports and feedback.

In January 2015 Marco Rondon from IDRC conducted a monitoring visit to Barbados and Trinidad. An Interim Report was submitted to IDRC in November 2015. And, as noted above a full Project Meeting was held in February 2016.

Due to the technical issues noted above under the individual work packages as well as securing the participation of the work packages in meetings and reporting has made the management of the project extremely problematic. Additional project management issues have been noted in section 7.1 above.

6.1.3 Human Resources and Technical Challenges

The following issues with respect to Human Resources may be noted:

Table 4: Human Resource Challenges

Work Packages	Human Resource Challenges	Technical Challenges
WP 1	Personnel assigned to the project were over committed with other related work. This affected the	Outputs from the regional downscaling were delayed due to computer storage space for the outputs generated. Additional

	Regional downscale modelling and the generation of written outputs. The person responsible for the DAD did not engage in the manner expected.	storage was purchased through another project. DAD was hampered by the poor quality and coverage of historic climate data which is critical for the downscaling to be conducted.
WP 2 & 9	The original PhD candidate resigned and there was a delay in identifying suitable replacements. The work was taken over by Research Assistants.	
WP 3	No human resources challenges were experienced.	Experienced difficulties and delays in sourcing data from government agencies. In addition, some of the information has been of poor quality. Procurement of the computer server to host the GIS and satellite data was not budgeted for and took longer than expected. This delayed the installation and operationalising of the Geonode software.
WP 4	Personnel carrying out fieldwork in Carriacou provided by the Forestry Dept. were reassigned half way through the fieldwork and this brought work to a halt. Otherwise no outstanding personnel issues.	Has been hampered by the poor quality of downscaled climate data as well as errors in the GIS data provided by WP3
WP 5	There has been a high turnover in project staff.	Experienced problems in obtaining equipment and test kits with which to carry out field work.
WP 6/7	The person assigned to the project by CIMH resigned and was not replaced.	
WP 8	No human resource challenges were encountered.	Has been hampered by the lack of data and in the case of Nariva an absence of primary data to undertake the work. Additional instrumentation is being acquired to be installed to address this.
WP 10	The identified person to carry out the work was delayed in taking up the position and then went on the resign to take up a study scholarship.	Lack of data and software problems with the WEAP program have been encountered, linking it with MODFLOW.
WP 11	Additional person hired to assist, costs are covered by another project.	This work took longer to conduct than planned, due to an underestimation of the challenges and resources needed.
WP 12	Person hired to undertake the work resigned and a replacement had to be found.	

6.1.4 Capacity-building

The research project has already contributed to research capacity building through the various work packages.

Although there were no project specific outputs from the regional climate modelling and downscaling, the outputs from work package 1 should rather be seen as a part of a continuing process on the part of the Climate Studies Group Mona to explore and understand the likely effects of climate change on future Caribbean climates. The work undertaken couples with other existing and ongoing research they have been conducting. This contributes to the expertise within the Climate Studies Group Mona.

Through work package 2 an existing research methodology, the Livelihoods Vulnerability Index (LVI) has extended the traditional sustainable livelihoods framework by incorporating another set of capitals related to coping with natural disasters. This additional dimension contributes to a better understanding of community vulnerabilities to natural disasters and hence vulnerability to future climate variability and change. The development of the index allows the exploration of the potential effect of policy interventions options on the various factors contributing to vulnerabilities at the community

level. A training workshops on the use of this approach was held in Trinidad and was attended by 19 people. The next step is to use the material generated to develop further training material and a short on-line course.

The development and application of the Rapid Botanical Assessment utilised in the research in work package 4 departs from previous practice through the generation of randomised sampling points to provide a better representation of species distribution and subsequent modelling of vegetation changes in response to climate change. As highlighted previously, the training of forestry staff in the RBS technique was undertaken in Carriacou and Trinidad though only in Trinidad was the training completed.

