DEVELOPMENT OF A NATIONAL WATER SECTOR ADAPTATION STRATEGY TO ADDRESS CLIMATE CHANGE IN JAMAICA

Prepared for:

Mainstreaming Adaptation to Climate Change Project
c/o Caribbean Community Climate Change Centre (CCCCC)
2nd Floor Lawrence Nicholas Building
Bliss Parade
P.O. Box 536, Belmopan City
Belize

Submitted by:

ESL MANAGEMENT SOLUTIONS LIMITED
20 West Kings House Road
Kingston 10, Jamaica

January 2009

Technical Report 5C/MACC-01-09-2

Published by Caribbean Community Climate Change Centre, Belmopan, Belize

Digital Edition (February 2010)

Caribbean Community Climate Change Centre, Ring Road, P.O. Box 563, Belmopan, Belize

Visit our website at http://www.caribbeanclimate.bz

ISBN-13 978-976-8236-11-1 (pdf)

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

APPENDICES
Separately Bound

LIST OF ACRONYMS AND ABBREVIATIONS

AGD	Attorney General's Department
CCCCC	Caribbean community Climate Change Centre
ENSO	El Nino/Southern Oscillation
GCM	General Circulation Model
GDP	Gross Domestic Product
HEP	Hydro-Electric Power
IWCAM	Integrating Watershed and Coastal Area Management
MACC	Mainstreaming Adaptation to Climate Change
NEPA	National Environment and Planning Agency
NIC	National Irrigation Commission
NATL	North Atlantic Ocean
NCEP	National Centres for Environmental Prediction
NWC	National Water Commission
PRECIS	Providing Regional Climates for Impact Studies
Q90	Stream flow that occurs more than 90% of the time
RCM	Regional Climate Model
SIDS	Small Island Developing States
SDSM	Statistical Downscaling Model
SRES	Special Report Emissions Scenarios
SST	Sea Surface Temperature
UNFCC	United Nations Framework Convention on Climate Change
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
URCR	Upper Rio Cobre Rainfall
WRA	Water Resources Authority
WMU	Water Management Unit: A single or group of watersheds that have been grouped together for the purposes of management

GLOSSARY

Aquiclude: An aquiclude is a saturated geologic unit that is incapable of transmitting significant quantities of water under ordinary hydraulic gradients.

Aquifer: An aquifer is a saturated permeable geologic unit that is capable of transmitting significant quantities of water under ordinary hydraulic gradients or is permeable enough to yield economic quantities of water to wells.

Atlantic Multi-decadal Oscillation (AMO) A multi-decadal (65 to 75 year) fluctuation in the North Atlantic, in which sea surface temperatures showed warm phases during roughly 1860 to 1880 and 1930 to 1960 and cool phases during 1905 to 1925 and 1970 to 1990 with a range of order 0.4°C.

Cryosphere: One of the interrelated components of the Earth's system, the cryosphere is frozen water in the form of snow, permanently frozen ground (permafrost), floating ice, and glaciers. Fluctuations in the volume of the cryosphere cause changes in ocean sea level, which directly impact the atmosphere and biosphere.

Downscaling: Downscaling is a method that derives local- to regional-scale (10 to 100 km) information from larger-scale models or data analyses. Two main methods are distinguished: dynamical downscaling and empirical/statistical downscaling. The dynamical method uses the output of regional climate models, global models with variable spatial resolution or high-resolution global models. The empirical/statistical methods develop statistical relationships that link the large-scale atmospheric variables with local/regional climate variables. In all cases, the quality of the downscaled product depends on the quality of the driving model.

Drought: Drought is viewed as a sustained and regionally extensive occurrence of below average natural water availability, either in the form of precipitation, river runoff, or groundwater.

El Niño: Refers to a sustained warming of sea surface temperatures (SSTs) across a broad region of the eastern and central tropical Pacific Ocean. El Niño events are also called warm events.

El Niño Southern Oscillation (ENSO): The term is used to describe basin-wide changes every 2 to 7 years in air-sea interaction in the equatorial Pacific Ocean. El Niño/La Niña is the oceanic component and the Southern Oscillation is the atmospheric component of the phenomenon.

Emissions Scenario: A plausible representation of the future development of emissions of substances that are potentially radiatively active (e.g., *greenhouse gases*, aerosols), based on a coherent and internally consistent set of assumptions about driving forces (such as demographic and socioeconomic development, technological change) and their key relationships. In 1992, the IPCC presented a set of emissions scenarios that were used as a basis for the climate projections in the Second Assessment Report (IPCC, 1996). These emissions scenarios are referred to as the IS92 scenarios. In the IPCC *Special Report on Emissions Scenarios (SRES)* (Nakićenović et al., 2000), new emissions scenarios – the so-called *SRES* scenarios, were published.

Evapotranspiration: The combined process of evaporation from the Earth's surface and transpiration from vegetation.

Flood: An overflow of water from a river, lake or other body of water due to excessive precipitation or other input of water.

Front The transition zone between two distinct air masses.

General Circulation Model (GCM): A global, three-dimensional computer model of the climate system which can be used to simulate human-induced climate change. GCMs are highly complex and they represent the effects of such factors as reflective and absorptive properties of atmospheric water vapor, greenhouse gas concentrations, clouds, annual and daily solar heating, ocean temperatures and ice boundaries. The most recent GCMs include global representations of the atmosphere, oceans, and land surface.

Global Climate Models: Sophisticated computer models of the atmosphere and oceans that attempt to include all the processes known to affect climate.

Groundwater: Groundwater is that subsurface water contained in the interconnected pore spaces below the water table of an aquifer.

Groundwater Discharge: The removal of water from the saturated zone is called groundwater discharge. The discharge area is simply the geographic area in which discharge occurs.

Groundwater Recharge: The addition of water to the saturated zone is called groundwater recharge. In another context, recharge may refer to the amount of water added per unit of time, e.g. cubic metres per year. The recharge area is simply the geographic area in which recharge occurs.

Gross Domestic Product: The market value of all the goods and services produced by labour and property located in a particular country or region.

Intermittent Streams: Streams which go dry if much time elapses between rains.

Intergovernmental Panel on Climate Change (IPCC): The IPCC was established jointly by the United Nations Environment Programme and the World Meteorological Organization in 1988. The purpose of the IPCC is to assess information in the scientific and technical literature related to all significant components of the issue of climate change. The IPCC draws upon hundreds of the world's expert scientists as authors and thousands as expert reviewers. Leading experts on climate change and environmental, social, and economic sciences from some 60 nations have helped the IPCC to prepare periodic assessments of the scientific underpinnings for understanding global climate change and its consequences. With its capacity for reporting on climate change, its consequences, and the viability of adaptation and mitigation measures, the IPCC is also looked to as the official advisory body to the world's governments on the state of the science of the climate change issue.

La Niña: Refers to a sustained cooling of sea surface temperatures (SSTs) across a broad region of the eastern and central tropical Pacific Ocean. La Niña events are also called cold events.

North Atlantic Oscillation (NAO): The NAO is the dominant mode of winter climate variability in the North Atlantic region ranging from central North America to Europe and into much of Northern Asia. The NAO is a large scale seesaw in atmospheric mass between the subtropical high and the polar low.

Pacific Decadal Oscillation (PDO): A long-term El Niño-like pattern of North Pacific climate variability, with phases that persist from 20-30 years. The positive (warm) phase of the PDO is characterized by cooler than average SSTs and air pressure near the Aleutian Islands and warmer than average SSTs near the California coast; these conditions tend to enhance El Niño teleconnections. The negative (cool) phase tends to enhance La Niña teleconnections (i.e., winter wetness in the Pacific Northwest and winter dryness in the Southwest United States).

Perennial River: Rivers with continuous flow.

Precipitation: This is any product of the condensation of atmospheric water vapor that is deposited on the earth's surface. Precipitation that reaches the surface of the earth can occur in many different forms, including rain, freezing rain, drizzle, snow, ice pellets, and hail. In Jamaica, the great majority of precipitation occurs as rainfall.

Relative humidity : The ratio of the amount of water vapor actually in the air compared to the amount of water vapor the air can hold at the particular temperature and pressure. The ratio of the air's actual vapor pressure to its saturation vapor pressure.

Scenario: A plausible and often simplified description of how the future may develop based on a coherent and internally consistent set of assumptions about driving forces and key relationships. Scenarios may be derived from projections but are often based on additional information from other sources, sometimes combined with a "narrative storyline."

Sea Level Rise: An increase in the mean level of the ocean. Eustatic sea level rise is a change in global average sea level brought about by an increase in the volume of the world ocean. Relative sea level rise occurs where there is a local increase in the level of the ocean relative to the land, which might be due to ocean rise and/or land-level subsidence. In areas subject to rapid land level uplift, relative sea level can fall.

Seawater Intrusion: Aquifers in island and coastal areas are prone to seawater intrusion. As seawater is denser than freshwater, it will invade aquifers which are hydraulically connected to the ocean. Under natural conditions, fresh water recharge forms a lens that floats on top of a base of seawater. This equilibrium condition can be disturbed by changes in recharge and/or induced conditions of pumpage and artificial recharge.

Storm Surge: A rise above normal water level on the open coast due only to the action of wind stress on the water surface; includes the rise in level due to atmospheric pressure reduction as well as that due to wind stress.

Watershed or basin or catchment: A geographical area drained by a particular surface water and/or groundwater system. The basin boundaries are demarcated so that there is generally no flow from one basin into another.

Water Management Unit: A single or group of watersheds that have been grouped together for the purposes of management.

Well: A well is a borehole, adit tunnel, or any other excavation constructed or used for the abstraction of water.

EXECUTIVE SUMMARY

Executive Summary

Background – The Water Sector and Climate Change

Jamaica is in the process of drafting the Second National Communication to the United Nations Framework Convention on Climate Change (UNFCCC). The Mainstreaming Adaptation to Climate Change (MACC) Project under the Caribbean Community Climate Change Centre (CCCCC) has provided support to Jamaica to prepare a National Adaptation Strategy (NAS) for the water sector to adapt to the adverse effects of climate change. The sector strategy has been informed by climate projections; an analysis of the institutional framework within which the sector operates; an assessment of the economic impact of climate change on the sector; and a review of current policies and legal instruments.

A National Water Sector Policy was approved by the Government of Jamaica in January 1999. The Water Resources Master Plan is in its final stage of preparation and the National Irrigation Development Plan is in place.

A 100-year review of destructive events from natural hazards in Jamaica reveals that on average one disastrous flood event occurs every four years. These flood events bring with them high volumes of sediment-laden runoff, ponding in low-lying and drainage restricted areas, debris flows and landslides. The result is often damage and / or destruction of distribution systems, submerged wells and other facilities, high turbidity levels which cannot be handled by the treatment facilities, and damaged infrastructure.

Findings

The findings of the climate assessment and modeling activities included scenario based forecasts for future climate in Jamaica to the 2080's with some spatial variability. The PRECIS regional climate model and statistical downscaling at specific locations were used to develop the scenarios. The issues, vulnerabilities and threats faced by the water sector as a result of these scenario based forecasts in climate change and climate variability are explored and presented.

Precipitation changes for the 2015's, 2030's, 2050's and 2080's were simulated over seven regions of Jamaica using the PRECIS model. For the same periods, precipitation changes and streamflow changes for three stations were downscaled. Most stations begin to show decreases in precipitation by 2050's and

2080's with a drying effect noted all over Jamaica. Analysis of the degree of uncertainty indicated that the results are all significant by the 2080's.

Threats to the Sector

From the analysis undertaken of the likely performance of the water sector under climate change, existing vulnerabilities are likely to increase, and the climate modeling results also projected increased climate variability. Likely impacts on the water sector include the following:

1. Increasing length of the dry season will increase the vulnerability of communities that are supplied by single spring or river sources. In contrast the increased frequency of intense rains are likely to result in high sediment loads.
2. The likely increase in frequency of high intensity rainfall events will increase the frequency of the occurrence of landslides and floods.
3. Increased frequency of more intense rainfall events will accelerate sediment erosion, movement and transport within basin river systems.
4. The likely increase in climatic variability will increase the vulnerability of the agricultural sector.
5. Sea level rise is expected to increase by between 0.18m and 0.59 m by the 2090's (IPCC, 2007). Other projections have estimated up to 1.4 m over the same period.

Recommended Strategies

Although the impacts of climate change on the water sector are wide ranging and significant, there are a number of positive measures that can be taken to increase the adaptive capacity of the sector. These include:

1. Investment in hydrological and water quality monitoring, and dissemination of data to the stakeholder community.
2. Development of appropriate hydrological and water resources modeling tools in parallel with capacity building within key stakeholder organizations.
3. More integration and stricter enforcement of physical planning laws and regulations to reduce risks to life and property from extreme rainfall and coastal flooding events.
4. Identify and replicate best practice programs in local community and stakeholder engagement.
5. Support the update of relevant national plans and policies.
6. Continue programs to increase the efficiency in water storage and delivery systems.

As a part of the preparation of this study, meetings were held with key stakeholders and Government of Jamaica agencies. A National Stakeholder Workshop was also held to present the findings and to solicit feedback from the respective constituencies. Feedback comments have been integrated into the Final Sector Strategy Report.

1 INTRODUCTION

1.1 Purpose

Jamaica is in the process of drafting the Second National Communication to the United Nations Framework Convention on Climate Change (UNFCCC). The Mainstreaming Adaptation to Climate Change (MACC) Project[1] under the Caribbean Community Climate Change Centre (CCCCC) has provided support to Jamaica to prepare a National Adaptation Strategy (NAS) for the water sector to adapt to the adverse effects of climate change. The sector strategy has been informed by climate projections; an analysis of the institutional framework within which the sector operates; an assessment of the economic impact of climate change on the sector; and a review of current policies and legal instruments.

Jamaica is taking some initiatives to mainstream climate change into its national development processes and mechanisms. The Government of Jamaica (GOJ) approved a National Water Sector Policy, in January 1999; The Water Resources Development Master Plan (Draft 2005) is in its final stage of preparation; and a National Irrigation Development Plan (1997) is in place. Of additional relevance are the Forestry Master Plan and the initiative toward Vision 2030 being spearheaded through the Planning Institute of Jamaica (PIOJ)? Vision 2030, a national development plan to the year 2030, includes task forces focused on the Water Sector, Natural Resources Management and Climate Change and Natural Hazard Reduction, Urban and Regional planning as well as several sector and social themes. These initiatives have been incorporated in the review of information and data to support the preparation of the Strategy.

The report entitled "Development of a National Water Sector Adaptation Strategy to Address Climate Change in Jamaica", presents four technical areas reviewed as specified in the Terms of Reference for the project. These are climate change modelling; water sector issues and threats; policy, legal and institutional framework; and economic review.

1.2 Background

The Third World Water Forum held in 2003 highlighted the fact that the quality and quantity of water resources are integrally tied to the economic and social well-being of small island countries. The health of the populations and the development of small island economies are being threatened by trends such as rising sea levels, increasingly variable rainfall, accelerated storm water runoff, increasing demand for water, and increasing pollution of surface, ground and coastal waters (3rd World Water Forum, 2003).

In the Jamaican environment the water sector is critical not only for potable purposes but also for agriculture, food security, tourism, industrial applications and other uses. Increasing variability and erratic patterns of weather associated with global warming and climate change are already being felt dramatically in Jamaica, as indeed the entire Caribbean. The increasing frequency and intensity of hydro-meteorological events have resulted in more intense floods, and evidence of sea level rise has also been indicated in some areas.

A 100-year review (1887-1987) of destructive events from natural hazards in Jamaica reveals one disastrous flood event every four years. (WMORAIV Hurricane Committee, 1987). These flood events bring with them high volumes of sediment-laden runoff, ponding in low-lying and drainage restricted areas, debris flows and landslides. The result is often damage/destruction of distribution systems, submerged wells and other facilities, and high turbidity levels which cannot be handled by treatment facilities and which damage infrastructure. There is also often general "wash out" of water supply facilities.

Between 1987 and 2002 (15 years) there have been several devastating precipitation events, which wreaked havoc on the island's infrastructure. Hurricane Gilbert in 1988 caused extensive damage across the island from wind and rain; flood rains in 1992 destroyed the diversion dam at the Rio Cobre Irrigation Scheme Headworks; three flood events in 1993; two in 1994, four in 1995-1996, 1998, and four devastating events 2001-2002– all tell a tale of woe. A review of drought conditions over the period illustrates the dichotomy in weather patterns experienced by Jamaica; flood producing conditions alternate with extended dry periods and water shortages in many parts of the island.

Between 1979 and 2007 Caribbean territories including Jamaica experienced severe economic and social dislocation from several natural hazard events including hurricanes and tropical storms, flood producing precipitation events, and drought. The high vulnerability and low adaptation strategies for the water sector in Jamaica have been particularly highlighted.

With the increasing level of extreme weather events, adaptation strategies for the water sector are therefore of long term importance. Governance structures (institutional framework and policy), security of the quality and quantity of water sources, protection of distribution networks, and management of demand and supply, must be considered. Climate change scenarios will help to inform the potential vulnerability and predicted adverse impacts on Jamaica.

1.2.1 Climate Change and Climate Change Issues

Climate change is defined as any long-term significant change in the "average weather" that a given region experiences. Average weather may include average temperature, precipitation and wind patterns. It involves changes in the variability or average state of the atmosphere over durations ranging from decades to millions of years. Climate changes reflect variations within the Earth's atmosphere, processes in other parts of the Earth such as oceans and ice caps, and the effects of human activity. The external factors that can shape climate are often called "climate forcings" and include such processes as variations in solar radiation, the Earth's orbit, and greenhouse gas concentrations.

1.2.2 The Water Sector

The water sector includes quantity and quality of ground water systems as well as the water supply and wastewater components and associated infrastructure. It also considers the role of land use and watershed management and protection, as these are considered to be key to the protection, maintenance and strengthening of the resilience of Jamaica's water resources to the threats posed by climate change, in terms of quantity and quality.

1.2.3 Vision 2030: National Development Plan

The Vision 2030 Jamaica: National Development Plan, Jamaica's first twenty-five year development Plan, has its overarching objective putting Jamaica in a position to achieve developed country status by 2030.

The long-term development plan is based on a comprehensive vision, "Jamaica, the place of choice to live, work, raise families, and do business", and on guiding principles which put 'people' at the centre of

Jamaica's transformation. Several strategic priorities have been identified as critical elements to fulfill the objectives of the Plan. These include the development of human resources, international competitiveness, environmental sustainability, health, social protection, science, technology and innovation, effective governance, and law and order.

The Threshold 21 (T21) – Jamaica, an integrated development model is being used to assist with integrating the multifaceted components of the planning exercise for the successful achievement of the Vision. It focuses on the dynamic interactions of various aspects of our local economy, society and the environment, and facilitates long-range forecasting.

Vision 2030 Jamaica is based on the following Guiding Principles:

- People must be at the centre of development for Jamaica's Transformation.
- An over-arching vision for the society should direct the transformation. It should be buttressed by strong, extra-ordinary leadership and guided by a cohesive and comprehensive development plan.
- Sustainability – integrating economic, social and environmental issues
- Fostering balanced development in rural, urban and regional areas
- Equity – ensuring that the Plan facilitates equality of opportunity and equal rights
- Social cohesion and partnerships

These Guiding Principles prioritize the elements which are absolutely critical for enhancing the quality of life of all Jamaicans and for the country's achievement of world class standards in specific or predetermined areas.

Vision 2030 Jamaica will give priority attention to the following key areas of national development in order to achieve developed country status:

- Developing Human Resources
- Effective Governance
- Environmental Sustainability
- Gender, Culture & Values
- Health
- Infrastructure
- International Competitiveness
- Law & Order
- Population
- Regional Development
- Science, Technology & Innovation
- Social Protection

1.3 The Scope and Approach

1.3.1 Climate Change Projections/ Scenarios

The primary methodology for generating scenarios of precipitation and/or stream flow and temperature was by statistical downscaling. The aim of statistical downscaling was to generate the climate scenarios for a small region or even a point such as a weather station, using the output of a dynamic model for a larger region; hence the term downscaling. The process consists of generating and validating regression equations that relate the climate parameters to be downscaled for the small region, called predictands, with climate predictors, such as surface temperatures, pressure and vertical velocity. These are available from data sets, such as the National Centre for Environmental Prediction (NCEP) re-analysis dataset (Kalnay *et al*., 1996). These regression equations were then employed to find scenarios of future climate for the small region by using future values of the predictors generated by the dynamic model. The downscaling model used was the Statistical Down Scaling Model (SDSM) developed by Wilby *et al* (2002).

The PRECIS regional model, described herein, was used for comparison with the SDSM results. Estimates of sea level rise and evapotranspiration were obtained from observations and global models.

1.3.2 Water Sector Vulnerability Issues and Threats

The methodology for Section 3 of the report "Water Sector Vulnerability Issues and Threats" was based upon a summarising of the existing status, issues and threats faced by the water sector. This included water availability supply demand balances for each of the basins of Jamaica. The results from the climate modelling projections presented in Section 2 were taken forward to provide both preliminary quantitative and qualitative assessments of the possible impacts of climate change on the water sector. Based on this assessment, recommendations for activities to be included within the Action Plan and Strategy were made.

1.3.3 Institutional, Policy and Legislative Review

A thorough review was conducted of all the government of Jamaica agencies and other relevant agencies and organisations that are involved in research, regulations, provision or enforcement within the water sector and especially as related to climate change. Interviews and meetings were held with key stakeholders individually and within meeting and workshop settings to share the TOR's for conducting the study, gather information and obtain tangible inputs to the text of this document (Appendices 5 and 6). Current legal instruments, regulations and policies were also reviewed and recommendations made where gaps were identified.

1.3.4 Economic Sector Review

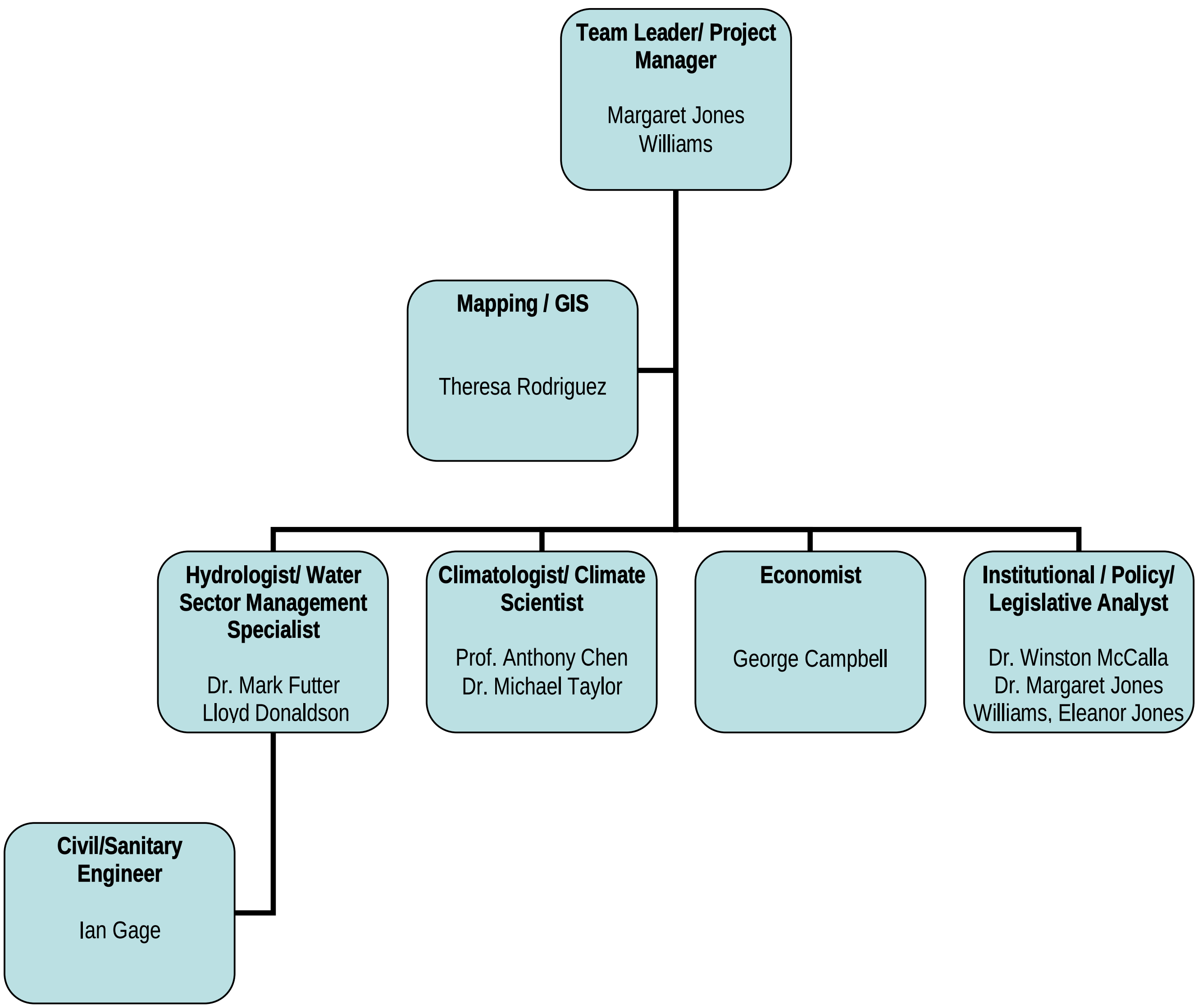
The approach to the economic review entailed the consulting of secondary source material and drawing inferences from the assembled data. It also required close consultation across the team's professional disciplines as well as with technocrats in the water sector.