The major contribution of work package 5 to capacity building has been through the investigation of microbiological water quality utilising three testing approaches among rural communities in the pilot catchments of Carriacou Grenada, Nariva Trinidad and Speightstown Barbados. The purpose was to characterise the environmental health vulnerability of communities to water-based infections. The approaches have not been utilised in the Caribbean previously and thus the work package developed expertise in the application of this approach. The work has formed the basis of an MPhil, being upgraded to PhD.

The quantification of ecosystem services (work package 8) and the utilisation of this information as a mean of informing decision-making is an area that has been receiving increasing attention, as evidenced by the interest in the development of payment for ecosystem services schemes. Previously, descriptive approaches have been used as actual quantification is data intensive. The work package employed two approaches; one based on the valuation of ecosystem services for the Carriacou and Rio Cobre catchments and another based on the use of InVEST and RIOS modelling approaches applied to the Speightstown and Nariva catchments. The techniques used to develop the value of ecosystems services, how those value might be affected by climate change and potential adaptations formed the basis of a training workshop in Grenada in November 2016 attended by 22 persons from across the Caribbean. InVEST is a suite of models that can be used to map and value the goods and services and explore how changes in ecosystems can lead to changes in the flow of goods and services. RIOS is an approach to watershed management that helps users identify the best locations for ecosystem protection and restoration. This was the first application of these two approaches in the Caribbean. A researcher was mentored in the application of the software by the consultant brought in to work on this work package. However, a drawback was that there were no further opportunities to develop and apply this approach building on the experienced gained.

Work package10 looked directly at the impact of climate change on water availability. To do this two approaches were developed; one using the proprietary modelling software WEAP and the other also using proprietary systems dynamic software VENSIM. Neither of these two modelling approaches had been used in the Caribbean before, although both have had wide application. Whilst the two approaches are complementary the use of VENSIM was discontinued during the course of the research and efforts focused on the use of WEAP. The first application was to the Speightstown catchment. Here another Caribbean first was attempted, the coupling of the WEAP software with the groundwater modelling software MODFLOW. Attempting this as revealed a number of issues which the work package had to work with the software developers to overcome – they had not previously been encountered as few attempts globally to do this have been made. The approach taken in this work package has to an extent enabled the project to bypass some of the problems caused by the delays in WP6/7. The use of WEAP was extended to the Carriacou and Nariva catchments. The experience with the application of the WEAP software to water availability modelling has been incorporated into the CERMES teaching programme, since 2016. The approach being taken has the potential to be further developed into a powerful management tool for water managers and policy makers.

Very little future foresight scenario (work package 11) development work has taken place in the Caribbean and even less that incorporates macro-economic modelling into the scenarios. In addition, the use of e-Delphi as part of the scenario elicitation process as utilised in WP11 represents a significant development as there have only been a handful of attempts at this globally. The attendance at a future scenarios international workshop at the University of Manchester indicated how far advanced this research package was compared to other work being undertaken. The use of scenarios has the potential for widespread use to inform the choice of future policy and would be applicable to a variety of disciplines, with the UWI potentially being a centre of expertise in this area. The work has been used to inform a variety of stakeholders including decision-makers in Barbados and the outputs have been shared with Caribbean ministers at Caribbean Water and Wastewater conference.

Much of the work carried out on the research project has been carried out by Research Assistants. Many of these were recently graduate masters or MPhil level postgraduates, just starting out on their careers. This project has afforded them practical research experience which they would not otherwise have gained. Through the project a number of student-based research projects have been supported as contributing to the research. A listing of those benefiting from the research is given in Table 1.