1.3.5 National Stakeholder Workshop and Stakeholder Meeting

The aim of the National Workshop was to present the findings, conclusions and recommendations of the main report and engage stakeholders in further discussion. The comments, views and recommendations were recorded for inputs into the final report and strategy. Present at the workshop, which was held in July 2008, were the relevant government agencies, and key stakeholders from private sector, the non-government sector and civil society. (Appendix 5)

A Stakeholder Meeting was also held after incorporating the comments from the National Stakeholder Workshop. The meeting was targeted to the key regulatory agencies and was arranged in a workshop format to present and finalise the Strategy and Plan of Action. The Stakeholder Meeting was held in November 2008 (Appendix 6).

1.3.6 The Study Team



2 AN ANALYSIS OF JAMAICA'S FUTURE CLIMATE FOR WATER SECTOR GUIDANCE

2.1 Climate of Jamaica

2.1.1 General Climatic Setting

Jamaica has a total area of 11,244 km^2. The island is surrounded by the Caribbean Sea and is located in the Tropics at approximately latitude 18ºN and longitude 77ºW, about 4.5 degrees south of the Tropic of Cancer or about midway between the southern tip of Florida and the Panama Canal, as can be seen in Figure 2-1.

Figure 2-1: The Caribbean

Among the most important climatic influences are the Northeast Trade Winds, the range of mountains which runs east-southeast to west-southwest along the centre of the island, the warm waters of the Caribbean Sea, and weather systems such as upper- and low-level low-pressure centres, troughs and cold fronts. The cold fronts, usually weak after migrating from the North American continent, are evident from mid-October to mid-April; whilst the Tropical Weather Systems, namely Tropical Waves, Tropical Depressions, Tropical

Storms and Hurricanes occur from April to December. The official hurricane season is from June to November.

Climate plays an important role in the ordering of life in Jamaica. Many activities (e.g. planting and harvesting cycles, tourism, and lifestyle related activities) revolve around the timing of peaks in climate variables such as temperature and precipitation. Water availability and supply is also strongly linked to the climate regime of Jamaica.

2.1.2 Precipitation

Precipitation is the most variable climatic factor. Island wide, over the available period of record (1881-2007) mean annual precipitation is 1871 mm. Historically, the wettest year on record was 1933 with an annual precipitation of 2914 mm, whilst the driest year was 1920 with an annual precipitation of 1301 mm. This wide annual variation is presented in Figure 2-2, with the red line showing the annual average value of 1871 mm/yr.

This series show no trends over the complete period of record, although within the series there are runs of above average and below average precipitation. Further analysis looking at trends within the series is presented in Figure 2-3. This plots cumulated departures from the mean over this 1881-2007 series, with upward trends in the cumulated plot showing runs of years with above average precipitation, and downward trends showing runs of years with below average precipitation.

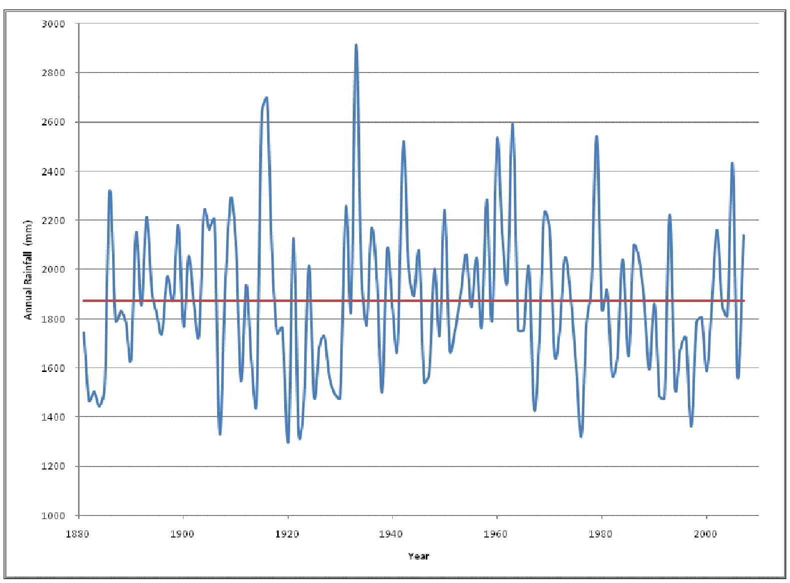


Figure 2-2: Jamaica Annual Precipitation (mm) 1881-2007

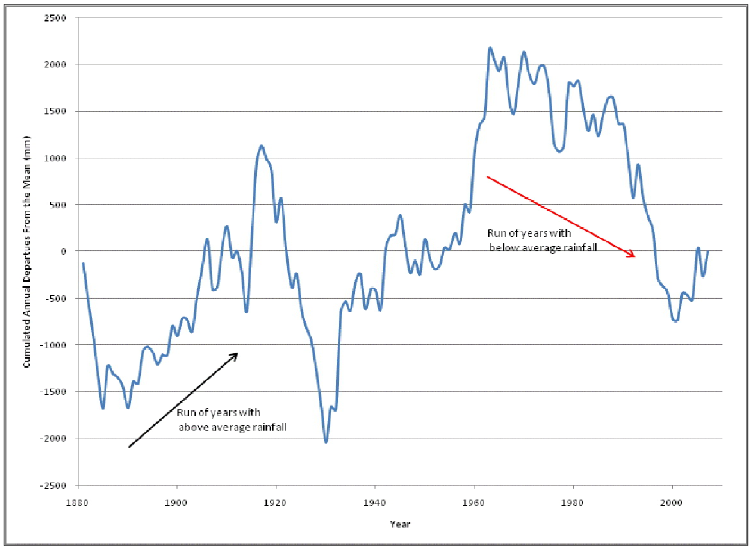


Figure 2-3: Jamaica Annual Precipitation Cumulated Departures from Mean 1881-2007

As can be seen, Figure 2-3 shows runs of years (decadal periods) with above average precipitation from the mid-1880s to mid-1910s, 1930 to early1960s and from 2000 to date. Periods of below average precipitation are identified in the 1920s and from the early 1960s to 2000, especially from the early-1980s to the late 1990s. Further analysis is required to identify any linkages and causal mechanisms between these patterns and global climatic features such as the Atlantic Multi-decadal Oscillation and the Pacific Decadal Oscillation.

Most areas of the island have a distinct bi-modal precipitation pattern, May to June and September to November; these wet seasons occur as regular yearly cycles. This is illustrated in Figure 2-4 again based on the Jamaica island precipitation series for 1881-2007.

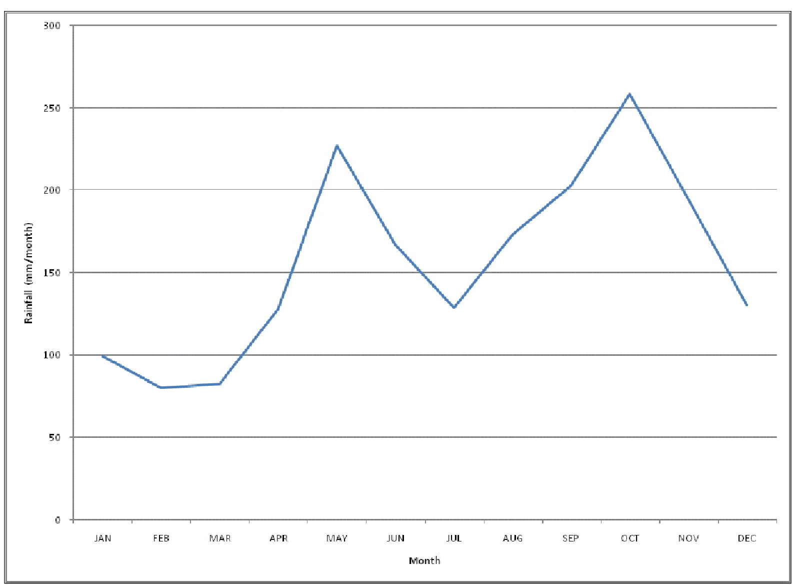


Figure 2-4: Jamaica Mean Monthly Precipitation (mm) 1881-2007

Most of the precipitation during the May to June period is as a result of the periodic increase in solar radiation intensity, which peaks at that time. During the period September to November the precipitation is more directly the result of the lifting and movement of the sub-tropical high-pressure cell in the Atlantic Ocean. Such behaviour deepens the easterly Trades, allowing instability zones to develop. This in turn results in a significant portion of the precipitation during this period being produced by upper- and low-level troughs, tropical waves, tropical depressions, tropical storms and hurricanes.

The driest period is usually December to March. Most of the precipitation during this period is associated with cold fronts migrating from North America. Whether during the dry or rainy season, however, other rain-producing systems are influenced by the sea breeze and orographic effects which tend to produce short-duration showers, mainly during mid-afternoon.

Some mountainous areas in the island's northeast receive more than 5080 mm. annually, whilst Northeastern Jamaica receives highest precipitation, and the southern plains are the driest regions (less that 1200 mm annually).

By virtue of its location, Jamaica is also prone to the influence of hurricanes which pass through the north tropical Atlantic.

2.1.3 Temperature

Like many of the other Caribbean islands, Jamaica possesses a cool-dry winter/hot-wet summer climate regime. The temperature pattern generally follows the motion of the sun, with annual variation limited to approximately 12^{o}C. July is the warmest month while January/February is the coolest period. There is also spatial variation across the island as coastal areas exhibit warmer temperatures compared to the cooler mountainous interior of the island. Sea breezes and the warm ocean temperatures of the Gulf and Caribbean Sea also help modulate temperature year round.

2.1.4 Winds

For most of the year, the daily wind pattern is dominated by the Northeast Trades. By day on the North Coast, the sea breeze combines with the Trades to give an east-northeasterly wind at an average speed of 15 knots, and along the South Coast, an east-southeasterly wind with an average speed of 18 knots. In the period December to March, however, the Trades are lowest and the local wind regime is a combination of trades, sea breeze, and a northerly or northwesterly component associated with cold fronts and high-pressure areas from the United States.

By night, the trades combine with land breezes which blow offshore down the slopes of the hills near the coasts. As a result, on the North Coast, night time winds generally have a southerly component with a mean speed of 5 knots and on the South Coast, a northerly component with a mean speed of 7 knots. By day, from June to July, mean onshore winds often reach a maximum of up to 23 knots along the North Coast and 26 knots along the South Coast during mid-afternoon. However, winds are generally lighter inland and towards the west. Calms, therefore, attain their highest frequency in the western extremity of the island and in the two intervening periods between the full development of the land and sea breezes

2.1.5 Sunshine

Variations of sunshine from month to month in any area are usually small, approximately one hour. Differences, however, are much greater between coastal and inland stations. Maximum day-length occurs in June when 13.2 hours of sunshine are possible and the minimum day-length occurs in December when 11.0 hours of sunshine are possible. However, the mean sunshine in mountainous areas is less than 6 hours per day, while in coastal areas it is near 8 hours per day. The shorter duration in the hilly areas is caused mainly by the persistence of clouds.

2.1.6 Relative Humidity

Afternoon showers are the major cause of most daily variations in relative humidity. Highest humidity values recorded during the cooler morning hours near dawn are followed by a decrease until the early afternoon when temperatures are highest. Although relative humidity in coastal areas averages 84% at 7 a.m. temperatures at this time are in the mid 20's ºC and therefore, little or no discomfort results. At 1 p.m. the average relative humidity on the coasts is 71% while values in the plains will average about 77% reflecting the effects of afternoon showers in the nearby hills.

2.1.7 Natural Climate Variability

Jamaica's tropical maritime climate is conditioned by the large scale features of the tropical Atlantic and the island's orography as previously detailed. To a large extent, then, it is the variability in the factors that facilitate a favourable convective environment which modulate the variability of Jamaican precipitation on seasonal to inter-annual and decadal timescales. For example, on the seasonal time scale, precipitation is strongly tied to the northward movement of the North Atlantic High in early spring, which results in reduced surface pressures and weaker trades across the Caribbean - both of which favour convection. Similarly, the appearance of warm ocean surface temperatures and lower vertical shears in the wind field from May onwards (and especially in September-October) provide a favourable environment for cloud formation and rain and help determine the onset, duration and peak of Jamaica's wet season.

Global phenomena also contribute to the variability of Jamaica's climate by similarly enhancing or diminishing the conditions for precipitation development. An example is the El Niño Southern Oscillation (ENSO) which is a global coupled ocean-atmosphere phenomenon. El Niño and La Niña are temperature fluctuations in surface waters of the tropical Eastern Pacific Ocean. El Niño and La Niña are officially defined as sustained sea surface temperature anomalies of magnitude greater than 0.5°C across the central tropical Pacific Ocean. When the condition is met for a period of less than five months, it is classified as El Niño or La Niña conditions; if the anomaly persists for five months or longer, it is classified as an El Niño or La Niña episode. Historically, it has occurred at irregular intervals of 2-7 years and has usually lasted one or two years. The Southern Oscillation (SO) reflects the monthly or seasonal fluctuations in the air pressure difference between Tahiti and Darwin. Taken together, ENSO is a set of specific interacting parts of a single global system of coupled ocean-atmosphere climate fluctuations that come about as a consequence of oceanic and atmospheric circulation.

ENSO is the most prominent known source of inter-annual variability in weather and climate around the world, though not all areas are affected. ENSO has signatures in the Pacific, Atlantic and Indian Oceans. El Niño causes weather patterns involving increased rain in specific places but not in others.

This global climatic phenomenon has a significant influence on climatic variability in Jamaica. It generally creates unfavourable conditions for precipitation and hurricane development in the main Caribbean basin during the late season of the year of El Niño occurrence. This is due to the stronger vertical shears it creates in the wind field (Gray et al., 1994). La Niña, however, results in decreased wind shear and therefore enhances the opportunity for storm development. For example, the 1997 drought experienced in Jamaica is strongly linked with the 1997-1998 El Niño event, while more recently, the reduced number of tropical cyclones and hurricanes that were observed during the 2006 hurricane season compared with the predicted occurrences was partly attributable to a decrease in La Niña conditions (Klotzbach & Gray, 2006). El Niño also enhances precipitation potential and Caribbean surface temperatures during the early wet season of the year of its decline due to the warm ocean temperatures it induces in the north tropical Atlantic (Chen and Taylor, 2002).

Other global climatic phenomena which may also influence Jamaica's interannual and decadal variability include the North Atlantic Oscillation (NAO) and the Atlantic Multidecadal Oscillation (AMO).The Atlantic Multi-Decadal Oscillation has been shown to have a significant influence on the frequency of Atlantic and Caribbean hurricanes. The North Atlantic oscillation is a climatic phenomenon in the North Atlantic Ocean related to the fluctuations in the difference of sea-level pressure between the Icelandic Low and the Azores high. Through east-west rocking motions of the Icelandic Low and the Azores High, it controls the strength and direction of westerly winds and storm tracks across the North Atlantic.

Figure 2-5 shows the paths of Atlantic hurricanes during the two phases of the Atlantic Multi-decadal Oscillation. The left sketch shows a Cold Phase with reduced frequency of hurricanes, while the right sketch shows a Warm Phase with an increased frequency of hurricanes.

It is interesting to note that it was during the period of reduced Atlantic hurricane activity from 1970-1994 as shown in Figure 2-5 that Jamaica suffered a direct "hit" and a very near miss, while during periods of increased activity from 1953 to 1970 and 1995-2000, Jamaica suffered limited impact from hurricane activity. Since 2000 Jamaica has unfortunately suffered from the impacts of a number of tropical storms and hurricanes, most recently Hurricane Dean in August 2007. Nevertheless, the analysis presented here does illustrate some of the risks associated with generalising climatic variations given the random nature of the processes of interest.

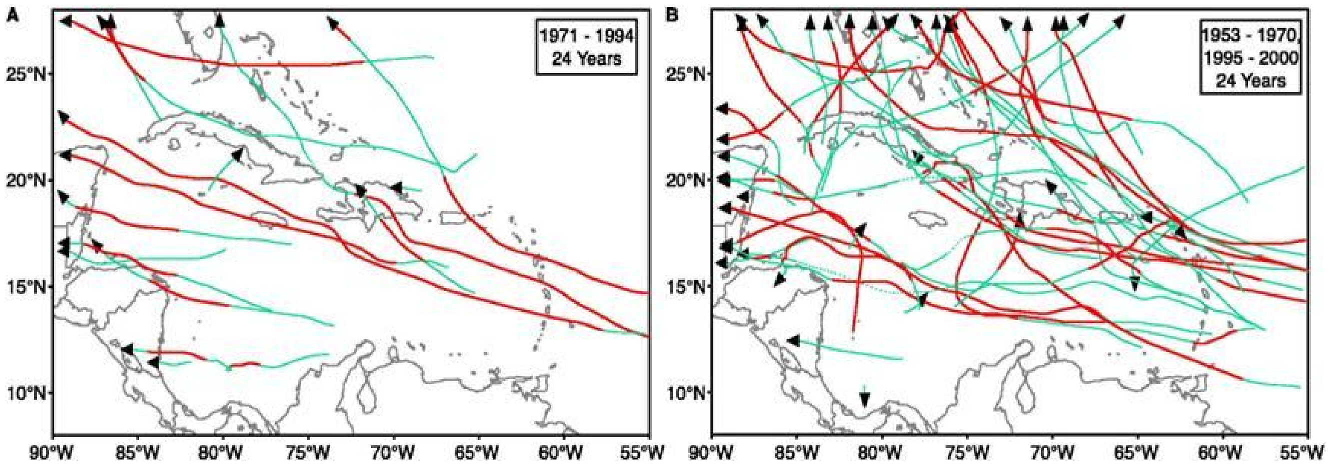


Figure 2-5: Atlantic Multi-Decadal Oscillation and the Atlantic Hurricane Season

(Goldenberg et al. 2001)

[Contrast of Caribbean hurricanes between colder (**A**) and warmer (**B**) values of the Atlantic multidecadal mode. The solid green (thin) and red (thick) lines indicate where the hurricanes were at non-major and major hurricanes intensities, respectively. Tropical storm intensity is indicated by dotted lines in cases where a hurricane weakened to tropical storm strength and then re-intensified to hurricane status. The years are similar to (34) except that the first nine warmer years (1944-1952) are not included to make the number of colder and warmer years equal. The colder years (24 years) include 1971-1994. The warmer years (24 years) include 1953-1970 and 1995-2000.]

2.1.8 Climate Change

The Caribbean and Jamaica are not immune to climate change effects resulting from global warming scenarios. A warming scenario can alter the onset, duration, magnitude, spatial extent, and decline in climate regimes across the Caribbean region. For example, a shortening of the return cycle of ENSO events under a warmer world scenario would alter the cycle of extreme events such as floods, droughts, warm and cold spells, and hurricane frequency and intensity.

In this chapter an assessment is made of the possible impact of global warming on Jamaica's climate in general and in particular on those variables which are strongly linked to the water sector. A reporting is first made of the likely impact of increased emission scenarios on the *Caribbean* as reported in the Intergovernmental Panel on Climate Change's Fourth Assessment Report. A number of atmospheric variables are analysed in addition to sea level rise, hurricane frequency and intensity and evaporation rates. This is done to put Jamaica's future climate change in a regional context of change. The pattern followed is to report first on historical trends in the selected climate variable and then to examine future projections for the same variable.

The remainder of the chapter is an assessment specific to Jamaica. The impact of climate change on precipitation and streamflow rates for three rivers that contribute significantly to water sector usage is examined. The methodology for generating the climate change data for Jamaican streamflow is outlined in section 2.3 and results are given in Section 2.4. Some conclusions about the manifestation of climate change in Jamaican are drawn in section 2.5 and best estimates of the change provided for further use in the water sector vulnerability analysis (ensuing chapters).

2.2 Caribbean Climate Trends and Projections from the IPCC

2.2.1 Temperature

2.2.1.1 Trends

Global temperatures have increased by about 0.74˚C (0.56˚C to 0.92˚C) since the 19th century (IPCC, 2007). There has been a warming trend from 1950-2001 with minimum temperatures increasing at a higher rate than maximum (Alexander et al., 2006). An increasing trend in both variables is also observed for the Caribbean region (Peterson et al., 2002). Peterson et al. (2002) used ten globate climate indices to examine changes in extremes in Caribbean climate from 1950 to 2000. They found that the difference between the highest and lowest temperature for the year (i.e. the diurnal range) is decreasing but is not significant at the 10% significance level. Temperatures falling at or above the 90th percentile (i.e. really hot days) are also increasing while those at or below the 10th percentile (really cool days and nights) are decreasing (both significant at the 1% significant level). These results indicate that the region has experienced some warming over the past fifty years.

2.2.1.2 IPCC Projections

The IPCC projection is for continued warming through the end of the current century. IPCC scenarios of temperature change for the Caribbean between the present (1980-1999) and the future (2080-2099) are based on a coordinated set of climate model simulations (hereafter referred to as the multi-model data set or MMD) which are archived at the Program for Climate Model Diagnosis and Intercomparison[1] (PCMDI); (Christensen et al., 2007). The results of the analysis using A1B Special Report Emission Scenario (SRES)[2] (Nakićenović and Swart, 2000) are summarised in Table 2-1 (Christensen et al., 2007).

In the Table, the small value of T (column 8 for temperature) implies a large signal-to-noise ratio, so that the temperature results (T=10 years) are significant. The probability of extreme warm seasons is 100% (column 15) in all cases and the scenarios of warming are all very significant by the end of the century. Table 2-1 also shows that the MMD-simulated annual temperature increases for the Caribbean at the end of the 21st century range from 1.4°C to 3.2°C with a median of 2.0°C, somewhat below the global average. Fifty percent of the models give values differing from the median by only ±0.4°C. There were no noticeable differences in monthly changes.

[1] See http://www-pcmdi.llnl.gov/
[2] See Section 2.3. for an expanded description of Climate models and SRES Scenarios

Table 2-1: Regional average of Caribbean (CAR) temperature and precipitation projections from a set of 21 global models in the MMD for the A1B scenario. *The mean temperature and precipitation responses are first averaged for each model over all available realisations of the 1980 to 1999 period from the 20th Century Climate in Coupled Models (20C3M) simulations and the 2080 to 2099 period of A1B. Computing the difference between these two periods, the table shows the minimum, maximum, median (50%), and 25 and 75% quartile values among the 21 models, for temperature (°C) and precipitation (%) change. Regions in which the middle half (25–75%) of this distribution is all of the same sign in the precipitation response are coloured light brown for decreasing precipitation. T years (yrs) are meaures of the signal-to-noise ratios for these 20-year mean responses. They are estimates of the times for emergence of a clearly discernible signal. The frequency (%) of extremely warm, wet and dry seasons, averaged over the models, is also presented. Values are only shown when at least 14 out of the 21 models agree on an increase (bold) or a decrease in the extremes (From* Christensen et al., 2007*).*

	Temperature Response (°C)							Precipitation Response (%)						Extreme Seasons (%)		
Region[a]	Season	Min	25	50	75	Max	T yrs	Min	25	50	75	Max	T yrs	Warm	Wet	Dry
CAR	DJF	1.4	1.8	2.1	2.4	3.2	10	-21	-11	-6	0	10		100	2	
	MAM	1.3	1.8	2.2	2.4	3.2	10	-28	-20	-13	-6	6	>100	100	3	18
10N,85W	JJA	1.3	1.8	2.0	2.4	3.2	10	-57	-35	-20	-6	8	60	100	2	40
to	SON	1.6	1.9	2.0	2.5	3.4	10	-38	-18	-6	1	19		100		22
25N,60W	Annual	1.4	1.8	2.0	2.4	3.2	10	-39	-19	-12	-3	11	60	100	3	39

2.2.2 Precipitation

2.2.2.1 Trends

Significant changes are shown in two of the Caribbean precipitation indices used by Peterson et al. (2002). The greatest 5 day precipitation total increased over the period under analysis (10% significance level) while the number of consecutive dry days decreased (1% significant level). The results, however, may not take into account differences in the precipitation regime between the north and south Caribbean. Using several observed data sets, Neelin et al., (2006) also noted a modest but statistically significant drying trend for the Caribbean's summer period in recent decades.

2.2.2.2 IPCC Projections

IPCC scenarios of percentage precipitation change for the Caribbean are also based on the multi-model data set (MMD) and are also summarised in Table 2-1 for the A1B scenario. The large value of T for precipitation (T > 60 years, column 14) implies a small signal-to-noise ratio. In general, then, the signal-to-noise ratio is greater for temperature change than for precipitation change, implying that the temperature results are more significant. In other words, it takes a long time for the change in precipitation to become significant.

From Table 2-1, most models project decreases in annual precipitation, with a few suggesting increases. Generally, the change varies from –39 to +11%, with a median of -12%. Figure 2-6 (Christensen et al., 2007) shows that the annual mean decrease is spread across the entire region (left panels). In December, January and February (DJF), some areas of increases are evident (middle panels), but by June, July and August (JJA) the decrease is region-wide and of larger magnitude (right panels), especially in the region of the Greater Antilles, where the model consensus is strong (right bottom panels).

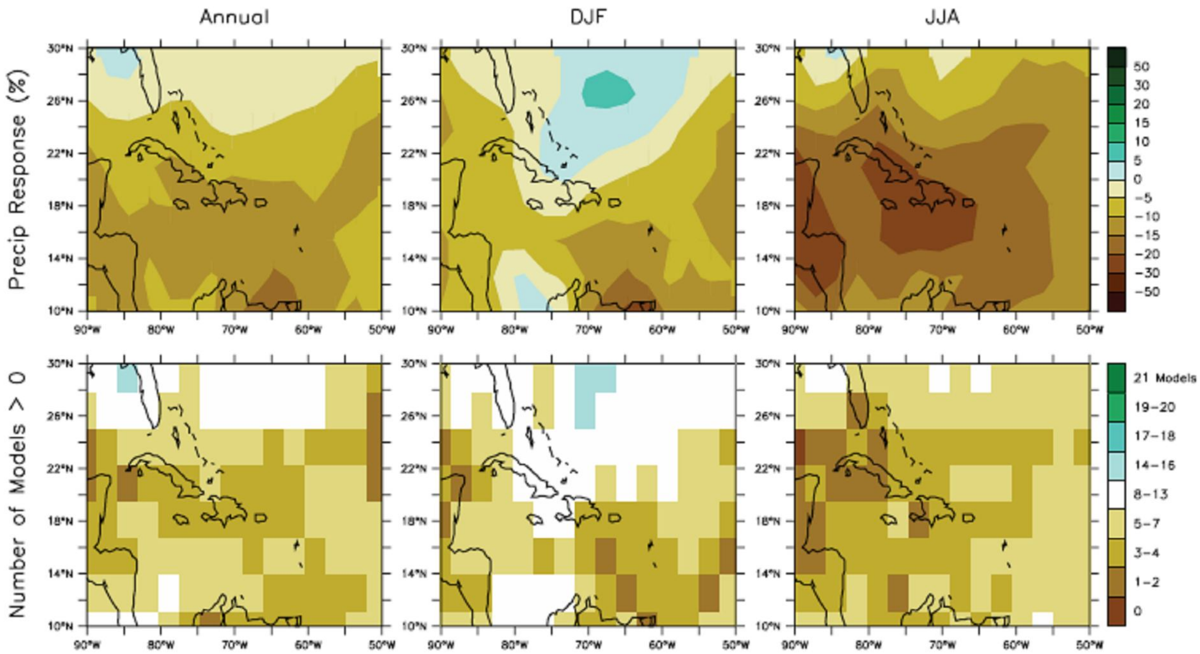


Figure 2-6 : Precipitation changes over the Caribbean from the MMD-A1B simulations. ***Top row: Annual mean, DJF and JJA fractional precipitation change between 1980 to 1999 and 2080 to 2099, averaged over 21 models. Bottom row: number of models out of 21 that project increases in precipitation (From*** **Christensen et al., 2007*****).***

2.2.3 Hurricanes

2.2.3.1 Trends

Analysis of observed tropical cyclones in the Caribbean and wider North Atlantic Basin shows a dramatic increase since 1995. This increase however has been attributed to the region being in the positive (warm) phase of a multidecadal signal and not necessarily due to global warming (Goldenberg et al., 2001). Results per year obtained from Goldenberg et al. (2001), show that during the negative (cold) phase of the oscillation the average number of hurricanes in the Caribbean Sea is 0.5 per year with a dramatic increase to 1.7 per year during the positive phase. Attempts to link warmer sea surface temperatures (SSTs) with the increased number of hurricanes have proven to be inconclusive (Peilke et al., 2005). Webster et al., (2005) found that while SSTs in tropical oceans have increased by approximately 0.5˚C between 1970 and 2004, only the North Atlantic Ocean (NATL) shows a statistically significant increase in the total number of hurricanes since 1995.

In an analysis of the frequency and duration of the hurricanes for the same time period, significant trends were only apparent in the NATL. Both frequency and duration display increasing trends significant at the 99% confidence level. Webster et al., (2005) also noted an almost doubling of the category 4 and 5 hurricanes in the same time period for all ocean basins. While the number of intense hurricanes has been rising, the maximum intensity of hurricanes has remained fairly constant over the 35 year period examined.

2.2.3.2 Projections[3]

Using a high resolution global 20-km grid atmospheric model, Oouchi et al., (2006) generated tropical cyclones that began to approximate real storms. The model was run in time slice experiments for a present-day 10-year period and a 10-year period at the end of the 21st century under the A1B scenario. In the study, tropical cyclone frequency decreased 30% globally, but increased by about 34% in the North Atlantic. The strongest tropical cyclones with extreme surface winds increased in number while weaker storms decreased. The tracks were not appreciably altered, and maximum peak wind speeds in future simulated tropical cyclones increased by about 14% in that model, although statistically significant increases were not found in all basins (Meehler et al., 2007). It must be noted, however, that these regional changes are largely dependent on the spatial pattern of future simulated SST changes (Yoshimura et al., 2006) which are uncertain.

2.2.4 Sea Level Rise

Global sea level is projected to rise between the present (1980–1999) and the end of this century (2090–2099) by 0.35 m (0.23 to 0.47 m) for the A1B scenario (IPCCa, 2007). The projected increases in sea level within the Caribbean and around the coasts of Jamaica vary from 0.17 m. to 0.24 m by 2050 (IPCCb, 2007). Others (Rahmstorf, 2007) have given higher magnitudes of 0.25 m to 0.36 m, against 1990 sea level. Due to ocean density and circulation changes, the distribution will not be uniform. However, large deviations among models make estimates of distribution across the Caribbean uncertain. The range of uncertainty cannot be reliably quantified due to the limited set of models addressing the problem. The changes in the Caribbean are, however, expected to be near the global mean. This is in agreement with observed trends in sea level rise from 1950 to 2000, which were similarly near the global mean (Church et al., 2004).

2.2.5 Evapotranspiration

The IPCC report does not address evapotranspiration specifically within the Caribbean. However, mean annual changes in evaporation for the SRES A1B scenario are given on a global scale as shown in Figure 2-7. From the figure it appears that by the end of the century (2080-2099) evaporation in the vicinity of Jamaica will increase by about 0.3 mm day^{-1} relative to current (1980-1999) values. It is to be noted that the evaporation value in the vicinity of Jamaica is given over the ocean, and evaporation over land may be less.

[3] This projection is based on a single model run and is only mentioned in IPCC (2007) with no level of significance indicated.

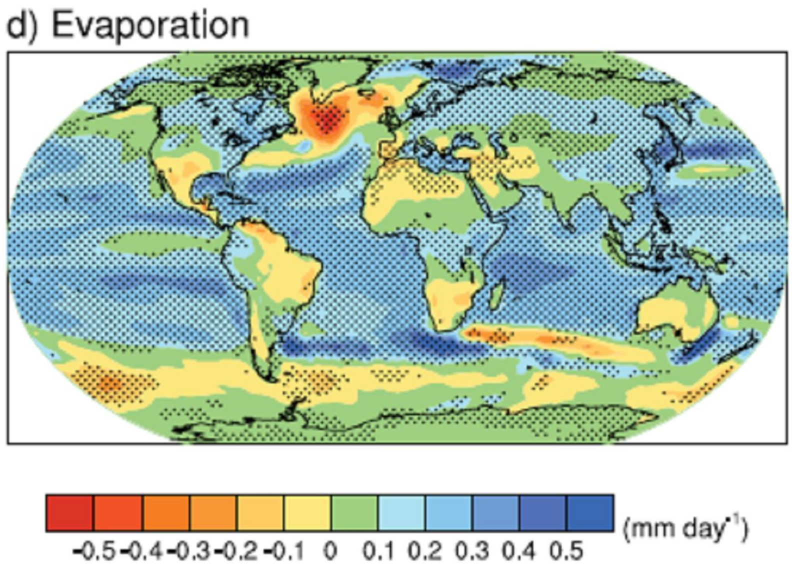


Figure 2-7: Multi-model mean changes in evaporation (mm day–1). To indicate consistency in the sign of change, regions are stippled where at least 80% of models agree on the sign of the mean change. Changes are annual means for the SRES A1B scenario for the period 2080 to 2099 relative to 1980 to 1999.

2.2.6 IPCC 4th Assessment Summary for the Caribbean

Based on the SRES A1B scenario, the following summary can be made about future climate conditions within the Caribbean (from Christensen et al., 2007).

- Sea levels are likely[4] to continue to rise on average during the century around the small islands of the Caribbean Sea …. Models indicate that the rise will not be geographically uniform but large deviations among models make regional estimates across the Caribbean … uncertain.

Note: Based on the personal judgement of the consultants, the increase will probably follow the global average.

- All Caribbean … islands are very likely to warm during this century. The warming is likely to be somewhat smaller than the global annual mean warming in all seasons.

- Summer precipitation in the Caribbean is likely to decrease in the vicinity of the Greater Antilles but changes elsewhere and in winter are uncertain.

Note: On-going analysis of precipitation changes by the Climate Studies Group Mona warrants upgrading the 'likely' decrease of precipitation in the Greater Antilles to 'very likely'

[4] In the IPCC Summary for Policymakers, the following terms have been used to indicate the assessed likelihood, using expert judgement, of an outcome or a result: *Virtually certain* > 99% probability of occurrence, *Extremely likely* > 95%, *Very likely* > 90%, *Likely* > 66%, *More likely than not* > 50%, *Unlikely* < 33%, *Very unlikely* < 10%, *Extremely unlikely* < 5%

- It is likely that intense tropical cyclone activity will increase (but tracks and the global distribution are uncertain).

It is to be noted that the A1B scenario on which these statements are predicated gives an average global increase in temperature of 2.8º C over the present century. If all developed countries were to cut greenhouse gas emissions at the rate now proposed by the United Kingdom and France[5], then the global temperature increase would be limited to just under 2º C.

2.3 Obtaining future scenarios for Jamaica

2.3.1 GCMs, RCMs, and Statistical Models

As has been clearly illustrated in the previous section, information on future climates commonly comes from General Circulation Models (GCMs). GCMs are mathematical representations of the physical and dynamical processes in the atmosphere, ocean, cryosphere and land surfaces. Their physical consistency and skill at representing current and past climates make them useful for simulating future climates due to differing scenarios of increasing greenhouse gas concentrations.

Due to the large resource requirements, GCMs are normally run by large research centres worldwide and the data made freely available. Table 2-2 lists the properties of three GCMs for which data have been extracted for the Caribbean region and for Jamaica in particular (Watson et al., 2008). These GCMs are used because of their ability to somewhat capture the climatology of the Caribbean. The table also suggests a limitation of GCMs, particularly for a study of this nature. Their coarse resolution relative to the scale of required information (country or station level) suggests the need for *downscaling* techniques in order to yield more detailed information at a finer scale.

Table 2-2: Characteristics of Climate models from which Caribbean climate information has been extracted

	ECHAM5-OM	**HADCM3**	**CGCM2.3.2**	**PRECIS**
Acronym	ECH	HAD	MRI	PRECIS
Model	GCM	GCM	GCM	RCM
Data Type	gridded monthly	gridded monthly	gridded monthly	gridded monthly
Resolution	1.875˚×1.875˚	2.5˚×3.75˚	2.8˚×2.8˚	50km×50km
Scenarios	Baseline, A2 A1B, B1	Baseline, A2 A1B, B1	Baseline, A2 A1B, B1	Baseline, A2 B2
Simulation Period	1860-2100, 2001-2200	1860-1999, 2000-2199	1850-2000, 2001-2300	1961-90, 2001--2099
Organization	Max-Planck Institute for Meteorology, Germany	Hadley Centre, UK	Meteorological Research Institute, Japan	Climate Studies Group Mona, University of the West Indies, Jamaica

[5] The proposed reduction are approximately 50% by 2050 and 80% thereafter.

Typically, two downscaling methods are applied – dynamical downscaling and statistical downscaling. With dynamical downscaling a regional climate model (RCM) uses the outputs of the GCMs as boundary conditions to provide more detailed information over a smaller geographical area. Like GCMs, the RCMs rely on mathematical representations of the physical processes. They are especially useful for spatial representations of future climates.

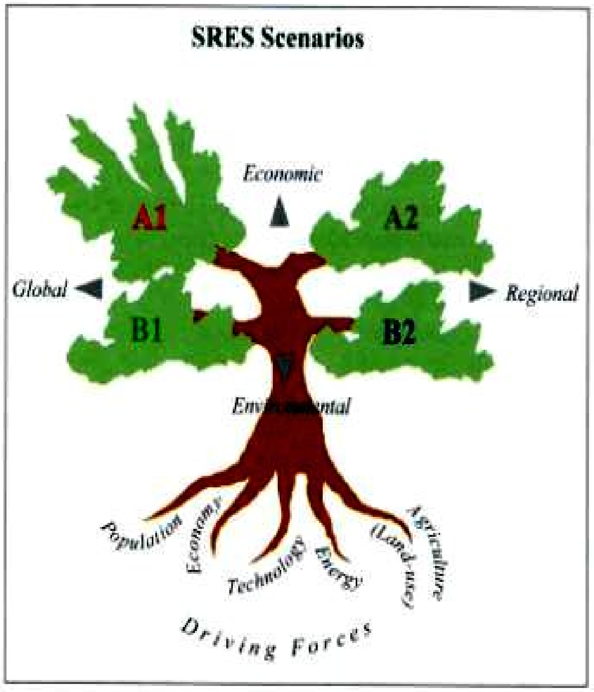
Statistical downscaling enables the projection into the future of a local variable by first developing statistical relationships between the local variable and large scale climate variables for current or *baseline* periods. The relationships are assumed to hold true for the future and so the local variable can be predicted utilising GCM simulated future large scale conditions as predictors. Statistical downscaling is especially useful for generating projections at a particular location.

Data from all three methods (GCMs, RCMs, and statistical downscaling) are employed to assess both changes in precipitation and streamflow for Jamaica under future global warming scenarios. The methodology is detailed below.

2.3.2 Methodology

2.3.2.1 GCMs

Data for Jamaica are extracted from simulations carried out using the three GCMs detailed in Table 2-2. Time series of current and future monthly precipitation are extracted for each model's grid box over Jamaica for the *baseline* climate (1960-1990) and for decadal periods centered on the 2015s, 2030s, 2050s and 2080s. The models are run under the A2, B2 and A1B Special Report Emission Scenarios (SRES). The SRES scenarios represent plausible alternative futures and are summarized in Figure 2-8. The future change in Jamaica's precipitation regime under each scenario and for each model is determined by subtracting the baseline climatology (as simulated by the models) from the simulated future climate.



- **A1** storyline and scenario family: a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and rapid introduction of new and more efficient technologies.
- **A2** storyline and scenario family: a very heterogeneous world with continuously increasing global population and regionally oriented economic growth that is more fragmented and slower than in other storylines.
- **B1** storyline and scenario family: a convergent world with the same global population as in the A1 storyline but with rapid changes in economic structures toward a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies.
- **B2** storyline and scenario family: a world in which the emphasis is on local solutions to economic, social, and environmental sustainability, with continuously increasing population (lower than A2) and intermediate economic development.

Figure 2-8: Special Report on Emission Scenarios (SRES) schematic and storyline summary (Nakicenovic et al., 2000).

2.3.2.2 PRECIS

The methodology for generating future *Jamaican* climate using an RCM is identical to that already described for the GCM. Available RCM data come from the PRECIS (Providing Regional Climates for Impact Studies) model which was run within the region at the University of the West Indies (Taylor et al., 2007). Details of the PRECIS model are also provided in Table 2-2. Noteworthy is its 50 km resolution and its restriction to a Caribbean domain. Because of its finer resolution, data are extracted for seven grid boxes (as opposed to the one GCM gird box) which cover Jamaica (see Figure 2-9 and Appendix 2). Data for three grid boxes (boxes 3, 4 and 5) covering the three watershed regions to be analyzed (see section 2.3.3) are analyzed in conjunction with statistical downscaling. Data are extracted for the baseline and future time periods noted above and for the A2 and B2 scenarios.

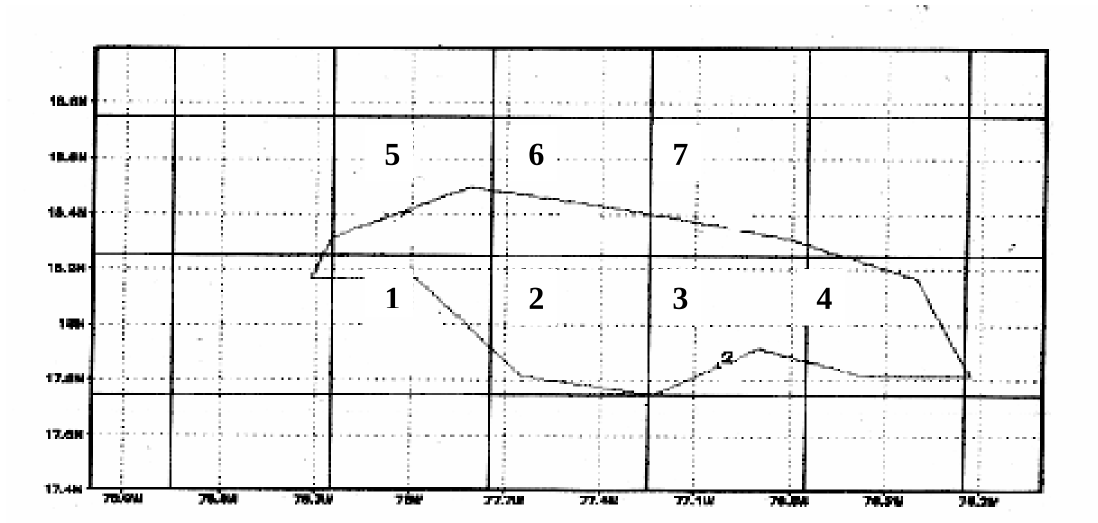


Figure 2-9: PRECIS grid boxes surrounding Jamaica. Grid boxes are labelled between 1 and 7 for ease of reference in the text.

2.3.2.3 SDSM

Statistical downscaling is facilitated by the use of the Statistical Downscaling Model (SDSM). The model allows for the development of statistical relationships between local variables (in this case precipitation and streamflow) and large scale weather indices from GCMs. Details about the precipitation and streamflow data used in this study are given in the following section. In the development of the relationships, reanalysis data from the National Centres for Environmental Prediction (NCEP) are used to provide the large scale current climate information. Future data for the same large scale predictors are then extracted from the HADCM3 GCM run under the A2 and B2 scenarios and used to generate the future values of the local variables. The climate change data (future minus baseline) are generated for the same future time periods noted above.

2.3.3 Data - Precipitation and Streamflow

Streamflow data for three rivers in Jamaica are utilised in this study. The rivers are the Great River (St. James) at Lethe, the Rio Grande (Portland) at Fellowship and the Hope River (St. Andrew) at Gordon Town, all of which are primarily fed by precipitation runoff (Basil Fernandez, personal communication). Details of the streamflow data are provided in Table 2-3. The approach taken is to directly downscale the streamflow data using SDSM, and to compare the results to downscaled precipitation results for three nearby precipitation stations.

The requirement of SDSM for at least 20 years of *daily* data proved a constraint, and as a result the precipitation stations used in the study were from both airports Manley (Kingston) and Sangster (St. James) and an Upper Rio Cobre Precipitation (URCR) index which combines precipitation data from four stations in the Rio Cobre watershed region: Swansea, Enfield, New Hall and Worthy Park (Brown, 2008). Characteristics of the precipitation data are given in Table 2-3. The stations were the nearest to the watershed regions which had data of sufficient length and quality to inspire confidence when using the SDSM technique.

Table 2-3 : Precipitation and Streamflow Data Characteristics. Data provided by Water Resources Authority and the National Meteorological Service of Jamaica. *In the final column URCR is a combined precipitation index from four stations in the Upper Rio Cobre Region.*

	STREAMFLOW			**PRECIPITATION**		
STATION	**Great River**	**Rio Grande**	**Hope River**	**Manley**	**Sangster**	**URCR**
DATA LENGTH	1960-2000	1960-2000	1960-2000	1961-1990	1961-1990	1960-1990
%MISSING DATA	0%	0%	0%	40%	39%	0%

2.3.4 General Approach and Study Limitations

Generally, the approach taken was a comparative one. That is:

- The output from the three GCMs is compared to provide a range of possible future precipitation and temperature regimes for Jamaica. Though each model run under each scenario is a plausible future, the results are analysed for general consensus. This is done for setting context.
- The output from the RCM is compared to that from the GCMs for consistency of the projected climate trends. Additionally, the output over the RCM grid boxes covering the three watershed regions is extracted and region specific scenarios of future climate generated.
- The SDSM generated future precipitation scenarios for the three precipitation stations are compared with the RCM generated future climates for the grid box in which the station resides.
- The SDSM generated future streamflows are compared with the future precipitation scenarios (i) for the nearby station as generated by SDSM and (ii) for the RCM grid box in which the watershed region resides. This is done to determine consistency (if any) between the trend in future precipitation in the watershed regions and the future streamflows.

It is based on the above comparisons that the severity of the impact of global warming on Jamaica's climate and streamflows are deduced and conclusions drawn.

Each methodology employed possesses its inherent limitations. For example, the GCM information is coarse and may not in fact account for land interactions, since the country is smaller than the grid box. The GCMs also do not all possess the same capabilities at simulating all variables across all seasons for the region of interest. The RCM, on the other hand, may be biased by the forcing GCM, while the SDSM technique assumes stationarity i.e. a constancy into the future of the developed empirical relationships on which the predictions are based. Similarly, the data used in the SDSM methodology also has its limitations which include missing data stretches, and the inability to access data of suitable quality nearer the watershed sites of study.

The limitations of the methodologies and the data do not however preclude their use. Instead, the full range of future climates derived from each method is reported as a means of expressing the uncertainty in the results. It is then based on the degree of consensus between all or most of the methods that expressions of confidence are attached to the conclusions drawn. The results and conclusions drawn are presented in the following sections.

2.4 Downscaled Results Relevant to the Water Sector

The results given in Sections 2.4.1 offer a look at future precipitation and streamflow for Jamaica downscaled using PRECIS and SDSM (as explained in Section 2.3). To provide context, the values for precipitation and temperature for Jamaica from the three GCMs (Table 2-3) are first analyzed to produce scatter plots of projected change relative to the 1961-90 baseline. The results are shown for the annual change and the change during June July August (JJA) for the 2015s, 2030s and 2050s using the A2, A1B, B1 scenarios (Figure 2-10).

All models show increases in annual temperature between 0.4ºC to 0.7ºC for the 2015s, 0.6ºC and 1.0ºC for the 2030s' and 1.0ºC and 1.5ºC for the 2050s. Changes in JJA are not much different from the annual changes. Most models show a decrease in precipitation, which is more pronounced in JJA and become greater with time.

2.4.1 Jamaican Precipitation in the future

2.4.1.1 From PRECIS

Precipitation change in the 7 PRECIS grid boxes described in Section 2.3.2.2 were extracted for the future time slices previously noted under the A2 and B2 scenarios. The A2 and B2 results from PRECIS were then averaged to give an intermediary value between low and high emission scenarios, similar to the A1B scenario used in IPCC 4th Assessment. The results of the averaging for the 2050s and 2080s are shown in Figure 2-10. Precipitation begins to decrease in most regions by the 2050s, and by the 2080s the decrease in precipitation becomes significant in all regions, ranging from 25 to 40%. Detailed results for all time slices are given in Appendix 1.

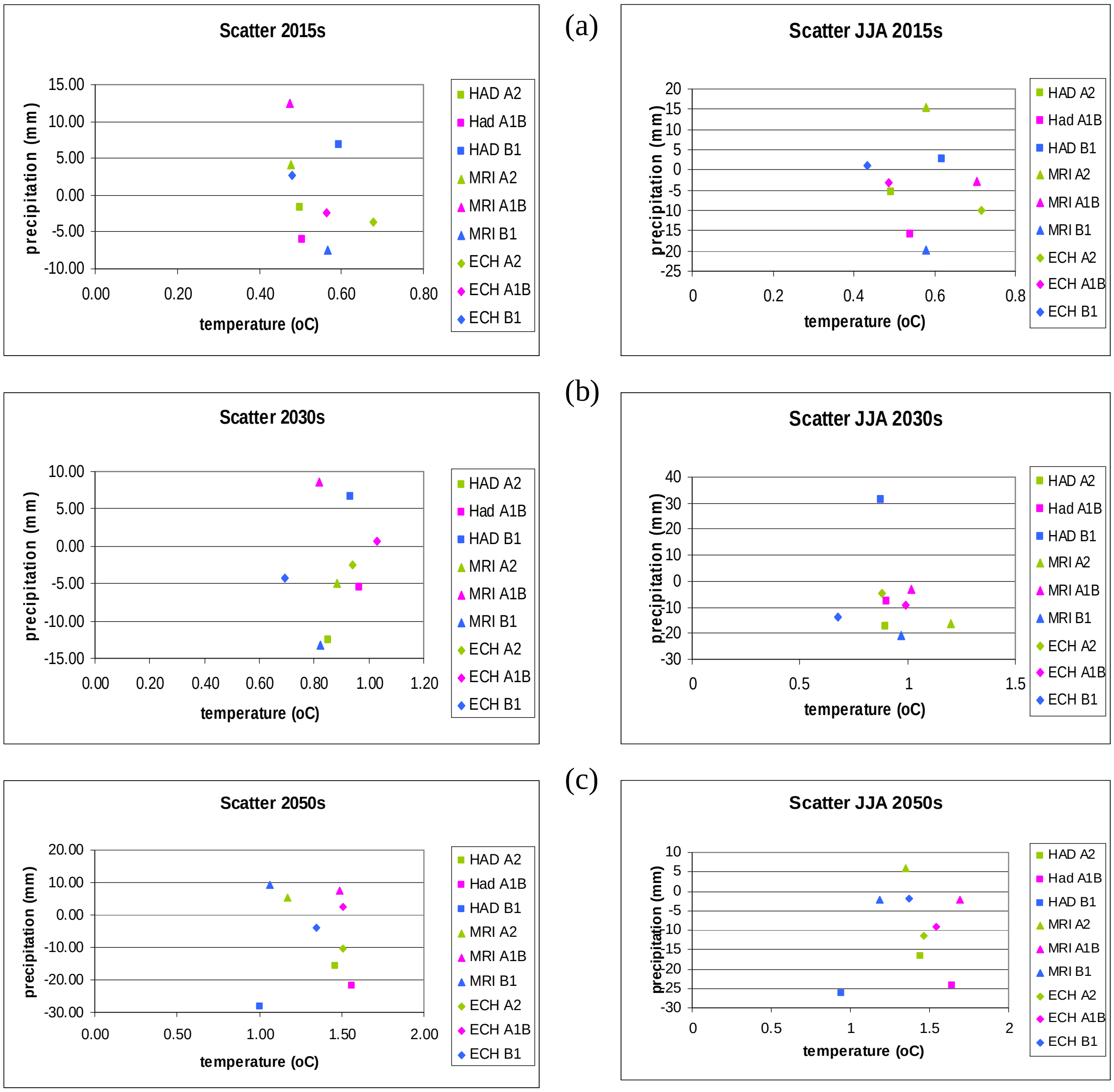


Figure 2-10: Left panels: Scatter graphs of scenarios of annual precipitation changes vs temperature changes relative to a 1961-90 baseline, simulated by Hadley (HAD, United Kingdom), Meteorological Research Institute (MRI, Japan) and European Centre for Medium-range Weather Forecasts High resolution (ECH) General Circulation Models for (a) 2015s, (b) 2030s and (c) 2050s using A2, A1B, B1 Special Emission Report Scenarios. Right panels: Same as for left panels but for June July August (JJA) changes. Note that the scales are not the same and the position of the 0% change on the precipitation axis varies.