Table 5: List of Research Associates, PhD candidates and Master's students

Name	Role/Contribution	Comment
Researchers/Research Associates		
Candi Hosein	WP12. Working on the development of adaptation options but due to family reasons left shortly after joining.	Has subsequently worked for Global Water Partnership Caribbean in the Regional Office and is now working for Caribbean Water and Wastewater Association.
Anuradha Maharaj	WP10. Worked on the development of water availability models, coupling a downscaled groundwater model of Barbados to a WEAP (Water Evaluation and Planning System) model of the Speightstown catchment, Barbados to investigate the effect of climate change on water demand and resources.	Financially supported by the project. Went on to study at UNESCO-IHE Institute for Water Education in Delft, The Netherlands.
Brian Kastl	Carried out Ecosystems modelling on Nariva, Trinidad and Speightstown, Barbados under WP8.	Has gone on to do a PhD at the University of California, Santa Barbara.
Crystal Dasent	Continued from her masters research project to work on developing water availability models for Carriacou and for Speightstown, Barbados under WP12	
Jamellia Harris	WP2 & 9. Worked on field sampling, administering questionnaires and data entry with respect to the following pilot sites: Nariva Swamp, Trinidad; Speightstown catchment, Barbados and; Carriacou, Grenada.	Continues to work as a researcher with St Augustine Campus, Trinidad.
Catherine Seepersad	WP5. Assisted with the collection of water samples in Nariva Swamp, Trinidad Speightstown catchment, Barbados and Carriacou during the wet and dry seasons as well as the administration of questionnaires and data entry.	Continues to work as a researcher with St Augustine Campus, Trinidad.
Crystal Drakes	WP11. Worked on the development of econometric models that link global data sets for Shared Socioeconomic Pathways compatible with RCPs with the development of regional and national foresight scenarios to frame adaptation strategies.	Researcher and a co-partner in Blue Green Initiative, a cooperative social enterprise company. Has been accepted for a PhD at Waterloo University, Canada.
Shobha Maharaj	WP4 Carried out dry and wet season field sampling of forest vegetation in Carriacou and Nariva Swamp, Trinidad for input into a model of the response of high conservation value tree species to different climate change scenarios. Responsible for the development and application of the modelling approach. Also, used historical forestry data sets for Rio Cobre, Jamaica to model future forest cover and composition changes under different climate change scenarios.	Working as a consultant, running her own business in Germany.
Katia del Rosario	WP8 Worked on the valuation of ecosystem goods and services and how the valuation changes under climate change for Carriacou and the Rio Cobre catchment, Jamaica.	Working as Specialist in Applied Meteorology of Centro Meteorológico Provincial, Cuba.
Eduardo Planos	WP8 Worked on the valuation of ecosystem goods and services and how the valuation changes under climate change for Carriacou and the Rio Cobre catchment, Jamaica.	Working as Senior Researcher of the Instituto de Meteorología
PhD Candidates		
Jayaka Campbell	Worked on WP1 Climate Modelling. Used the PRECIS model to downscale global and regional climate model outputs down to a resolution of 25km ² . This provided input for other work packages.	Financially supported by the project. Member of the Climate Modelling Group of the Dept. of Physics, UWI Jamaica.
Ramon Husein	Used the outputs from the climate modelling and land use modelling as inputs to the development of a 1-D stormwater management model to alleviate flooding in the Speightstown catchment, Barbados.	Not financially supported by the project. Dropped out of the PhD programme to set up his own engineering consultancy company in Barbados, working across the Caribbean.
Anushka Ramjag	<i>Worked on WP5 to develop a water poverty index and waterborne disease index for the Caribbean and an evaluation of current and future water adaptation strategies. Dropped out after one year. This work was taken over by Ms Akilah Stewart, after a delay caused by recruiting.</i>	Resigned
Akilah Stewart	WP5. Provided assistance to Brian Kastl. Worked on obtaining water samples during the wet and dry seasons in Speightstown catchment, Barbados Carriacou, Grenada and Nariva Swamp,	Financially supported by the project. Has upgraded for MPhil and continuing as a PhD candidate at UWI St Augustine, Trinidad.

	Trinidad to look at changes in bacteriological contaminants using three comparative methods as indicators of water quality.	
Afiyah DeSormeaux	WP2 & 9. Worked on field sampling, administering questionnaires and data entry with respect to the following pilot sites: Nariva Swamp, Trinidad; Speightstown catchment, Barbados and; Carriacou, Grenada. Has undertaken the analysis of the data and the development of an updated Livelihoods Vulnerability Index which incorporates a climate change and disaster management aspect.	Financially supported by the project. Is in the process of submitting her upgrade from MPhil to PhD candidate at UWI St Augustine, Trinidad.
Masters Student		
Candi Hosein	Carried out her research project on the development of a water poverty index for Carriacou.	Financially supported by the project. On the basis of her work she was hired to work on the project after graduation.
Edmund Brathwaite	Carried out research into sustainable water management for agriculture under climate change in the Speightstown catchment, Barbados catchment	Went on to work for the Barbados Agriculture and Marketing Corporation
Douglas Brown	Carried out research into the impact of climate change on rainwater harvesting in Jamaica. Used outputs from Water-aCCSIS for his research work	Environmental Officer, National Environment and Planning Agency, Jamaica
Crystal Dasent	Carried out her research project on modelling water availability using WEAP the first application in the Caribbean.	Financially supported by the project. On the basis of her work she was hired to work on the project after graduation.

7. RECOMMENDATIONS

It should be clear that in spite of the numerous difficulties encountered, the **research project has achieved a number of advances**; the Livelihood Indices work, the advances in microbiological water quality testing, mapping vegetation changes, using sparse data to developing hydrological models, applying WEAP modelling to mapping changes in water availability and, the development of Caribbean future scenarios. It is also clear that much of this work was undertaken in silos, without the expected level of integration across work packages. In fact, even the design of the 'flow' of the research, broken down into discrete work packages, presented researchers with innate challenges to work collaboratively.

Collaborative Approaches should be at the heart of any similar future research. The physical separation of the various partners and the different working timescales added to the challenge. One of the aims of the research was to try to integrate into a platform, different complementary aspects of landscape usages, eco-systems and hydrological functions. How this could be achieved requires a lot more thought and consideration and, it has to be recognised that this is extremely challenging. It is only recently that more attention is being paid to integrative and collaborative modelling. Interest in Collaborative Modelling which explicitly includes stakeholders, is growing. It is **stakeholders that define the issues and then jointly explore with researchers, supportive modelling approaches**. An implication of this is that there would be a much tighter focus to the research.

Capacity building initiatives that rely on the successful completion of research tasks should preferably not be an integral part of the research project. **Capacity building could be treated as a separate though connected and complementary component** of the research process. Treating it as a separate contract, contingent on the performance and outcomes of research, is suggested approach.

Providing **incentives to publish needs to be supported**. Although there were conference papers and presentations, the transition of the outputs from research findings to journal articles has been problematic. There needs to be though, a distinction between covering the cost of publishing in open access journals and actual incentives to publish.

Consideration should be given as to how to **support alternative and additional forms of dissemination**. Journal publications are not the only form of dissemination, more and more there is a desire to utilise other forms of dissemination; using non-traditional means, new media, social media, etc. These are things that may not come naturally to researchers or even stakeholders. If these are to be expected, then consideration should be given as to how best to develop and support these within a project.

The last recommendation is that consideration could be given, after a research proposal is developed, perhaps in concept, to there being an opportunity to **conduct a risks analysis together with the funder**, to ensure that there is a necessary degree of realism. In the light of this, the research proposal could be revised accordingly. In other words, develop a closer relationship between the grantor and the grantee.