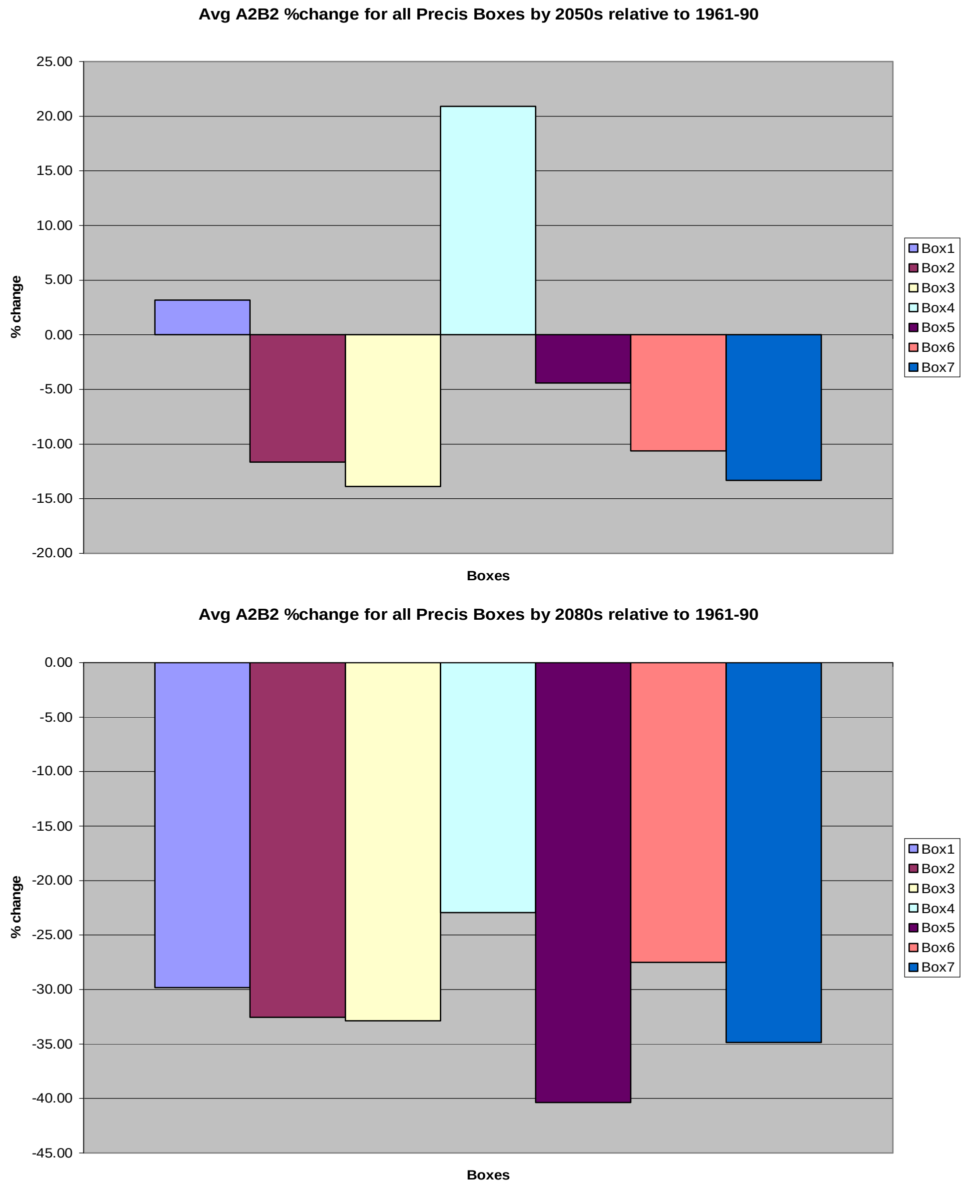


Figure 2-11: Average of percentage changes for A2 and B2 2050s and 2080s scenarios downscaled for the 7 regions defined in Section 2.3.1.2.1 using PRECIS.

2.4.1.2 From SDSM

An attempt is made to similarly quantify future changes in precipitation, but at the three precipitation stations previously identified, using SDSM (see again Section 2.3.2.3). Detailed results for the A2 and B2 scenarios are given in Appendix 3. Some graphical representations for the annual and seasonal (DJF, MAM, JJA, SON) precipitation and precipitation change under the A2 scenario at Manley, Sangster and URCR and for baseline, 1915s, 1930s, 1950s and 1980s are also given in Figures 2-11 to Figure 2-13.

A general pattern of decreased precipitation is again seen. The decrease in annual precipitation is almost linear, except for the 2015s and 2050s at Manley and the 2050s at URCR. Decreases occur in all time slices except for the 2015s at Manley, where a slight increase is seen. The decrease is also only 2% at Manley in 2050s. By the 2080's decreases are close to 20% at Manley, 60% at Sangster and 14% at URCR. By the 2050s the seasonal decrease in more pronounced in JJA and SON. Similar trends are noted under the B2 scenario.

2.4.1.3 Wet and Dry Spells

The percentage of days (wet day %) that exceed a wet-day threshold limit of 0.3 mm, the average length of continuous wet-days with amounts greater than or equal to the wet-day threshold (mean wet spell length), and the average length of continuous dry days with amounts less than the wet-day threshold for Manley are given in Figure 2-14. The corresponding graphs for Sangster and the Upper Rio Cobre River are given in Figures 2-15 and Figure 2-16. The values used in the graphs are given in Appendix 3.

The percentage wet days all decrease below the 1961-90 baseline in JJA except for Manley in the 2050s. The decrease is also noted in SON, except for the 2015s and 2030s at Manley and the 2015s at URCR. The concomitant decrease in wet spell length and increases in dry spell length are also noted in JJA and SON.

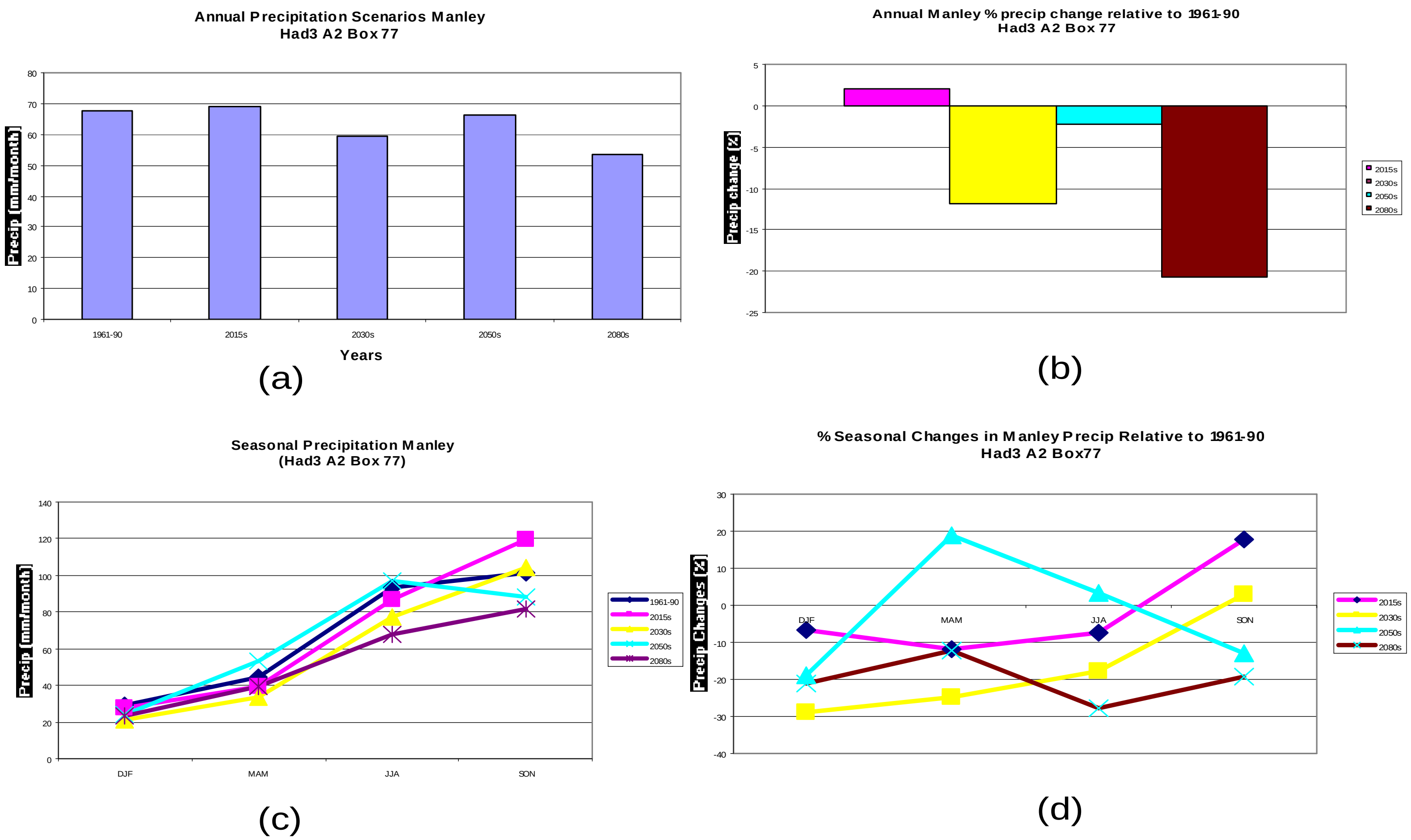


Figure 2-12: Absolute values of SDSM results using HAD3 A2 scenarios for (a) annual and (c) seasonal (DJF, MAM, JJA, SON) precipitation for 1960-90, 1915s, 1930s, 1950s and 1980s; percentages changes in (b) annual and (d) seasonal precipitation in 1915s, 1930s, 1950s and 1980s compared to 1961-90.

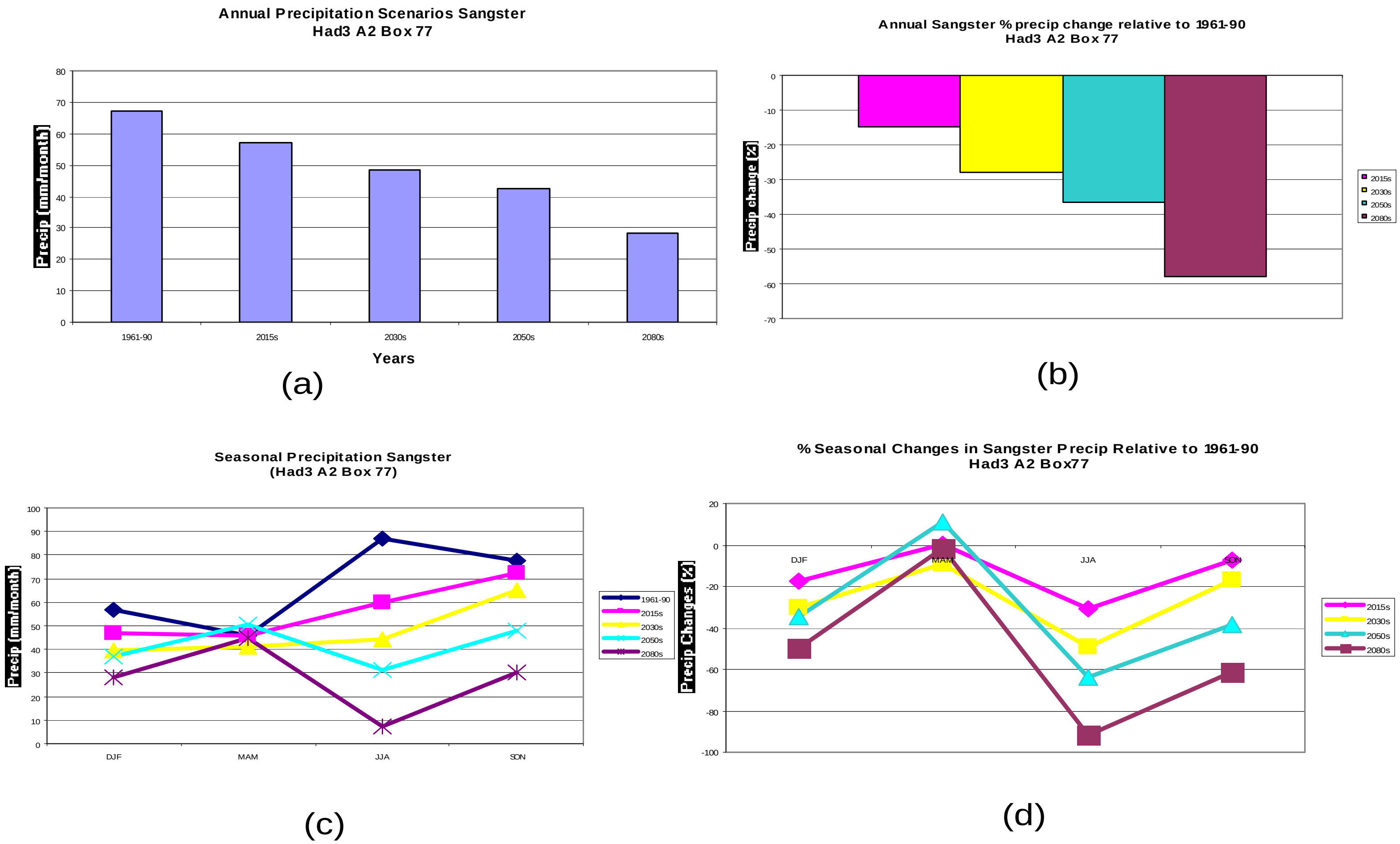


Figure 2-13: ***Same as for Fig. 2-12 but for Sangster*.**

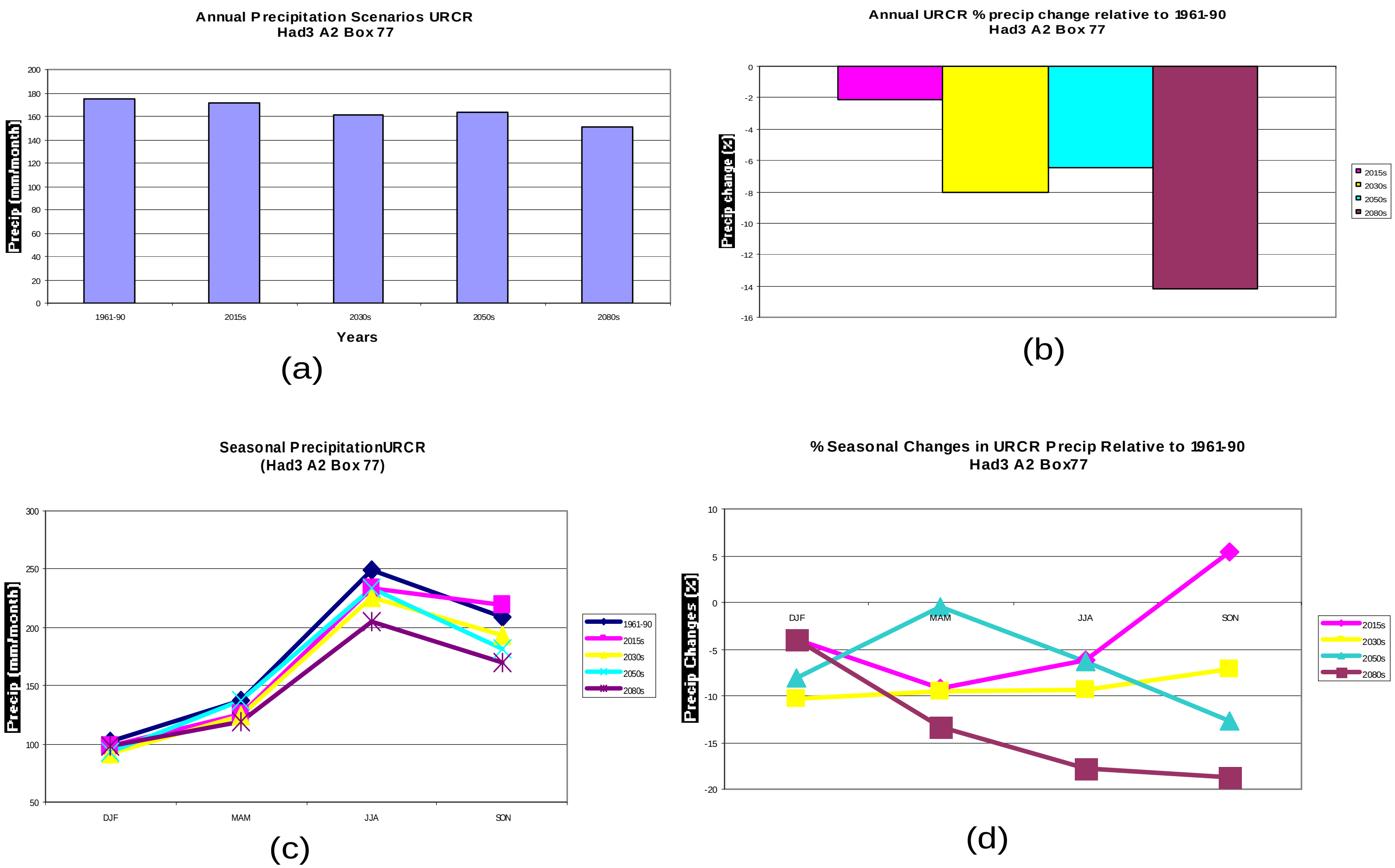


Figure 2-14: *Same as for Fig. 2-12 but for URCR.*

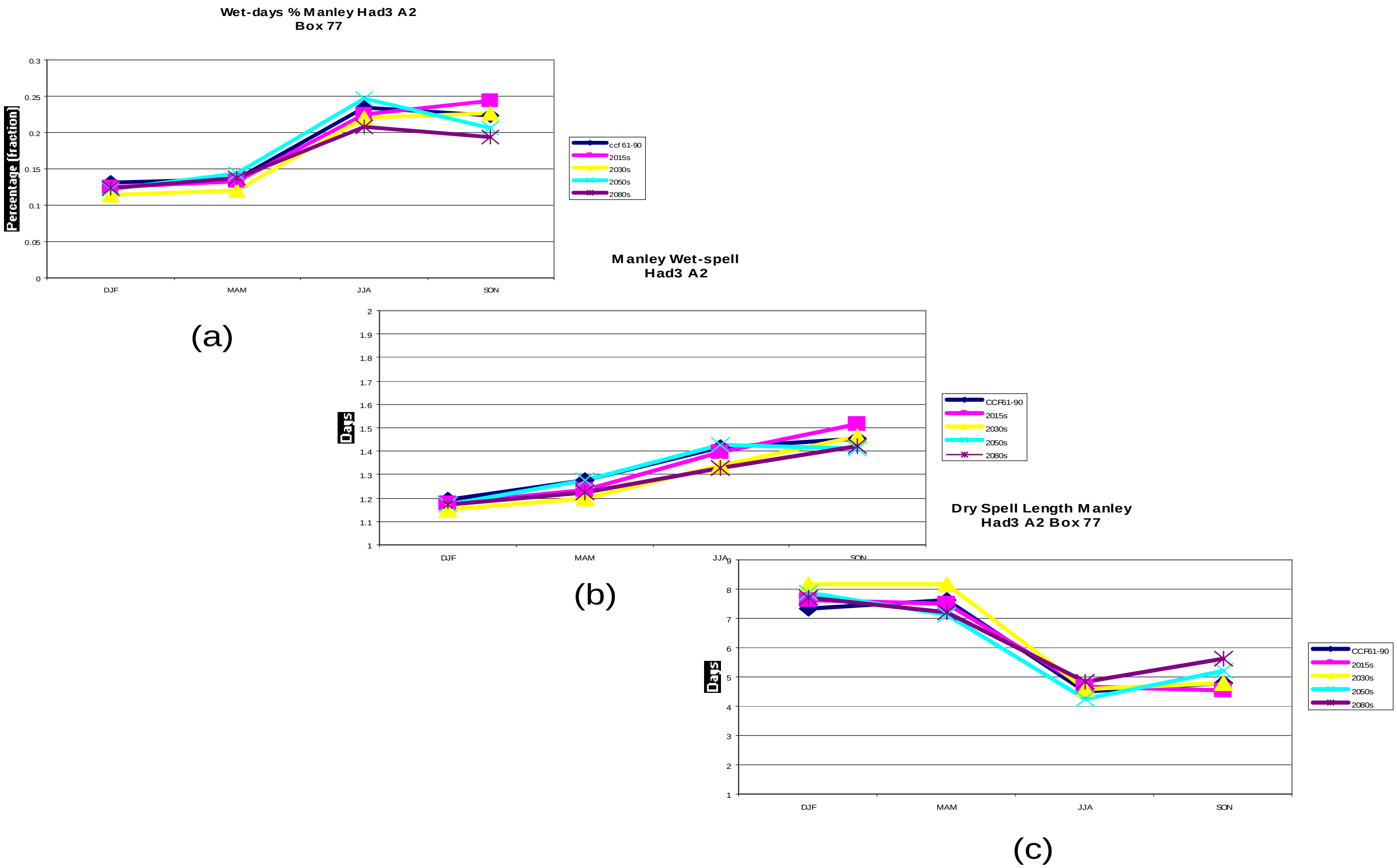


Figure 2-15: ***SDSM results (a) % wet days, (b) wet spell length and (c) dry spell length at Manley for 1961-90, 2015s, 2030s, 2050s and 2080s using HAD3 A2 scenarios.***