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APPENDIX I: PROJECT OUTPUTS AND DISSEMINATION

Conference Papers and Journal Articles

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Gohar, A. and Cashman, A. Exploring the economic impacts of adapting abstraction policies in response to climate change and variability: application for Small Island Developing States, <i>Climate and Development</i> 2017 , DOI: 10.1080/17565529.2017.1410083
Climate Studies Group, Mona (CSGM), 2017: State of the Jamaican Climate 2015: Information for Resilience Building (Summary for Policy Makers). Produced for the Planning Institute of Jamaica (PIOJ), Kingston, Jamaica. 41 pp. ISBN 978-976-8103-72-7.
Climate Studies Group, Mona (CSGM), 2017: Historical Trends and Projections: Barbados
Climate Studies Group, Mona (CSGM), 2017: Belize: Historical Trends and Future Climate Changes
Aladenola, O., Cashman, A. and Brown, D. Impact of El Niño and Climate Change on Rainwater Harvesting in a Caribbean State <i>Water Resources Management</i> 2016 , 30(10), 3459-3473
Gohar, A. A., and Cashman A. 2016. A methodology to assess the impact of climate variability and change on water resources, food security and economic welfare. <i>Agricultural System</i> . 147:51-64
Rolda, M., Marrero, M., Del Rosario, K. and Planos-Gutierrez, E. Economic assessment of impacts of climate change on Hydrological Ecosystem Services (HES) in Rio Cobre watershed, Jamaica 2016 <i>Journal of Water Resource and Protection</i> doi.org/10.4236/jwarp.2016
Jones, P. D., C. Harpham, I. Harris, C. M. Goodess, A. Burton, A. Centella-Artola, M. A. Taylor, A. Bezanilla-Morlot, D. Martinez-Castro, J. D. Campbell, T. S. Stephenson, O. Joslyn, K. Nicholls and T. Baur. Long-term trends in precipitation and temperature across the Caribbean. 2015 <i>Int. J. Climatol.</i> , 10.1002/joc.4557
Cashman, A, Laing, T., Mackey, T., Payne, K, and Maharaj, A., <i>Modelling the Impact of Climate Change in a Water Scarce Island Context</i> , 2016 , CERMES Technical Report, UWI Barbados
Drakes, C., Laing, T., Kemp-Benedict, E. and Cashman, A. <i>Caribbean Scenarios 2050</i> . 2016 , CERMES Technical Report , UWI Barbados
Drakes, C and Dasent, C. <i>Exploring A2 Futures: Combining modelling and scenarios to assess water availability and adaptation in Small Island State of Carriacou</i> . Sustainable Development Solutions Network Conference, 18-20 th September, New York, USA
Dasent, C. <i>Modelling changes in water availability under climate change for 3 Caribbean territories</i> . International Climate Change Conference for the Caribbean 9-12 October, 2017, Port of Spain, Trinidad.
Wilson, M. A <i>Preliminary assessment of the impact of climate change on Carriacou's water resources</i> . International Climate Change Conference for the Caribbean 9-12 October, 2017, Port of Spain, Trinidad.
Stewart, A. <i>Comparison of a Water Poverty Index in 3 Caribbean countries</i> . International Climate Change Conference for the Caribbean 9-12 October, 2017, Port of Spain, Trinidad.
Hutchinson, S. <i>Livelihood Vulnerability Assessment: An application to communities in the Nariva Swamp area of Trinidad</i> . International Climate Change Conference for the Caribbean 9-12 October, 2017, Port of Spain, Trinidad.
Drakes, C. <i>Scenarios and the future of the Caribbean under climate change</i> . International Climate Change Conference for the Caribbean 9-12 October, 2017, Port of Spain, Trinidad.
Maharaj, S. and Asmath, H. <i>Are Protected Areas effective in the face of climate change? A case study of the Nariva Watershed within the Caribbean Small Island</i> , Trinidad. International Climate Change Conference for the Caribbean 9-12 October, 2017, Port of Spain, Trinidad.
Dasent, C. and Cashman, A. <i>Catchment modelling and assessment of the impact of climate change on water availability in the Nariva River</i> ,

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Maharaj, A. <i>Improving fresh water availability: measures under climate change</i> . Adaptation Futures, Rotterdam, The Netherlands, 10-13 May, 2016.
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Drakes, C. <i>Socio-economic Foresight Scenarios for the Island of Barbados and Their Implications for Water Availability</i> . 14 th CWWA Annual Conference, Miami, USA, 25-28 August, 2015
Wood, J and Georges, J. <i>A Social Capital Assessment of Water Resource Management: A Case Study of Carriacou</i> . 14 th CWWA Annual Conference, Miami, USA, 25-28 August, 2015
Hutchinson, S., Sookram, S., Harris, J., and De Someaux, A. <i>Vulnerability Assessment of Livelihoods in Watersheds: A Case of Nariva, Trinidad and Tobago</i> . 2 nd International Conference on Global Food Security; 11-14 October 2015, Cornell University, Ithaca, New York, USA
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Gohar, A., and Cashman, A. (2015) <i>Modelling the impacts of climate change and variability on water scarcity and economic welfare: Example from Tropical Island</i> . 14 th CWWA Annual Conference, Miami, USA, 25-28 August, 2015
Gohar, A. and Cashman, A. (2015). <i>Modelling the impact of climate change and variability on water availability and economic likelihood: Example from the Caribbean</i> . Presented at International Conference on Water and Society, La Coruña, Galicia, Spain. 13 – 18 July, 2015
Gohar, A. and Cashman, A. <i>The impact of climate change and variability on agricultural water resources and food security: Integrated watershed analysis</i> . World Water Congress 2015 in Edinburgh, Scotland.
Cashman, A and Gohar, A. <i>The Implications of climate change and climate variability for water resources and food security in Barbados</i> . Barbados National Agricultural Conference 2015: Agriculture, Meeting Challenges for Increased Productivity and Sustainability. Barbados, 30-31 March 2015.
Stewart, A., Khan, K. and Chadee, D. A. <i>Knowledge, Attitudes and Practice (KAP) Survey on Water Quality and Human Health in two Communities in Nariva Swamp, Trinidad, West Indies</i> . 13 th CWWA Annual Conference, Nassau, The Bahamas, 6-10 th October, 2014
Stewart, A and Chadee, D. A. <i>Drinking Water and Public Health</i> . 13 th CWWA Annual Conference, Nassau, The Bahamas, 6-10 th October, 2014

Training

Work Package 2 Training Workshop "The Creation and Use of Livelihood Vulnerability Indies", held at the Social Sciences Computer Laboratory, the University of the West Indies, St. Augustine Campus on Tuesday 22nd September 2015. Nineteen

participants from a range of organisations (government ministries, FAO, IICA and the UWI).

Work Package 8 Training Workshop, Valuation of Ecosystem Goods and Services, held in Grenada November 016 attended by 22 persons from across the Caribbean.

APPENDIX 2: PROJECT PHOTOGRAPHS



Interviewing a female farmer in Carriacou



Stakeholder consultation in Carriacou



Ponds like this are used as a source of water for agriculture in Carriacou



Administering questionnaire for Work Package 5



Bridge over the Rio Cobre



A tributary of the Rio Cobre – it disappears down a sinkhole



View of the Rio Cobre catchment looking north



Orchards in the Rio Cobre catchment



The Nariva Swamp – cultivated area, with drainage channels



Cultivation in the Nariva Swamp, Trinidad



Collecting vegetation sample in the Nariva Swamp



Plant identification, Trinidad Forestry Dept.



Pressing vegetation sample in the field



Speightstown catchment, Barbados



Young boy collecting crabs, Nariva



Standpipes in Hillsborough, Carriacou



Communal Rainwater Harvesting and Cistern, Carriacou



Household rainwater harvesting, Carriacou



Water-aCCSIS team at the Miami, CWWA Conference



Akilah Stewart presenting to conference participants In South Africa



Crystal Drakes by her Foresight Scenarios poster at the Miami CWWA Conference



Land use, Carriacou.



Dr. Sharon Hutchinson at the 2nd International Conference on Global Food Security