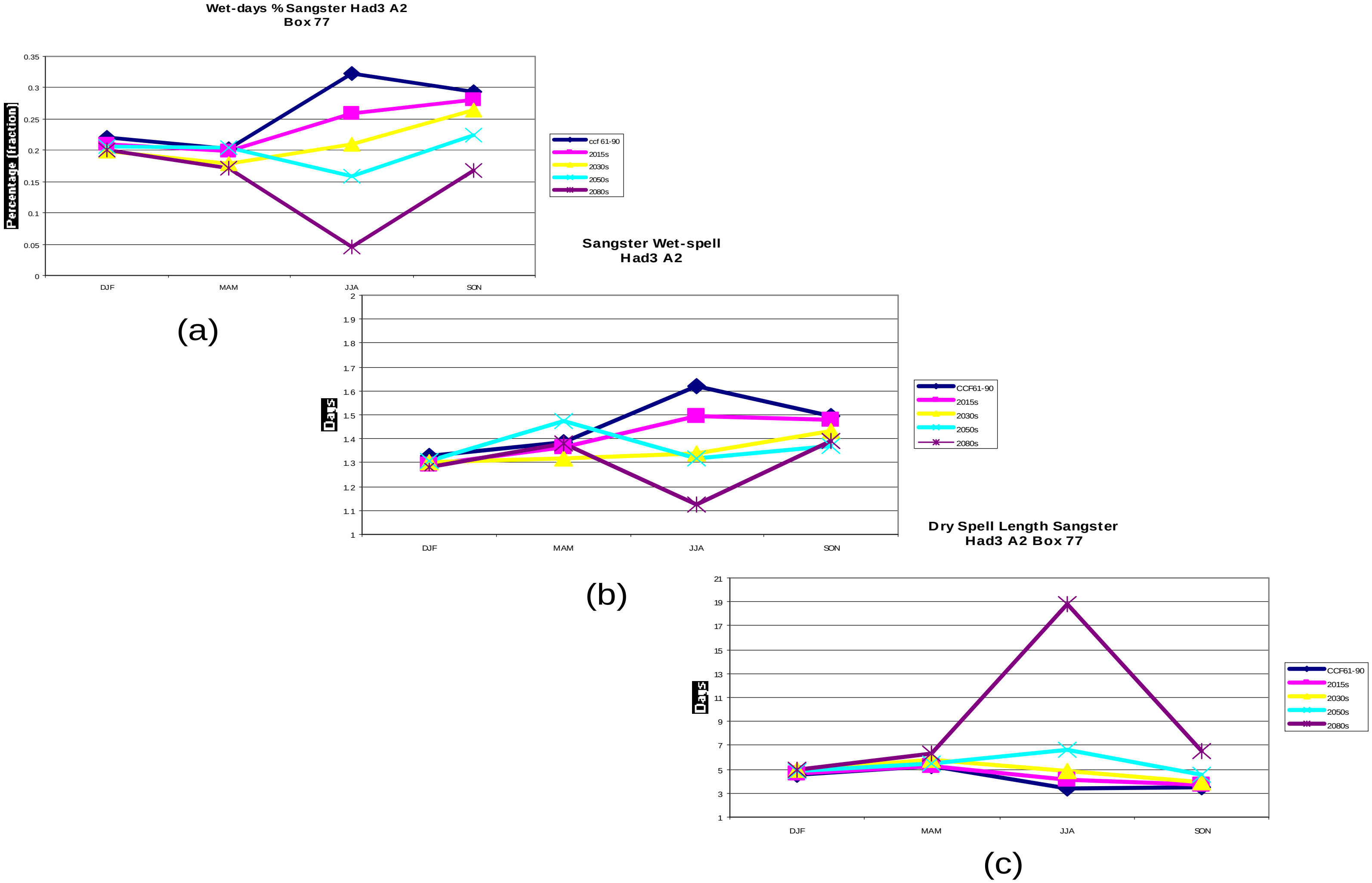


Figure 2-16: ***Same as for Fig. 2-12, but for Sangster.***

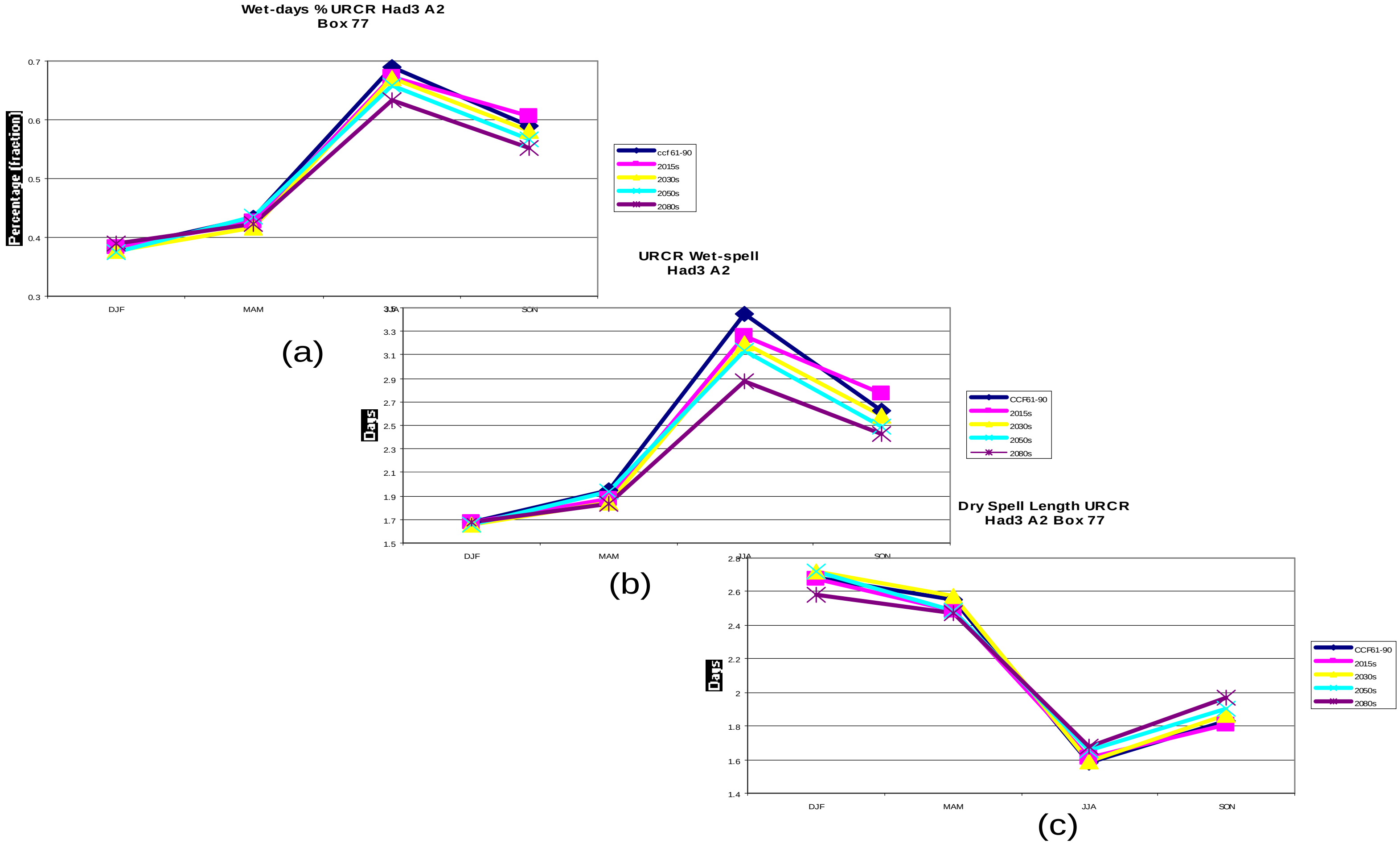


Figure 2-17: Same as for Fig2-16, but for URCR

2.4.2 Future Streamflow

To supplement the precipitation results, streamflow rates for the three river basins (See again section 2.3.3) were downscaled by SDSM. The results for Great River, Hope River and Rio Grande are shown in Figures 2-18 to Figure 2-20 respectively and are compared with the precipitation results.

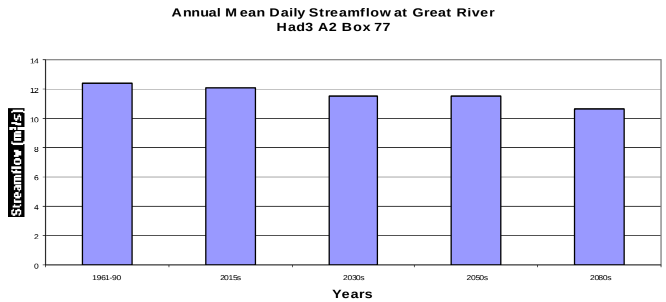
Streamflow changes at Great River and Hope River compare favourably with precipitation at Sangster. Annual values decrease progressively for 1960-90 to 2080s, except that the decrease at Great River in the 2030s and 2050s is practically the same. Seasonal decreases are greatest in JJA, followed by decreases in SON. While annual values of streamflow at Rio Grande also decrease progressively from 1960-90 to the 2080s, the seasonal pattern is different, showing marked decreases in all seasons, but least decrease in JJA. In addition the decreases are so marked that the streamflow is reduced to nil by 2080s. There is a greater uncertainty in the projections for Rio Grande and this will be discussed in Sections 2.4.3 and 2.5.

2.4.3 Physical Basis for Results (Predictors)

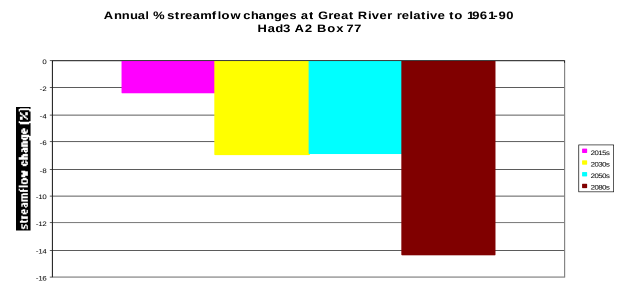
The predictors which correlated significantly with precipitation and streamflows are shown in Table 2-4. Since precipitation and streamflows decrease by 2080s, these predictors should be able to explain the decrease. Increasing geopotential heights (p500na and p850na) are associated with increasing atmospheric high pressure systems and therefore with less precipitation. Decreasing meridional velocity (8_vna) and vorticity (8_zna and zna) are linked with less atmospheric convergence and therefore less precipitation. Decreasing relative humidity (r500na and r850na) means that less moisture is in the atmosphere and therefore the chances of precipitation are less likely. Note that near surface relative humidity (rhumna) is increasing but the atmosphere dries out by the time it reaches 850 and 500 hPa. Surface air flow strength (fna) is a predictor only for Rio Grande. The Rio Grande is in a valley surrounded by high mountains. Orographic precipitation occurs when winds drive moisture up the mountains. Therefore decreasing air flow strengths would be associated with decreased precipitation.

Table 2-4: List of predictors used in SDSM and their tendency in 2080s. x's under a station indicate that the predictor was used.

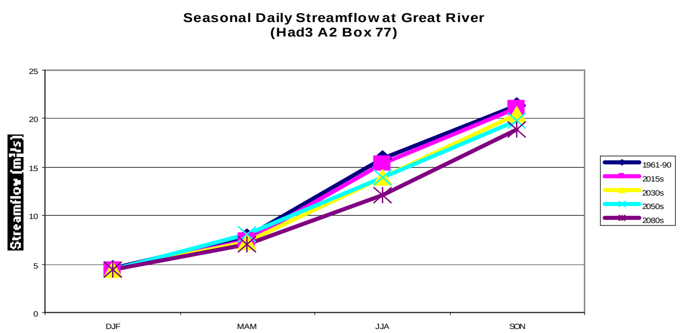
Predictors	Tendency in 2080s	Manley	Sangster	URCR	Great River	Hope River	Rio Grande
500 hPa Geopotential Height (p500na)	Increasing		x				x
850 hPa Geopotential Height (p850na)	Increasing			x	x		
850 hPa Meridional Velocity (8_vna)	Decreasing					x	
850 hPa Vorticity (8-zna)	Decreasing			x			
Near Surface Relative Humidity (rhumna)	Increasing						x
Relative Humidity at 500 hPa (r500na)	Decreasing	X	x	x	x	x	x
Relative Humidity at 850 hPa (r850na)	Decreasing	X	x	x			
Surface Air Flow Strength (fna)	Decreasing						x
Surface Vorticity (zna)	Decreasing					x	x



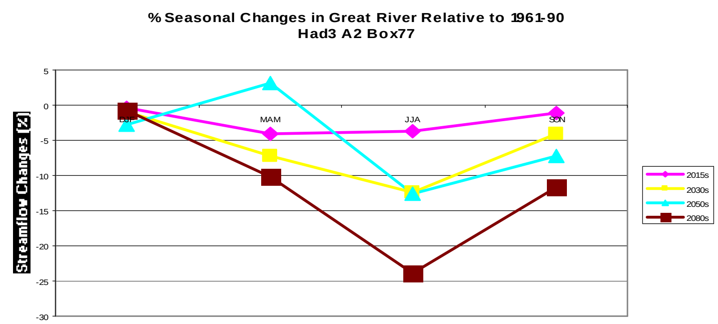
(a)



(b)



(c)



(d)

Figure 2-18: Absolute values of SDSM results using HAD3 A2 scenarios for (a) annual and (c) seasonal (DJF, MAM, JJA, SON) streamflow at Great River for 1960-90, 1915s, 1930s, 1950s and 1980s; percentages changes in (b) annual and (d) seasonal precipitation in 1915s, 1930s, 1950s and 1980s compared to 1961-90.

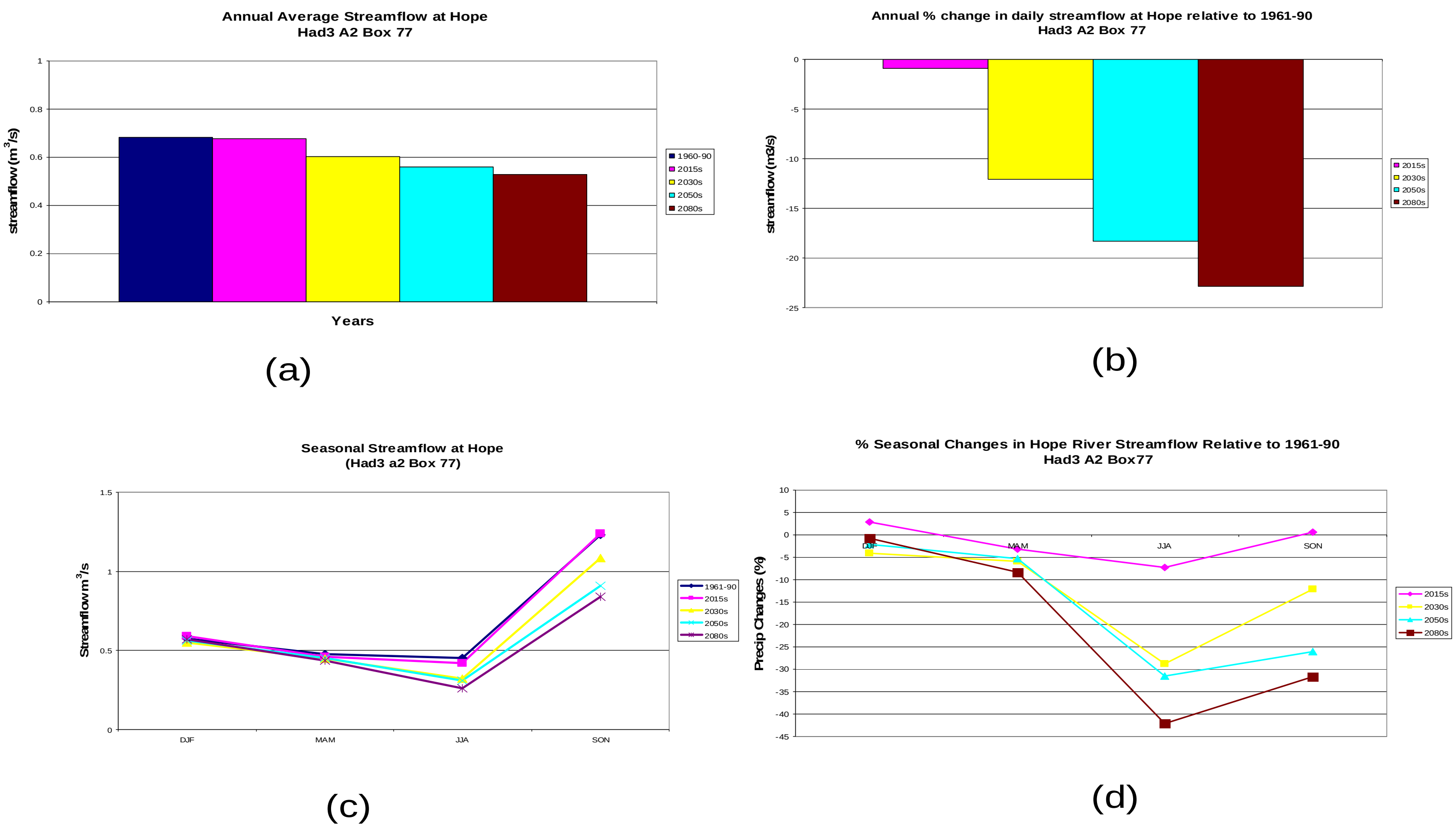


Figure 2-19: As in Figure 2-18 but for Hope River.

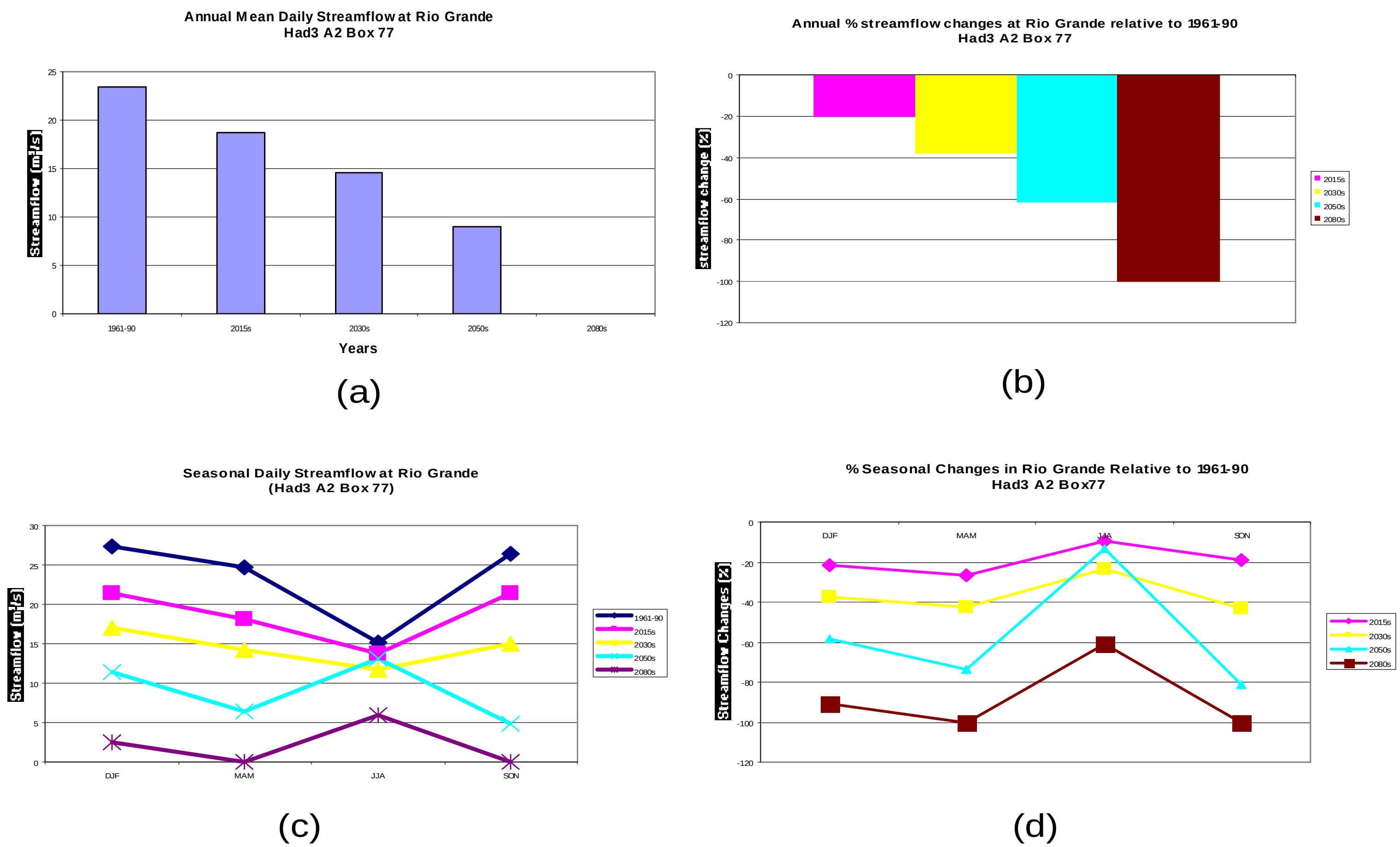


Figure 2-20: ***As in Figure 2-18 but for Hope River.***

2.5 Discussion and Conclusion

2.5.1 Temperatures

As previously suggested, the comparison of results from the GCMs, PRECIS and SDSM provides a means of assessing the confidence in results. The general agreement among GCMs that temperatures will increase gives a high probability that increases will occur in the Caribbean, especially since the temperature signal to noise ratio is high (Section 2.2.1.2) for the GCMs. The probability is increased because of agreement with other regional and statistical downscaling research not mentioned so far in this report (Taylor et al., 2007 and Chen et al., 2006), and because the science of global warming is well understood and almost universally accepted. The temperature increase will depend on the future emissions. Under the A1B scenario temperatures in the Caribbean are expected to rise by about 1.5ºC by 2050s and be just under the global average of 2.8ºC by the end of the 21st century.

2.5.2 Precipitation

Most GCM simulations of future Caribbean precipitation show a decrease in annual values, especially in JJA, by the end of the century under the A1B scenario. However, the signal to noise ratio is low and the precipitation signal does not become significant until the latter half of the century. The PRECIS and SDSM results for A2 and B2 scenarios given in Section 2.4 support the general trend and the probability is therefore high that decreases in precipitation will occur, especially by the 2080s. The magnitude of the decrease however is uncertain.

To help to reduce the uncertainty, we compare the PRECIS and SDSM results, i.e. we compare the station projections from SDSM with the projections for the grid box in which it falls from PRECIS. In doing so, it is noted that the uncertainty in precipitation decreases in the 2050s based on projections by PRECIS will also be compounded by the fact that the precipitation signal to noise ratio for GCMs do not become significant until late in the century and the same may be true for PRECIS.

Figure 2-21 shows the average annual precipitation percentage change for Great River streamflow, Sangster precipitation and PRECIS box 5 precipitation. There is good agreement between PRECIS and SDSM with respect to precipitation, with projected decreases being 40% and 55% respectively by the 2080s. The corresponding decrease in streamflow is over 10%. The streamflow here is not used as an estimate of precipitation, but merely to support the projection of a decrease. A conservative estimate of 40% decrease i.e., the decrease projected by PRECIS in box 5 is therefore recommended for use in estimating water resources in 2080s. For the 2050s the decreases given by PRECIS and SDSM are 4% and 36%. Since the change at Sangster is much greater, a conservative recommendation for decrease in precipitation in region 5 by 2050s is 10%.

Figure 2-22 gives the average of A2 and B2 projections of change in streamflow at Hope River, precipitation at Manley, precipitation in the Upper Rio Cobre Region, and PRECIS box 3 precipitation for the 2015s, 2030s, 2050s and 2080s. The results from Manley are questionable because of the large fraction of missing daily station data that were used in the SDSM analysis, and because the simulated baseline did not fit as well with the observed data, compared to the Sangster results. Decreases have set in from 2030s. By the 2080s PRECIS shows a precipitation decline of over 30%. Taking into consideration the smaller deficit projected for the Upper Rio Cobre River basin, a conservative estimate of reduction in precipitation by

2080s is 20%. The decline in streamflow at Hope River and precipitation at Manley support this estimate of reduction. Again based on the precipitation declines in Region 3 and in the Upper Rio Cobre River region, the estimate of reduction in precipitation in the 2050s is 10%.

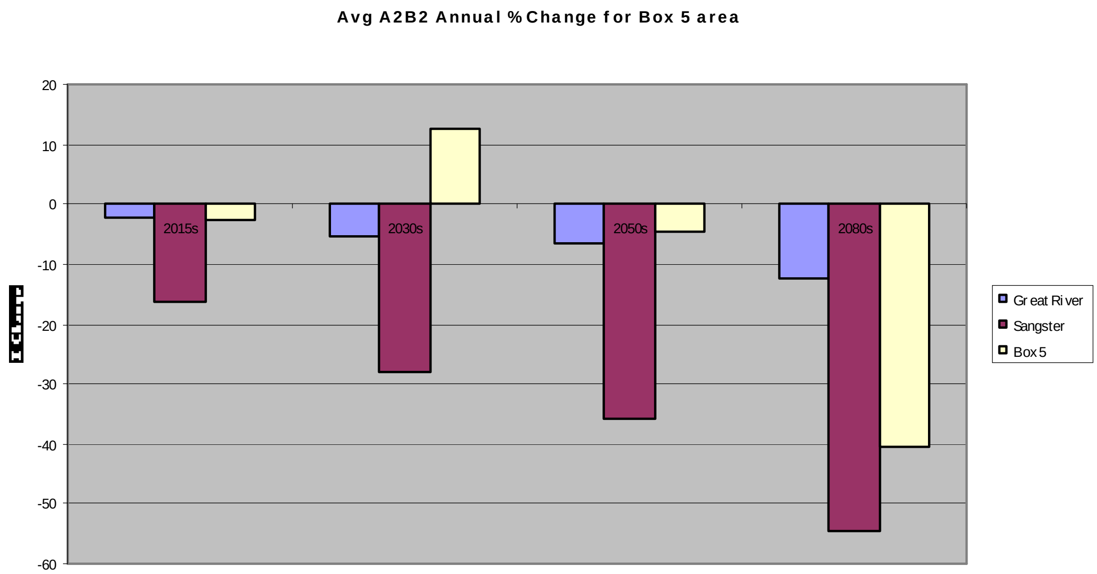


Figure 2-21: Average of A2 and B2 projected changes in streamflow at Great River and precipitation at Sangster and in region 5 for 2015s, 2030s, 2050s and 2080s.

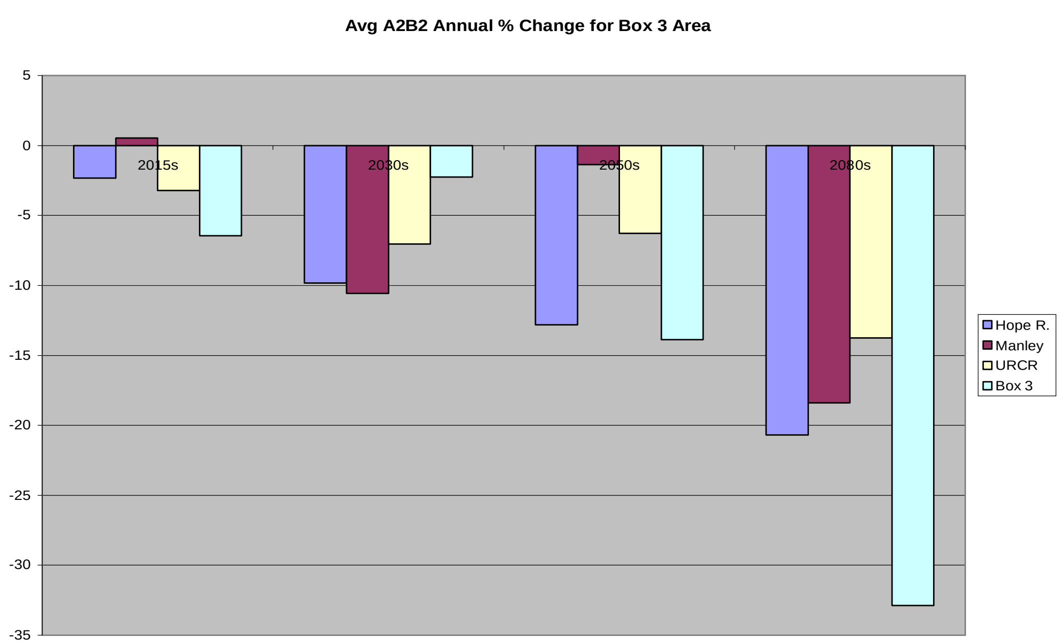


Figure 2-22: Average of A2 and B2 projected changes in streamflow at Hope River and precipitation at Manley, URCR and in region 5 for 2015s, 2030s, 2050s and 2080s

Figure 2-23 gives the changes downscaled for all PRECIS boxes by the 2080s. There are no SDSM results for comparison in Regions 1, 2, 6 and 7. For these regions an estimate of reduction in precipitation by the 2080s is 30%, which is close to the PRECIS results. The corresponding changes for 2050s are given in Figure 2-24. The estimate of changes in regions 2, 6 and 7 for this time slice is 10%, while for box 1 there is a small increase in precipitation. Owing to the uncertainty about the precipitation signal for the 2050s, it is best to assume that there is no change in precipitation in box 1 at this time.

Figure 2-233: The average of PRECIS A2 and B2 % changes in all regions by 2080s

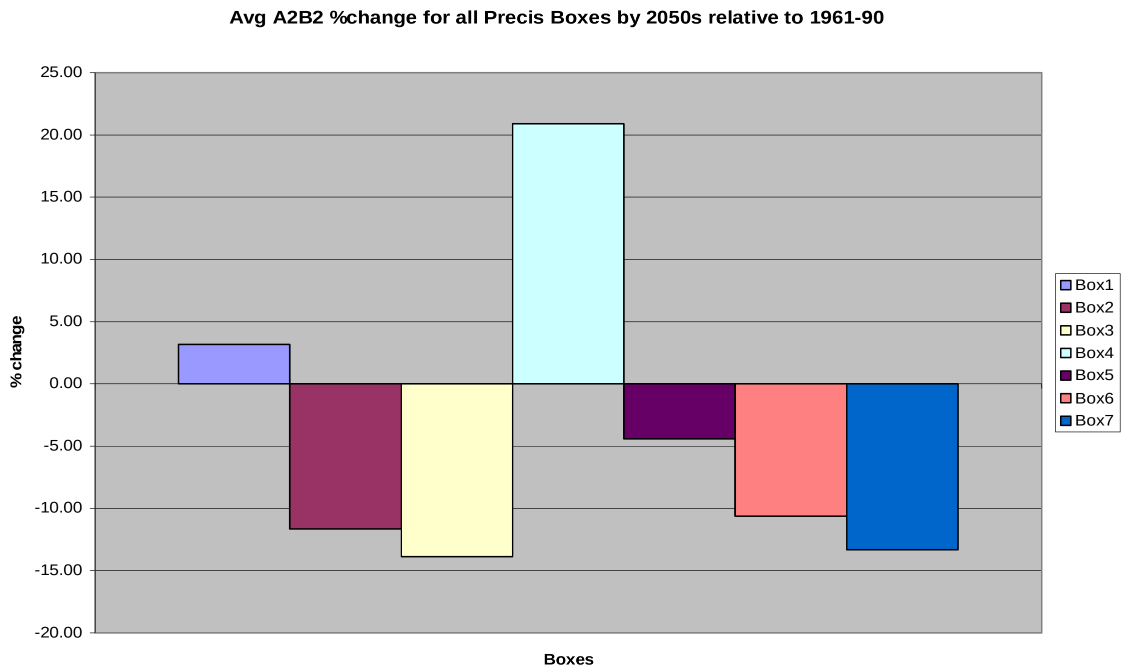


Figure 2-244: Same as for Fig 2-23, but for the 2050s.

The region covered by box 4 clearly poses a problem. Whereas PRECIS simulated an increase in precipitation in the 2050s, the downscaling of streamflow in the Rio Grande (which lies in box 4) projected decreases in streamflow of 60% i.e. a severe reduction of precipitation. By the 2080s streamflow is reduced to nil using SDSM downscaling, yet reduction in precipitation in box 4 was only simulated to decrease by about 25% by PRECIS.

To make some sense of this, the precipitation process in the region should be considered. The highest peaks in Jamaica, some over 2000 m, are situated in the parishes of Portland and St. Thomas, which comprise the region occupied by box 4. The precipitation is orographic[6], driven by winds pushing moisture up the mountains on the windward side in Portland. The windward side is consequently wetter (annual precipitation of 367 cm) and the leeward side in St. Thomas drier (annual precipitation of 229 cm). The major predictor for streamflow in Portland is the surface airflow strength, which forces the wind up the mountains. Future global warming will cause the surface airflow strength to decrease, leading to reduced orographic precipitation, and consequently a decrease of precipitation in Portland, affecting precipitation more in Portland than in St. Thomas. The decrease simulated in region 4 by PRECIS would likely be comprised of a greater decrease in Portland and a lesser decrease in St. Thomas.

The decrease in streamflow in the Rio Grande valley downscaled by SDSM is too severe to be accepted, since it is produced by only one simulation. Another SDSM simulation which did not use surface airflow strength gives less reduction in streamflow. As a compromise, then, it is suggested that the precipitation in

[6] No empirical study of orographic clouds has been done for Blue Mountains in the vicinity of Portland and St. Thomas, but the process is well known (See e.g., Wallace and Hobbs, Atmospheric Science, Academic Press, 1997), and the rainfall pattern there conforms to this process.

box 4 be considered in 2 parts - that in Portland and that in St. Thomas - and that the estimate of reduction in Portland be 40% and in St. Thomas be 20% by 2080s. Because of the problem of possible low precipitation signal to noise ratio in the 2050s, no estimate is made for box 4 despite the projected increase in precipitation.

2.5.3 Wet Spells and Dry Spells

Based on SDSM analysis of precipitation, wet-day % and wet spells lengths will decrease while dry spells lengths will increase. For Sangster (located in box 5), the decreases in wet-day% and wet spell are 24% and 7% respectively for the 2050s and 44% and 10% for the 2080s. Dry spells will increase by 32% and 80% by the 2050s and 2080s respectively. For box 3, based on an average of values for Manley and URCR, the decreases in wet-day% and wet spell lengths are 2% and 3% respectively by the 2050s and 7% and 6% respectively by the 2080s. Dry spell lengths will increase by 1% and 4% in the 2050s and 2080s respectively. There are no data with which to make estimates for the other regions. The major difference between Sangster, on the one hand, and Manley and URCR on the other seems to be that Sangster precipitation is controlled by a high pressure system (geopotential height) as well as relative humidity, whereas the others are controlled primarily by relative humidity.

2.5.4 Best Estimates

Based on the results presented, then, the best estimates for temperature and precipitation changes are summarised in the following table (Table 2-5).

	2050s	**2080s**
Temperature	1.5 degree C	2.8 degrees C
	% change	
Precipitation:		
Region 1	0	-30
Region 2	-10	-30
Region 3	-10	-20
Region 4:		
Portland	No estimate	-40
St. Thomas	No estimate	-20
Region 5	-10	-40
Region 6	-10	-30
Region 7	-10	-30
Region 5:		
Wet-day%	-24	-44
Wet spell length	-7	-10
Dry spell length	32	80
Region 3:		
Wet-day%	-2	-7
Wet spell length	-3	-6
Dry spell length	1	4

Table 2-5: Best estimates of (a) absolute change in temperature for Jamaica and (b) percentage change in rainfall for 7 regions. Regions refer to the portion of Jamaica contained in the PRECIS boxes 1 through 7 shown in Figure 2-10.

By the end of the century sea levels are also expected to rise by 0.21 to 0.48 meters under an A1B scenario, but the models exclude future rapid dynamical changes in ice flow. A recent study suggests that the rate of rise may actually double (Science Daily, Feb. 12, 2008). Evaporation is also projected to increase by approximately 0.3 mm/day over the sea. As noted before, the changes over land may be less. One model has projected more hurricanes and more intense hurricanes in the Atlantic.

2.5.5 Mitigation to Reduce Dangerous Climate Change

Many scientists and international organizations are now advocating significant cutbacks in greenhouse gases in order to limit temperature rises to less than 2ºC during this century (UNDP, 2007). Several countries of the European Union have given commitments to these drastic reductions. The Governments of France and the United Kingdom, for example, have stated their intention to cut emissions by approximately 80% by 2050. This does not however mean that we should stop planning adaptation strategies. In the first place, the chances of limiting temperature rise to less than 2ºC is slim because of economic and political hurdles. Energy Information Administration (Washington, DC), in its International Energy Outlook 2008 report released in June, predicts that world energy demand and carbon dioxide emissions will grow by about 50 percent over the next two decades. In the second place, the adaptation measures recommended herein are still applicable, regardless of climate change, and should be considered as 'no regrets' strategies.

2.6 In Summary

The future climate scenarios presented above are to be used as a guide for making recommendations about adaptation options for the water sector in coping with climate change. It started with an outline of the climate of Jamaica and natural variability to be expected. Next the observed trends in, and IPCC projections for, changes in temperature, precipitation, hurricanes, sea level rise and evapotranspiration were examined.

IPCC projects are based on low resolution models which simulate changes applicable to a large region as a whole (approximately 300km x 300km), and does not does not distinguish climate response over smaller regions, e.g., the parishes of Jamaica, therefore it was necessary to downscale the results of these low resolution models to distinguish climate response over smaller regions. This was done by the use of a dynamic model called PRECIS, which uses physical equations to simulate climate processes, and a statistical model called SDSM, which uses statistical relationships to project future processes. Precipitation changes for 2015s, 2030s, 2050s and 2080s were simulated over 7 regions of Jamaica by use of the PRECIS model. For the same periods, precipitation changes for 3 stations (Manley, Sangster and Upper Rio Cobre River) and supporting streamflow changes for 3 stations (Great River at Lethe, Rio Grande River at Fellowship and Hope River at Gordon Town) were downscaled by SDSM. Changes in wet spell and dry spell lengths were also produced by SDSM.

The SDSM results for precipitation were compared with the PRECIS results for consistency and the degree of confidence in the results was increased when all three gave some form of agreement. The streamflow results were used mainly for confirmation, while the PRECIS and SDSM results were used to obtain best estimate of changes in precipitation. These estimates are given in Section 2.5.4 and in Table 2.6. Most stations begin to show decreases in precipitation by 2050s and by 2080s, the drying effect is noted all over Jamaica. The degree of uncertainty is also discussed and the results indicate that the results are all significant by 2080s.

3 WATER SECTOR VULNERABILITY ISSUES & THREATS

This section of the report takes forward the climate change scenario based forecasts for Jamaica and presents the findings of the assessment of the impact of these forecasts on the water sector of Jamaica.

The water sector is taken to include the water supply and wastewater components of the human aspects of the hydrological cycle. However, it is not just limited to these facets of the hydrological cycle. It is wider, in that it also considers the role of land use and watershed management and protection, as these are considered to be important to the security, maintenance and strengthening the resilience of Jamaica's water resources, both in terms of quantity and quality, to the threats posed by climate change.

Jamaica is vulnerable to a range of natural hazards. These can be attributed to a number of factors, which include:

- Location of Jamaica, especially with respect to the paths of tropical storms / hurricanes, and the impacts of related storm surges along the coastline.
- The location of Jamaica is also an influence on its vulnerability to the occurrence of earthquakes and the related events such as tsunami.
- Geology and topography of Jamaica, which has an influence on flooding, landslides and subsidence.
- Hydrostratigraphy of Jamaica, which through the location and extent of aquifers and aquicludes, with the spatial and temporal distribution of precipitation, influences the distribution and availability of water during drought periods.

Prior to the assessment of the water sector vulnerabilities to climate change, some brief descriptions of the main geological, hydrogeological and hydrological features of Jamaica are presented.

3.1 Hydrological and Water Resources Characteristics of Jamaica

3.1.1 Hydrological Basins and Watershed Management Units

The Island is subdivided into ten major hydrological basins. A basin is a geographical area drained by a particular surface water and/or groundwater system. The basin boundaries are defined, as far as possible such that there is no flow from one basin to another, and are bounded by topographical or in some cases groundwater divides, especially in karstic outcrop areas where topographical divides are less meaningful. The basins have been further sub-divided into 26 watershed management units (WMU). A WMU is a single or group of watersheds that have been grouped together for the purposes of management. The basins and WMUs are presented in Figure 3-1 and listed in Table 3-1 Note that the WMU boundaries are subject to change, and the WMUs presented in Figure 3-1 are based on those presented in Brace Centre for Water Resources Management (2005) as part of the Water Resources Development Master Plan Update Second Draft 2005.

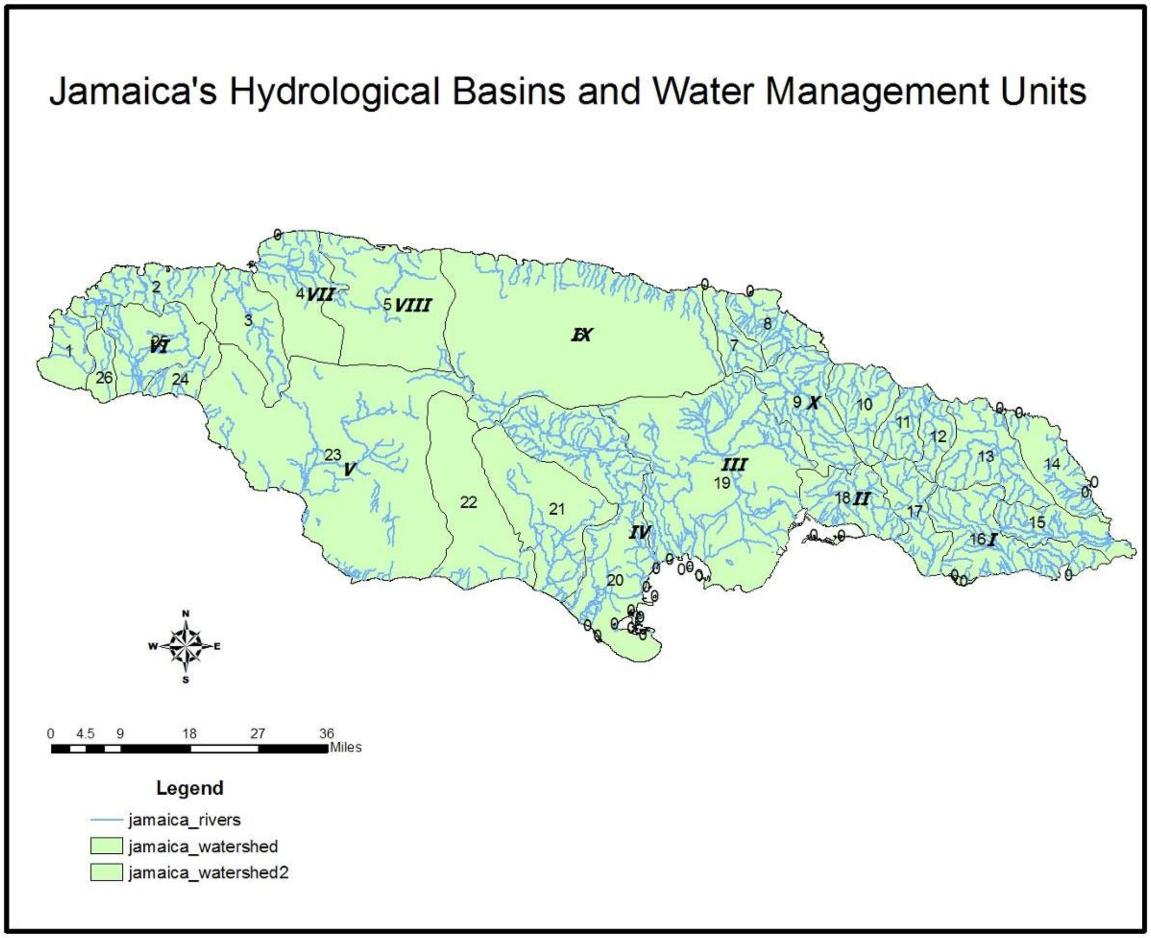


Figure 3-1: Jamaica's Basins & Water Management Units

3.1.2 Geology, Hydrogeology and Hydrology of Jamaica

The physiography of the island is characterised by a series of mountain ranges orientated along the major WNW-ESE axis of the island. The mountain ranges in the east of the island generally have elevations in excess of 1000 m, with the highest peak at 2,257 m. The southern half of the Island contains major alluvial lowlands associated with extensive coastal wetlands in some areas.

This physiography closely reflects the three major rock types of which the island is composed. These three major rock types are, in chronological order (youngest to oldest):

i.	Late Tertiary to Early Quaternary alluviums of generally moderate permeability, which occupy about 15 % of the land area - mainly in the coastal plains and in the floors of interior valleys.
ii.	Tertiary limestones with variably developed karstification and moderate to high permeabilities, which occupy about 60 % of the land area.
iii.	Cretaceous volcaniclastics of low permeability, which occupy about 25 % of the land area - mainly within inliers along the upland axis.

A simplified geology map of Jamaica is presented in Figure 3-2.

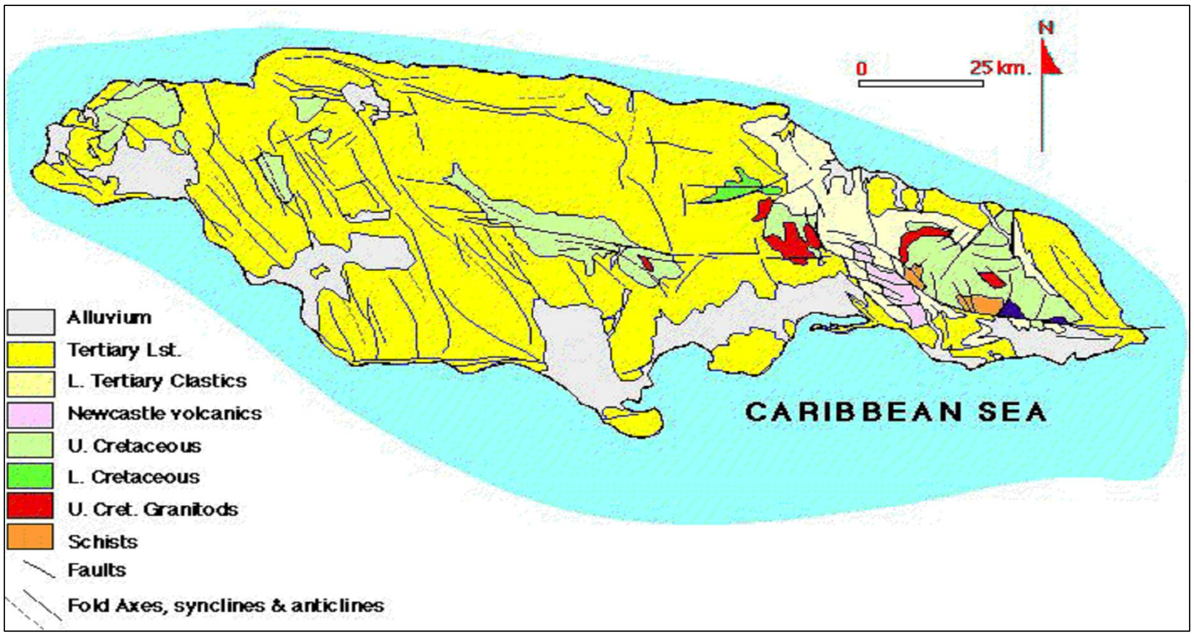


Figure 3-2: Simplified Geological Map of Jamaica (Source: Ahmed, 2005)

Based on their hydraulic properties, the geologic units of Jamaica are divided into either aquifers or aquicludes, depending on their abilities to yield economically significant quantities of water to wells or springs. The following hydrostratigraphic units have been identified and their distribution across Jamaica is presented in Figure 3-3.

- Basal aquiclude –This unit comprises volcaniclastic and limestone rocks on which the other units are deposited. It occupies about 25 % of the Island's surface area outcropping mainly in the Blue Mountains to the east and along the westnorthwest-eastsoutheast central spine of central and western Jamaica. The Basement Aquiclude outcrops are related to dense surface stream networks which have high peak flows in the wet season and low peak flows in the dry season.
- Limestone aquifer – This unit comprises highly karstified limestone. The Limestone aquifer rests unconformably on the Basement aquiclude and thickens towards the coast. It occupies about 50 %

of the Island's surface area. The Limestone aquifer outcrops are related to an absence of surface streams and to well-developed subsurface drainage systems. This is due to the high infiltration capacity of the Limestone Aquifer

- Limestone aquiclude – This unit comprises fine grained chalk and occurs as a coastal band. The Limestone aquiclude functions as a subsurface barrier and creates subsurface groundwater reservoirs within the Limestone Aquifer. This accounts for the high stream flows in the dry season of rivers draining Limestone Aquifer areas.
- Coastal aquiclude - This unit comprises soft marls which are patchily distributed along the coast. The Coastal aquiclude functions as a subsurface barrier to pond groundwater within the Limestone Aquifer.
- Coastal aquifer - This unit comprises raised reefs patchily distributed along the north coast.
- Alluvium aquifer - This unit comprises the upper sequences of coastal alluviums in the Rio Minho, Rio Cobre, Kingston, and Blue Mountain Basins.
- Alluvium Aquiclude- This comprises interior valley clays

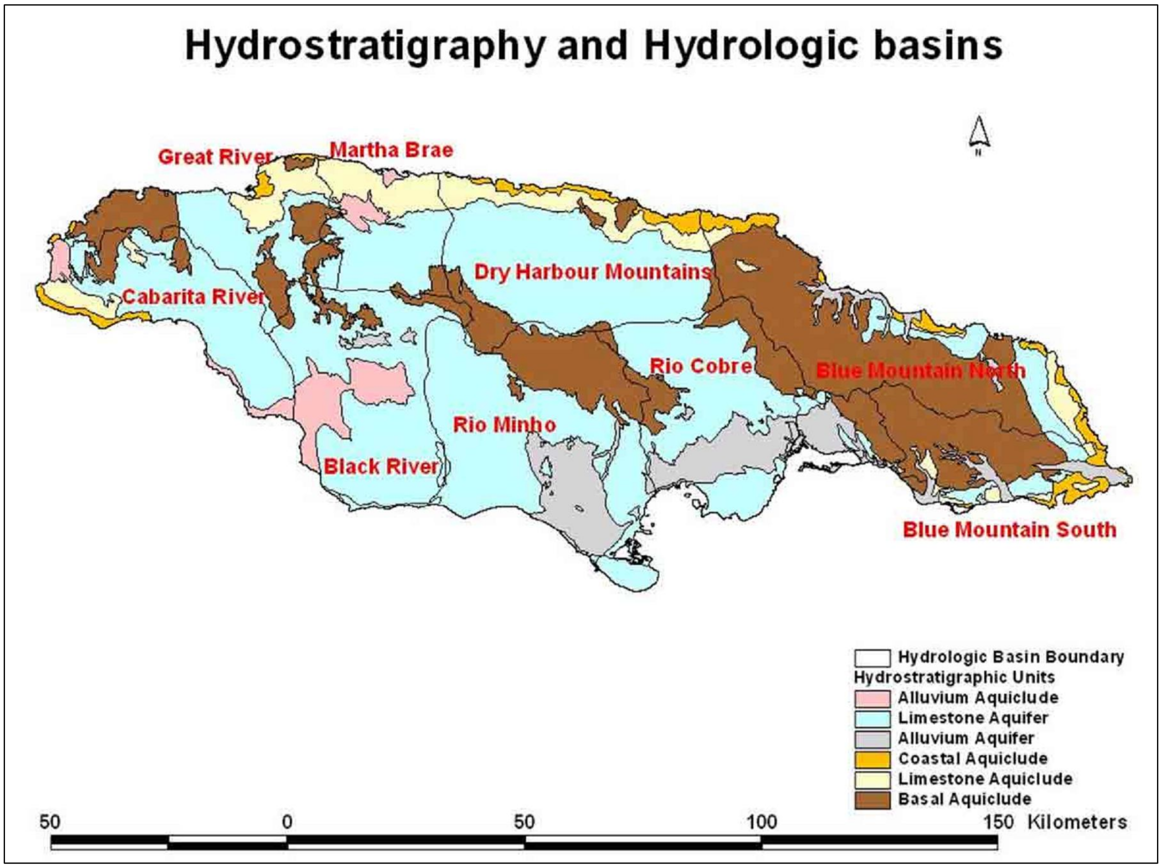


Figure 3-3: Jamaica Hydrostratigraphic Units and Basins (Source: http://www.geocities.com/watercaribbean/23.html#TNC, accessed 21 June 2008)

The central mountain ranges form the main watershed for rivers which drain either to the north or to the south coasts. Surface runoff predominates on the outcrops of basement rocks and interior valley alluviums, whereas groundwater is the dominant water resource associated with the karstic limestones and coastal alluviums. The surface water resources are characterized by a marked seasonal variability in flow.

Streams flowing northward originate mainly in the Tertiary limestones. These are mostly perennial rivers, like the Martha Brae and White River, with significant baseflow components and low seasonal flow variability. Exceptions are the Great River and several rivers in the Blue Mountains (North) Basin, which, like many of the south draining rivers, are characterized by widely varying seasonal flows and comparatively low baseflow. Some of their catchments consist of cretaceous volcaniclastics of low permeability. The Black River drains a predominantly limestone catchment.

The main hydrological and water resources characteristics of Jamaica's basins and WMUs are presented in Table 3.1.

Table 3-1: Jamaica's Hydrological Basins and Water Management Units

(Units $10^6 m^3$/yr except where stated)

Basin/WMU	Area (km^2)	Annual Average Precipitation	Annual Evapo-transpiration	Precipitation-ET	Surface Outflow	Marine Discharge	Groundwater Recharge[2,3]
I – Blue Mountain South							
15-Plaintain Garden River	186.7	512	230	282	199	1	82
16-Morant River	375.7	805	431	374	231	2	141
17-Yallahs River	200.4	418	224	194	125	1	68
II – Kingston							
18-Hope River	241.4	302	162	140	51	21	68
III- Rio Cobre							
19-Rio Cobre	1256.5	1747	935	812	401	73	308
IV – Rio Minho							
20 – Rio Minho	789.3	1058	566	492	156	91	245
21 – Milk River	882.1	1364	730	634	46	156	432
22 – Gut-Alligator Hole River	142.9	224	120	104	8	41	55
V – Black River							
23 – Black River	1698.3	3318	1686	1632	771	154	707
VI-Cabarita River							
24 – Deans Valley River	96.1	181	97	84	13	11	4
25 - Cabarita River	284.3	669	314	355	205	7	143
26 – New Savanna River	76.3	153	82	71	22	8	41
1 – S. Negril-Orange River	139.9	246	131	115	41	16	58
VII – Great River							
2 – Lucea River[1]	253.2	569	256	313	201	7	35
3 – Great River[1]	327.7	734	330	404	376	10	88
4 – Montego	283.3	559	252	307	98	18	191

Basin/WMU	Area (km^2)	Annual Average Precipitation	Annual Evapo-transpiration	Precipitation-ET	Surface Outflow	Marine Discharge	Groundwater Recharge[2,3]
River							
VIII – Martha Brae River							
5- Martha Brae River	622.2	1055	521	534	429	15	90
IX – Dry Harbour Mountains							
6 – Rio Bueno-White River	1563.1	2613	1398	1215	704	143	369
X – Blue Mountains North							
7 – Rio Nuevo	111.1	209	94	115	56	0	59
8 – Oracabessa-Pagee River	169.5	305	137	168	102	0	66
9 – Wagwater River	315.1	641	288	353	242	0	111
10- Pencar-Buff Bay River	202.1	512	178	333	313	0	20
11 – Spanish River	121.6	449	157	292	276	0	16
12 – Swift River	97.2	344	103	241	236	0	5
13 – Rio Grande	302.4	1401	420	981	968	0	13
14 – Drivers River	210.9	692	208	484	260	0	224
JAMAICA		21,080	10,050	11,029	6,350	775	3,725

Source: Brace Centre for Water Resources Management (2005). Notes (1) Inter WMU transfer of $70x10^6 m^3$/yr from Great River to Lucea River (2) Total of limestone and alluvial aquifer recharge (3) With long term no change in storage, total groundwater recharge = total groundwater discharge

3.1.3 Droughts

Drought events in Jamaica are primarily related to disruptions in the seasonal precipitation cycle. The primary cause of such seasonal disruptions is the El Nino/Southern Oscillation (ENSO). Other factors such as decadal fluctuations in Caribbean precipitation amounts can also cause drought. ENSO events impact Jamaican precipitation both directly and through a lag. When an El Nino event occurs, drier than normal conditions characterise Jamaican precipitation during the later months of the precipitation season just before the winter season. Since 1960, El Nino events were the cause of island wide meteorological droughts in 1965, 1969, 1972, 1976, 1982-83, 1991 and 1997. The worst drought conditions occurred in 1976 and 1991, when Jamaica received 72% and 73% respectively of average annual precipitation with respect to the 1951-1980 mean. El Nina events have also been linked to drought in Jamaica, where these events persist beyond the winter months. Island wide droughts in 1971, 1974, 1975, 1985, 1989 and 2000 show this association (Chen *et al*, 2002).

Given Jamaica's size, topography and orographic influences, some parts of Jamaica are more prone to drought than others. For example, during the El Nino year of 1997, regions of Jamaica that experienced drought conditions during the late precipitation season of August to October were situated mostly on the southern and eastern half of the island in the Parishes of St Thomas, Kingston and St Andrew and St Catherine. Similarly during the La Nina year of 2000, it was mainly St Thomas and St Catherine that were most severely affected in the early precipitation season (April-July), although the drought also extended to the west, on the southern plains of Clarendon and St Elizabeth and to the parish of Trelawny in the north of the island. (*ibid*).

3.1.4 Flooding

Flood events are common occurrences across Jamaica, given the nature of storm events and the characteristics of the island's topography. The impacts of flooding are compounded by poor physical planning, poor land use practices as well as a lack of understanding by policy and decision makers of flood generating processes and the associated risks.

In broad geographical terms, the flooding characteristics of Jamaica are summarised in Table 3.2. Figure 3-4 shows the surface water drainage network across Jamaica. The variability displayed in the network shows how the distribution of Jamaica's hydrostratigraphic units has a significant influence on the presence / absence and density of the network. For example, the highest drainage network density is displayed in the Blue Mountains area of Jamaica, associated with the Basement Aquiclude. It is these parts of Jamaica that also receive some of the highest precipitation. Given the small catchment areas, very steep side slopes, and impermeable nature of the soils and geology, these catchments are prone to significant flood events. However, it is not only water flood events that occur in these catchments, but significant risks are also posed by debris and sediment flows, as was experienced during the April 2008 flooding event in Ocho Rios (Water Resources Authority, 2008).

Table 3-2: Flooding Characteristics of Jamaica

FLOODING REGION	FLOODING CHARACTERISTICS	EXISTING VULNERABILITIES
Eastern Jamaica (Blue Mountains)	Watersheds are relatively small and steep. Rivers flow through steep canyons onto alluvial/debris fans before emptying into the Caribbean Sea. With the exception of alluvial fans, flat areas are rare in the parishes of Portland, St. Thomas, and Upper St. Andrew.	Landslides and flooding cause land degradation in watersheds, and extensive damage to road network, standing agricultural crops, communications, private and public buildings, given the limited availability of land for development, (including inappropriate development on sites at risk from floods and landslides).
Central Jamaica	Larger watersheds with flooding associated with significant, longer duration & widespread storm events.	When flooding occurs it is associated with inundation of large floodplain areas. Therefore vulnerabilities are linked with development on these flood plains.
Western Jamaica (Karst regions)	Very limited surface water drainage features, but localized drainage through internal systems into the karst limestone via sink holes	Poor land use management has resulted in the plugging of sinkholes with vegetable debris and silting. This has led to increased incidence of local flooding, property damage and loss of life e.g. Cave Valley, St. Ann.
Coastal Areas	Inundation of coastal low-lying areas by high tides with coastal swell and storm surges associated with tropical storms/ hurricanes.	A large proportion of the Jamaican population is located in areas at risk from coastal flooding. The largest is Portmore with a population of 170,000, which is located on a low lying drained coastal wetland

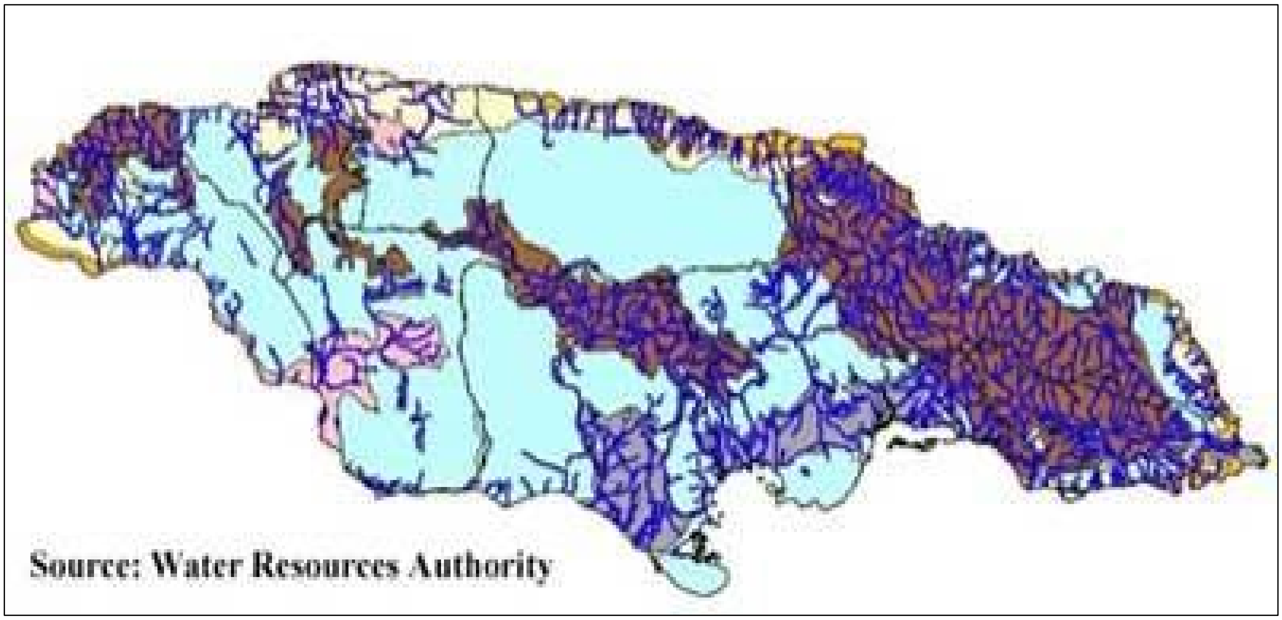


Figure 3-4: Jamaica's Surface Water Drainage Network and Geology

(Source: http://www.geocities.com/watercaribbean/23.html#TNC, accessed 21 June 2008)

Within central Jamaica, associated with the larger watersheds, flooding issues are linked with longer duration storm events, resulting in saturated conditions that result in widespread flooding. Examples include the widespread and catastrophic flooding that occurred in May- June 1986 across southern Jamaica, which was linked with a stationary tropical storm system.

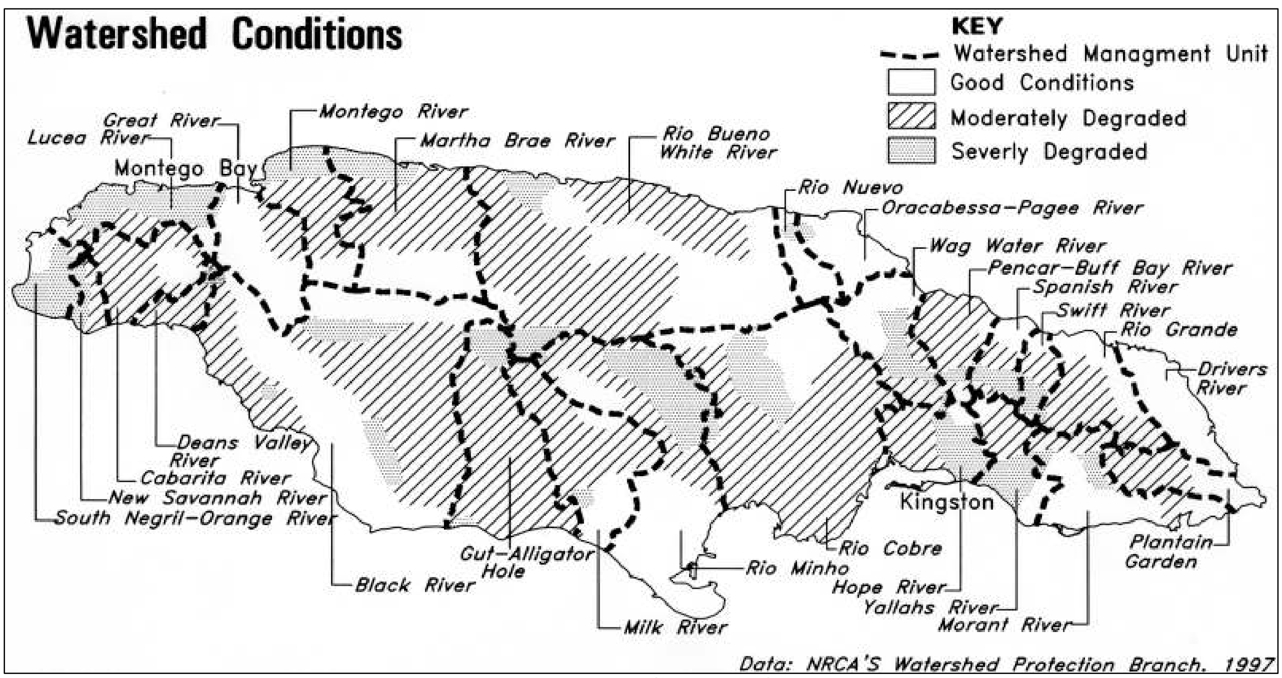
Within the karst areas of Jamaica, surface water flooding is less common. However, poor land use management has resulted in the clogging of natural surface water karst recharge features (sink holes) with, resulting in damage to property and risk to life. Examples include repeated flooding within the Cave Valley sinkhole system (Molina & McDonald, 1988).

Coastal flooding risk is also of concern, given the concentration of much of Jamaica's population in low lying coastal areas. Risks are associated with high tides, storm surges and the resulting inundation, especially when linked with the passage of tropical storms & hurricanes. Evidence of this can most recently be seen in the impact of Hurricane Ivan (2004) and Hurricane Dean in August 2007 on a number of coastal communities including Old Harbour in St Catherine and Caribbean Terrace in eastern Kingston.

3.1.5 Watershed Conditions & Trends

Jamaica is particularly susceptible to watershed degradation, as approximately 80 % of the land surface is hilly or mountainous. 30 % of the land has slopes ranging from 2 degrees to 20 degrees and more than 50 % have slopes greater than 20 degrees. The Natural Resources Conservation Department (NRCD 1984), which is now the National Environment & Planning Agency (NEPA), has reported that 16 % of the island's land area is seriously eroded and that loss of topsoil averages 40 to 50 tons annually. Each of Jamaica's 26 WMUs has portions which are considered badly eroded (NCRA, 1997). The extent of the problems as mapped in the mid-1990s is presented in Figure 3-5. Farming activities such as unregulated burning, cutting trees for logs, yam sticks, fuel-wood and charcoal burning, coupled with poor agronomic techniques, all contribute to the degradation of watershed areas.

Figure 3-5: Watershed Conditions in the Mid-1990s



Source: (NCRA, 1997)

Some caution must be advised here regarding land use change and deforestation. Deforestation has been quoted in many studies (e.g. US Army Corps Engineers, 2001) as taking place at rates of up to 3.3 % per year. However, a recent study undertaken by Evelyn and Camirand (2003) revisited these previous estimates and compared data sets to estimate forestry changes between 1989 and 1998. They found a range of fundamental differences in these earlier studies, which make inter-comparison very difficult and open to misinterpretation. These factors included differences in definitions, differences in data sets used and their precision, and differences in study objectives. Based on their analysis of consistent satellite data they estimated a net change in forest cover in Jamaica of -0.91%, equivalent to 0.1% per year. However, within this small net decline, changes were noted in the disturbed broadleaf classes, related to the net degradation of the forest cover, i.e. an increase of the mixed forest type with agriculture fields. Thus, although under the consistent approach reported here by Evelyn and Camirand (2003) the overall net decline in forested areas is smaller than earlier estimates, within the details of the analysis, there are signs that encroachment of agriculture onto marginal forested areas did take place in the 1990s and is likely to be continuing.

Nevertheless, where deforestation and poor land use practices do take place, there can be adverse impacts on surface water quality. In general terms, with the destruction of the forest cover, water runs off the surface at a faster rate. This causes the rivers to achieve larger peak discharges at a faster rate, increasing the intensity of flooding. Most rivers have increased sediment loads due to this problem. Deforestation also decreases the productivity of the soil on the cleared land and lessens the amount of infiltration, causing dryer than expected conditions. Debris and sediment from deforestation can also clog drainage systems and create unnecessary flooding.

3.1.5.1 IWCAM

Several initiatives to improve watershed management have been undertaken at varying times over several decades. They seek to improve land use practice and address threats posed by poor land use practice and improve watershed conditions. One that is currently being executed by NEPA is the Integrating Watershed and Coastal Area Management in Small Island Developing States of the Caribbean (IWCAM) project. The project is being implemented regionally by the UNEP with the UNDP, and UNEP with the Caribbean Environmental Health Institute is the regional executing agency. The project spans 13 Caribbean nations and in the case of Jamaica, the main project objectives are:

- To develop demonstration projects based on examples of best practice and lessons learnt from other coastal, watershed and community based management initiatives within Jamaica, to create an effective Watershed Area Management Mechanism (WAMM) within East Portland.
- To develop transfer methodologies to allow for replication of these lessons to adjacent Watershed Management Units (WMUs) and other Caribbean SIDS

Other objectives of the project include:

- Improving the institutional and human resources capacity of key stakeholders within the watershed
- Monitoring of environmental and other indicators
- Encouraging the development and implementation of participatory approaches to environmental stewardship and awareness
- Promoting the development of sustainable economic activities
- Identifying solutions to ongoing environmental and human health threatening activities

The demonstration project is being undertaken in the Drivers River Watershed in East Central Portland. This area was selected as it faces a number of interconnected issues / challenges common to watersheds throughout Jamaica (and other SIDS). These include wastewater disposal, solid waste management and disposal, improper land management, sustainable agriculture and tourism development, inadequate drainage and consequent flooding, and (un)employment. The project started in 2007 and has a 3 year duration.

This project has significant potential benefits in terms of decreasing the vulnerability of watersheds and their inhabitants to current climate and climate variability, through the pro-active adoption of improved management and best practice activities. This should also decrease the vulnerability of these same communities to climate change and increased climate variability, and therefore is a potentially significant project for Jamaica as a whole.

3.1.5.2 National Forestry Plan

The Forestry Department has prepared and published the National Forest Management and Conservation Plan (Forestry Department, 2002). This document explicitly outlines one of the key values of forestry to Jamaica as supporting the water resources functions of forested watersheds, as well as soil conservation, protection of biodiversity and carbon sequestration. The Plan includes the development of a number of strategies to support the Plan's objectives. With respect to water resources, the most relevant strategy relates to Forest Protection. This includes a number of activities starting with forest inventory, development of guidelines on forest land use, identification of critical emphasis areas, and development of conservation and protection strategies, declaration of Forest Reserves, Forest Management Areas and Protected Areas, and restoration of mining disturbed forests. The Plan includes an implementation programme and budget for a number of activities and projects. It was approved by the Minister of Agriculture in 2001 and has a 5 year implementation programme. Updating the National Forestry Plan will commence later this year and is due for completion in 2009. It will explicitly include climate change issues and responses for Jamaican forestry.

The Forestry Department has also undertaken a number of detailed catchment / watershed based studies, with its Trees for Tomorrow project, looking at strengthening the Department's abilities to plan and manage forests and develop and implement soil conservation measures appropriate to Jamaica's environment. To assist the accomplishment of this aim, the Rio Minho, the Martha Brae and the Buff Bay / Pencar watersheds were chosen as WMU models for further study. From this work, two reports (Trees for Tomorrow Project, 2002 & 2004) were produced. They summarised the main physical-morphometric characteristics and the modification of the land-use conditions of the watershed, and how these have influenced their hydrological responses, investigated linkages between forest cover and watershed yield and recommended appropriate land treatments for erosion control.

Further work has been undertaken in this area, with the development of linked GIS land cover and hydrological modelling tools. These provide a framework which seeks to optimise forest cover to meet pre-defined land and water use management objectives (Evelyn, 2007). This work has been developed and piloted in the Rio Minho watershed, with plans to apply it across all the watersheds of Jamaica.

3.1.6 Water Quality Characteristics

The quality of surface and groundwater is germane to the usability of the resource. Although Jamaican rivers generally have good water quality, they do face a number of pollution risks from human and industrial wastes, as illustrated in Figure 3-6. Organic wastes from sugar, rum (dunder) and other food processing activities pollute surface water courses and can enter the groundwater with stream-aquifer interaction. A large proportion of the population does not have access to central sewage treatment systems, but use pit latrines and septic tanks. Where poorly constructed and maintained, these can pollute nearby surface water courses. Dumping solid waste into gullies, sinkholes, and mined limestone pits is also a pollution risk.

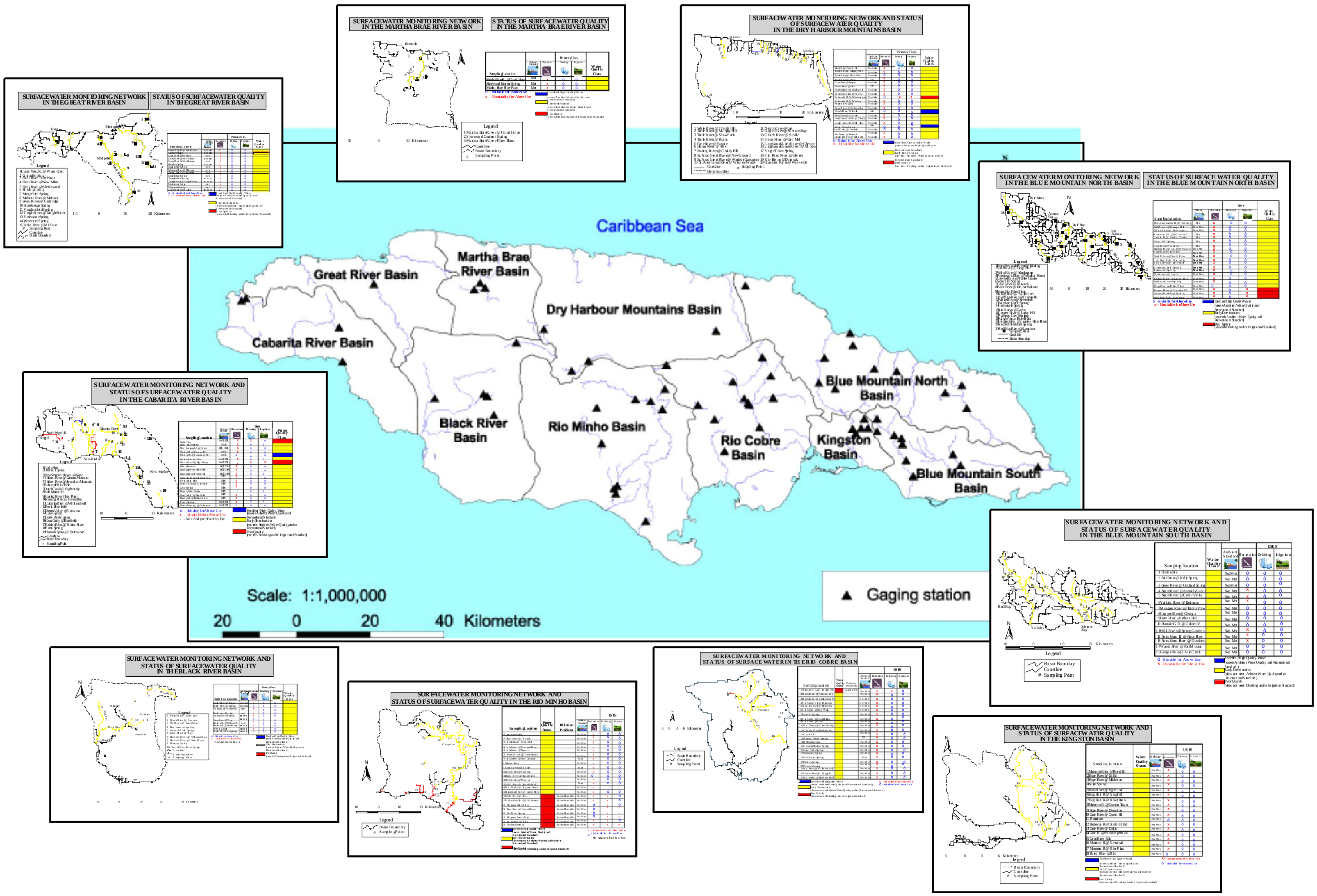


Figure 3-6: Jamaica's Surface Water Quality (source: Haiduk, pers. comm.)

The results presented in Figure 3-6 are based on the existing water quality sampling network operated by the Water Resources Authority and the analysis undertaken by the Authority on a relatively short time series of data, much of which only covers the 1990s. Thus, coverage is relatively sparse and in many cases available data sets are not up to date. Nevertheless, the data sets that are available indicate that in a majority of the monitored locations and reaches, surface water quality shows signs of "early deterioration". Given the lack of more recent data, it is difficult to comment on whether these signs of water quality deterioration have continued since 2000.

There have been studies on the amount of pesticide and herbicide pollution in Jamaica. One undertaken in the late 1990s (Witter, J.V., *et al.*, 1999) found that 14 out of 17 major rivers had detectable levels of insecticide residues. The amounts of these substances entering the water depend on leaching and runoff, and are therefore related to precipitation and land use / soil management practices.

Bauxite is extracted by surface mining, and land intensive. Jamaica can produce about 3 million tons of alumina per year. The refining process creates a thick fluid called "red mud" which has high levels of sodium and hydroxide ions, iron oxides, and organic substances. About 1 ton of red mud waste or residue will be produced from each ton of alumina. This waste is often ponded into lakes, either manmade or karst depressions. The effluent can create problems where it is free to seep into the subsurface, or to mix with precipitation, creating caustic ponds.

The groundwater quality of Jamaican aquifers in generally good. Water is generally hard due to the large percentage of limestone covering the island. Water originating from white limestone aquifers frequently shows high turbidity. Karst limestone allows water to move rapidly between the surface water and ground water environments via fractures, sinkholes, springs, and caves. This rapid movement creates a high potential for surface contaminants to pollute large volumes of ground water in a short period of time. Effluents from sewage soak-away pits, bauxite processing plants, and sugar cane refineries are the most prevalent manmade sources of ground water contamination. The primary method of sewage disposal is the use of soak-away pits. As a result, ground water sources near these pits may have high faecal coliform levels.

Over-abstraction from limestone and alluvial aquifers in the Liguanea Plain and the lower reaches of the Milk River, Rio Minho, Rio Cobre, and Montego River Basins has caused saltwater intrusion from the Caribbean Sea.

In the Kingston area many wells have been abandoned due to poor water quality resulting from saltwater intrusion in the case of coastal wells and high nitrates from sewage infiltration on the Liguanea Plains. Saltwater intrusion has also degraded water quality along sections of the south coast in the St. Catherine and Clarendon Plains, near the Black River and Alligator Pond and along the northern coast near Montego Bay.

Contaminated water usually has high amounts of sodium, calcium, chloride, and calcium carbonate. Chloride concentrations generally increase with depth as a result of upcoming of saltwater in wells drilled below sea level.

Therefore, groundwater in Jamaica is vulnerable due a number of factors. These include:

- Seawater intrusion: closeness to the coast, intrusion already advanced, over development of ground water.

- Soil cover: thickness, permeability, filtration and sorption capacity.
- Land use: agriculture with fertilizers (nitrates, phosphates, etc.).
- Disposal of sewage via soakaway pits into the limestone.
- Depth to ground water.
- Ground water gradient, velocity of flow, residence time.
- Alluvial deposits near rivers, rivers recharging aquifers, local cones of depression created near rivers.
- Industrial developments, waste water ponds, industrial canals.

Based on these factors, there are a number of locations within Jamaica that are experiencing deterioration in groundwater quality. These areas are highlighted in Figure 3-7 (Karanjac, 2005). Some wells have been abandoned due to increased salinity (Areas 1 and 4 in Figure 3-7); others produce water of such a quality that it is unsuitable for agricultural use. Industrial waste ponds with water enriched with sodium and metal impurities from the bauxite-to-alumina refining process (Area 2 in Figure 3-7) are located in highlands over limestone layers capped with thin soil layer. Dumping of industrial waste from rum distilleries into the surface and subsurface is a known practice that contaminates karstic aquifers and fouls surface water. Figure 3-7 points at the localities in which ground water quality has been already impaired. These are the most vulnerable areas in Jamaica.

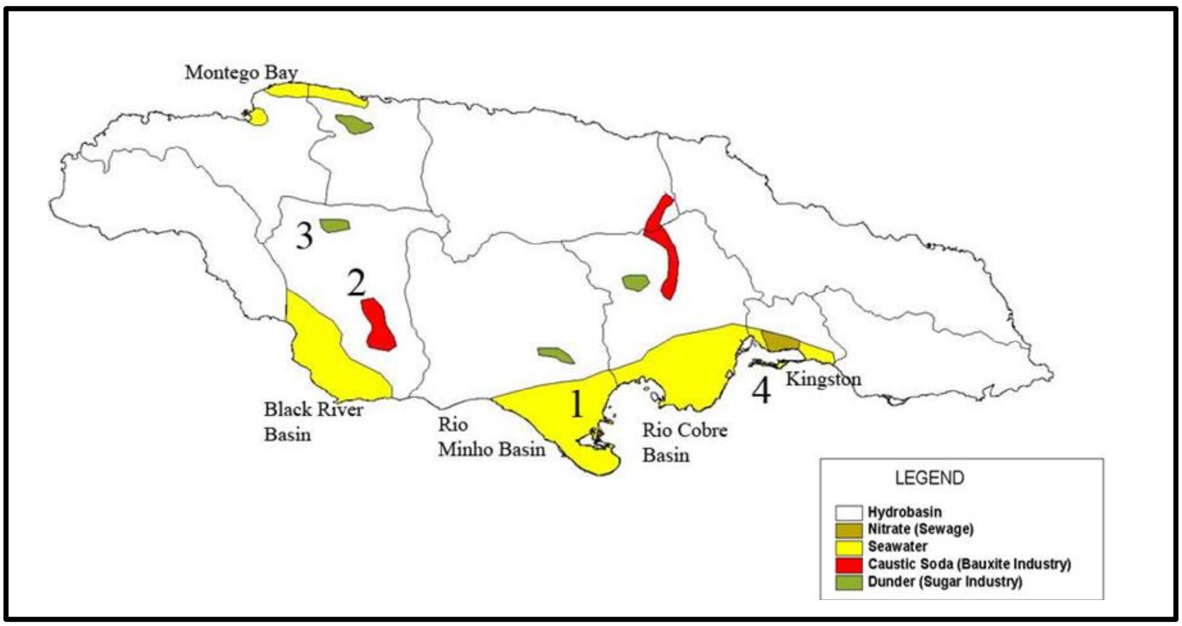


Figure 3-7: Contaminated Aquifers in Jamaica

Seawater intrusion. The Water Resource Authority has calculated that the degradation of water quality has resulted in the loss of some 100 million cubic meters annually, which is about 10% of all currently used ground water, primarily as a result of over abstraction that led to seawater intrusion. An additional 15% of fresh ground water is being affected by the same process but continues to be used for restricted purposes. Many production water wells in the south are no longer pumped and many sugarcane fields have been abandoned. In the Rio Minho and Rio Cobre areas (central-southern part; 1 in Figure 3-7) the increase in salinity is being observed at distance more than 10 km from the coast. However, one should point out that the saline intrusion along the south coast occurred prior to the 1961 period when the control of licensing was introduced onto the island. Since then the moratorium on new abstraction has reduced the salinity levels and the saline front has been pushed back several kilometres. (Karanjac, 2005)

Bauxite processing. An increased content of sodium (Na) in water wells in the Essex Valley, which is located within the eastern area of the Black River Basin, (Area 2 in Figure 3-7), is a cause of concern for the usability of good quality ground water for domestic uses. The contamination results from leaky industrial waste ponds, known as mud lakes, which were created as recipients of red mud waste from the bauxite-to-alumina processing. The lakes are "sitting" at an elevation of about 160 m AMSL over very permeable, fractured and karstified limestone rocks.

While sodium is not a "dangerous" contaminant (at least if its content is within the WHO's recommendation of 250 mg/L), the presence of other metals in wastewater after bauxite is processed, such as As, Cd, Al, Fe, Zn, etc. may be of concern if detected above maximum permissible concentrations. However, the risk of contamination reaching nearby water supply wells is managed by the use of "scavenger" wells at the processing plant that reclaim and re-circulate the contaminated groundwater.

Contamination by dunder – waste product of rum distillation. Distillation of sugarcane to produce rum leaves behind dunder, – a liquid foul smelling waste that is freely discharged through sinkholes into karstic systems reaching surface creeks and rivers (Area 3 in Figure 3-7). The effect of discharge of dunder on ground water is related to impacts on colour, odour, phosphates and pH values.

Nitrates in ground water. Nitrates pose a problem in agricultural lands along the southern coast of Jamaica. Ground water in both alluvial and limestone aquifers is affected (Areas 1 and 4 in Figure 3-7). The elevated concentration of nitrates come from the use of fertilizers and manure as an agricultural practice primarily in sugarcane fields. In urban areas, the source is the sewage disposal via septic tanks, soak-away pits, and pit latrines. Permissible level of nitrates (as nitrogen) is 10 mg/L, but in some wells concentrations many times this value are encountered.

The WRA also maintains a database on groundwater quality, which unfortunately only has island wide data up to the end of the 1990s. Funds and staff resources are no longer available to maintain an island wide monitoring programme. Ad-hoc monitoring has taken place but only on the back of specific projects, for example, water quality sampling of both surface water and groundwater in the Lower Rio Cobre basin as part of the data collection for the KMA water supply project.

3.2 Water Supply & Wastewater Disposal

Water resources play a significant role in the Jamaican economy. It supports important sectors including recreation & tourism, mining, food and beverage processing, irrigated agriculture and manufacturing. This significance to the Jamaican economy is presented in Table 3-3, which shows the contribution of the various economic sectors to Jamaica's estimated GDP and employment estimated for the mid 2000s.

Table 3-3: Approximate Economic Contributions and Water Use by Sectors, 2005

Sector	Direct Contribution to GDP (Con Prices)		Foreign Exchange Earnings	Employment	Annual Water Use		Principal Locations
Units	J$ billion	%	J$ billion	No.	10^6 m^3/yr	%	WMU
Manufacturing incl. Food	32	13	27	72,000	16	1	18,19
Mining and Construction	39	16	66	108,000	60	5	6,19,20,21,23
Irrigated Ag	7	3	7.4	191,300	439	33	19,20,23
Other Ag (Non Irrigated)	6	2	-		-	-	
Hotels	16	7	100	19,000 (N. Coast only)	4	0.3	4,5,6,18
Other services	157	65	-	56,000	10	1	All
Residential	-	-	-	-	274*	21	18,19
Environment	-	-	-	-	510	39	All
Less Financial Adjustments	16	(7)	-	-	-	-	
Total GDP	241	100			1,312	100	

Source: Planning Institute of Jamaica (2006) and Brace Centre for Water Resources Management (2005)
*The contribution of irrigation agriculture to GDP is taken as the equivalent of export agriculture

For example, manufacturing mining and construction, and other services make the highest contribution to GDP (94%) but consume 7% of annual water use. Irrigated agriculture and residential and environmental flows have the highest annual water use (93%), but contribute only 7% of total GDP. Further analysis of the links between water use and these sectors and the economy is presented in Section 6.

There is no direct correlation between contribution to GDP and employment within each sector and the amount of water used.

In terms of sources used, groundwater accounts for over 90% of water used to meet water supply demands/ needs, with surface water sources providing the balance of supply. This estimate is based on water withdrawals from wells as well as spring sources.

The distribution of wells across Jamaica is presented in Figure 3.8, while the locations of springs and caves are shown in Figure 3.9.

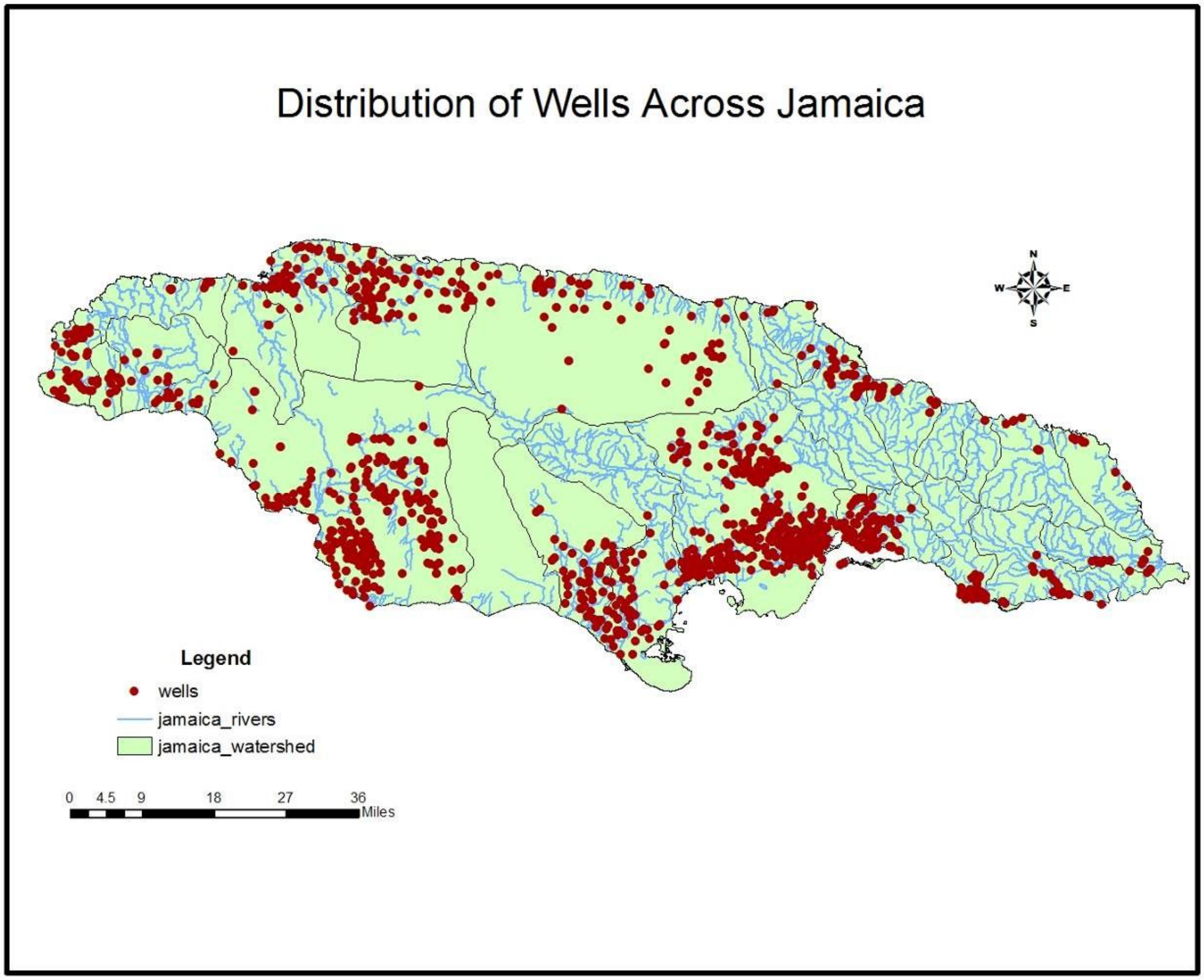


Figure 3-8: Distribution of Wells Across Jamaica

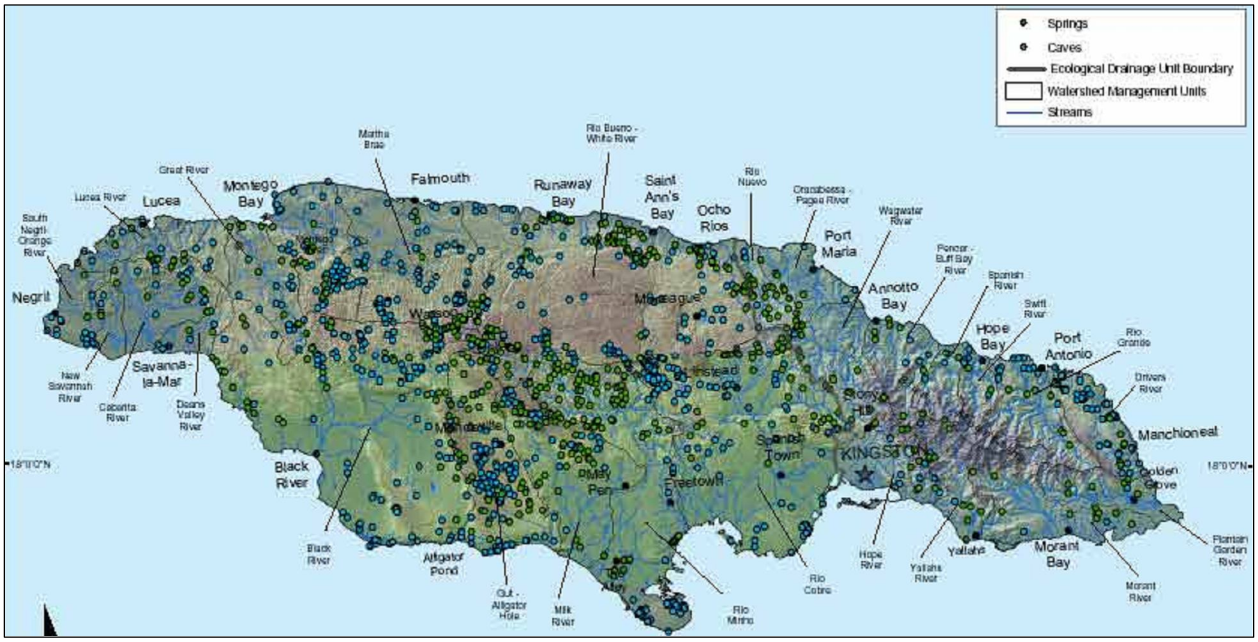


Figure 3-9: Springs and Caves in Jamaica

(Source: Karanjac, 2005)

3.2.1 Public Water Supply and Wastewater Treatment & Disposal

The vast majority of the public water supply in Jamaica is provided by the NWC. A summary of the NWC's water production supply and performance from 2002 to 2006 is presented in Table 3-4.

Table 3-4: Summary of NWC Water Supply Performance to 2006

Performance Indicator	2002	2003	2004	2005	2006p
Water Production (Ml/yr)	276,835.5	293,382.0	280,308.0	296,454.1	294,384.0
Consumption (Ml/yr)	95,094.0	96,329.0	94,729.0	94,415.7	95,318.0
Total No. Of Connections	375,431	388,460	400,102	410,286	418,347
Total Revenue (J$M)	5257.1	5793.0	7293.1	8436.2	9297.4

P=preliminary estimates. Reference: Planning Institute of Jamaica 2007

The decline in production in 2006 compared with 2005 was the result of drought conditions, which were more acute in eastern Jamaica. In some areas production fell to 30% of capacity in the period July to September. In some locations, the situation was aggravated by plant outages. The NWC introduced a number of drought management measures to deal with the situation, including scheduled restrictions on supply, maximising abstractions from some sources and water trucking. Note that total metered consumption was slightly increased in 2006 compared with 2005, despite drought conditions.

As can be seen from Table 3-4, of the total water produced in 2006, 67.6% was non-revenue water (NRW) i.e. the difference between production and billed consumption. This includes loss as a result of theft, leakage and underestimated consumption. Measures to reduce this are a priority area for the NWC and most of the projects being undertaken by the NWC include activities to reduce these “losses”. For example, almost 21,000 water meters were installed island wide in 2006, following from a similar number installed in 2005.

Connections continued to increase in the period 2005-2006 as in previous years. This, with changes in the water tariff, increased revenues by J$861.2M between 2005 and 2006.

Details regarding the NWC’s water supply operations across each of the parishes of Jamaica are presented in Figure 3-10 and summarised in Table 3-5

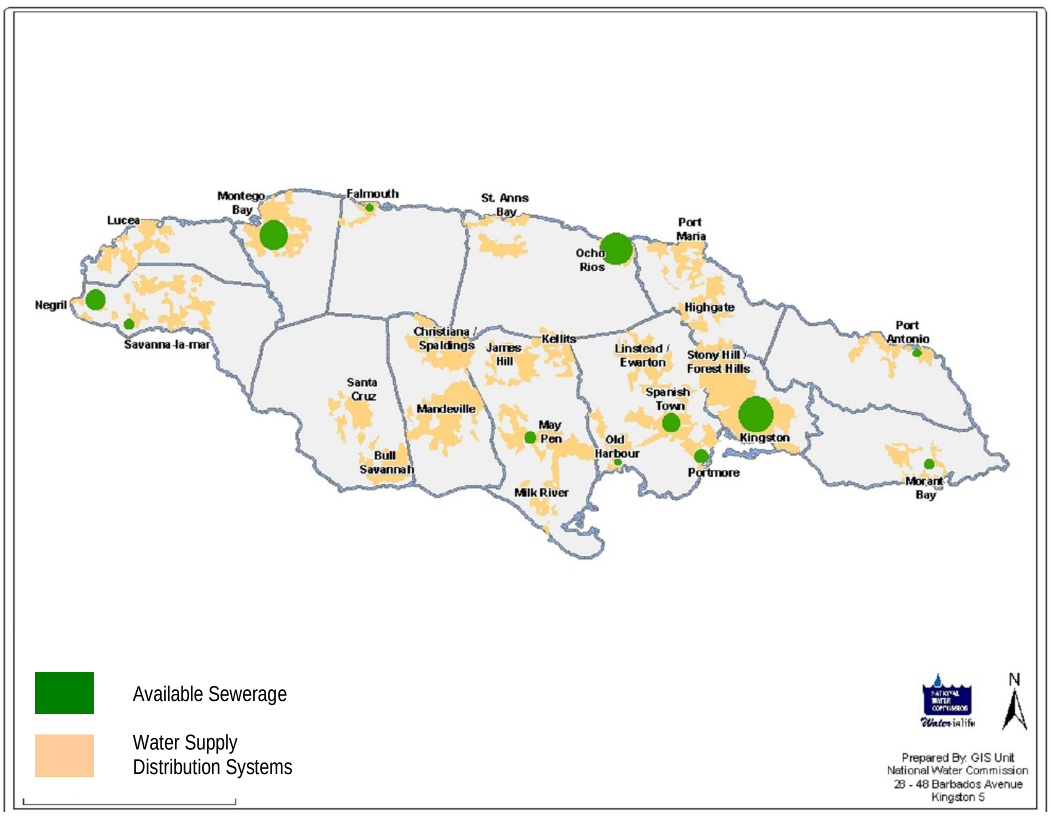


Figure 3-10: NWC Water Supply and Main Sewerage Systems

(Source www.un.org/esa/sustdev/sdissues/water/workshop_lac/presentations/hunter.pdf (accessed 21st June 2008)

Table 3-5: NWC Parish Water Supply Summary

Parish	Surface Water Sources / Schemes	Groundwater Sources / Scheme(s)	Existing Issues & Vulnerabilities
Kingston & St Andrew	Hermitage/Wagwater & Hope River supply systems	10 no. wells within KSA area	Significant imports from Yallahs and the Negro Rivers located in St. Thomas and from St. Catherine via the Rio Cobre system. Only surface water storage in Jamaica at Mona and Hermitage reservoirs. Supply restrictions occur during drought.
St Catherine	Rio Cobre to Spanish Town WTW	33 no. wells within the Parish + Tulloch Springs (as part of the Rio Cobre System)	Issues of low level of service to Portmore. Risk of saline intrusion into coastal aquifers
Clarendon	3 no. river sources	33 no. wells which provide over 80% of the supply, 9 no. springs sources	During dry periods, yield from river sources declines significantly. Also competition for water with agriculture. Risk of saline intrusion into coastal aquifers.
Manchester		Porus and Victoria wells are main sources.	Greater Mandeville Water Supply System which obtains water from the Pepper area in St. Elizabeth. Various communities in the parish are supplied by small springs with low outputs
St. Elizabeth	1 no. river source	23 no. wells, 3 no. spring sources	The parish is not fully served, however, since the transmission system is not extended to all areas in the parish
Westmoreland	2 no. river sources	16 no. springs, 4 no. well sources	The parish is not fully served by the transmission system with the west central areas of Little London to New Hope being particularly challenged.
Hanover	2 no. river sources	6 no. spring sources	Lucea/Negril Water Supply upgrading project will increase supply by 18Ml/d
St. James	2 no. river sources	10 no. well, 10 no. spring sources	Imports from the Martha Brae/Queen of Spain system located in Trelawny
Trelawny	4 no. river sources	9 no well, 6 no. spring sources	Inadequate transfer facilities to southern Trelawny.
St. Ann	37 no. sources within the parish		The level of service varies markedly as a result of the inadequacy of source and

Parish	Surface Water Sources / Schemes	Groundwater Sources / Scheme(s)	Existing Issues & Vulnerabilities
			transmission facilities.
St. Mary	2 no. river sources	14 no. spring sources	The absence of raw water storage makes the entire output from these systems susceptible to wide fluctuations in output during the year.
Portland		12 no. spring & 3 no. well sources	Distribution system in Port Antonio is old and has a negative impact on service in the Parish Capital
St. Thomas	9 no. river sources	16 no. spring & 8 no well sources	Communities which depend solely on rivers or springs are adversely affected during dry periods when there are significant reductions in the stream flows. Note that Yallahs and Negro River are run of river schemes.

As highlighted in Table 3.5, there are a number of climate related issues and vulnerabilities that currently have a negative impact on the levels of service of water supply systems across many of Jamaica's parishes. This includes saline intrusion risks in St. Catherine and Clarendon as well as the use of sources sensitive to dry periods and therefore having low reliable yields in, for example, St. Mary and St. Thomas, and washout of distribution systems during flood events.

Within the main urban centre of Kingston & St. Andrew, although the area is served by a number of inter-catchment transfers and other sources, there is currently limited capacity to move water around the urban area between these different water supply zones. Therefore, if drought conditions were to be experienced predominantly in the east of Jamaica, and so reduce the yield from the Yallahs and Negro Rivers into Mona Reservoir, there would be limited scope to move any available water from, for example the Rio Cobre Scheme, into those areas currently served by the Mona WTW.

For wastewater treatment and disposal, the NWC operates a number of schemes across the country which serve about 15% of the population. Centralized systems are located in Kingston and St. Andrew, southeast St. Catherine and Montego Bay in St. James. These are also illustrated in Figure 3-10. The NWC is responsible for a number of small sewerage systems, utilizing package plants, which are associated with housing developments in various locations throughout the country. Treatment is given to secondary level for 50% of the wastewater. These are summarised in Table 3.6. The remainder of the population is served by soakaways, septic tanks and pit latrines. Where these are poorly operated and maintained, they present a significant contamination risk to the water environment, and as commented earlier, have produced widespread contamination of the Liguanea Plains on which Kingston is situated.

Table 3-6: NWC Parish Wastewater Treatment Summary

Parish	Wastewater Treatment Facilities	Existing Issues and Vulnerabilities
Kingston & St.Andrew	There are 14 sewerage systems collecting in excess of 68 Ml/d of sewage. Greenwich and Western are the major sewerage treatment facilities; they are both primary treatment plants. These plants process more than 85% of the total sewage collected in sewerage facilities in the KSA.	A number of the sewerage treatment facilities are overloaded and long term plans have been developed to address this problem, through the construction and commissioning of the Soapberry Wastewater Treatment Plant which was due for completion in 2008
St. Catherine	There are 16 sewerage systems in St. Catherine with a combined installed capacity of just under 45 Ml/d. The Independence City (16 Ml/d) and Bridgeport (9 Ml/d) sewerage treatment plants, located in southeast St. Catherine, are the major sewerage treatment facilities in the parish. The largest facility is the 18 Ml/d sewerage treatment works for the Greater Portmore housing development. Near Spanish Town, sewerage facilities are in place in the large Horizon Park, Sydenham and Ensom City housing developments.	Large proportion of population not served by sewerage collection system and treatment
Clarendon	Seven (7) sewerage systems are operated in the parish. These are small systems which were constructed as part of housing schemes.	Large proportion of population not served by sewerage collection system and treatment
Manchester	No NWC operated systems	N/A – population not served
St. Elisabeth	No NWC operated systems	N/A – population not served
Westmoreland	The sewerage systems for the Shrewsbury and Llandilo housing schemes are operated by the NWC. These are extended aeration and oxidation ditch type plants, respectively.	Large proportion of population not served by sewerage collection system and treatment
Hanover	No NWC operated systems	N/A – population not served
St. James	At present, the existing 7 Ml/d trickling filter sewerage treatment is overloaded	The Montego Bay Sewerage System has been upgraded.
Trelawny	No NWC operated systems	N/A – population not served
St. Ann	The collection and treatment of sewage in a small section of Ocho Rios is now being done by the Urban Development Corporation. The NWC operates the small sewerage systems for the Moneague and Steer Town developments.	The NWC has constructed an improved sewerage system for the entire Ocho Rios and some adjoining communities
St. Mary	No NWC operated systems	N/A – population not served
Portland	No NWC operated systems	N/A – population not served

Parish	Wastewater Treatment Facilities	Existing Issues and Vulnerabilities
St. Thomas	The NWC operates two small sewerage systems - Red Hills Pen and the Yallahs Housing Estate, each being part of a housing scheme	Large proportion of population not served by sewerage collection system and treatment

3.2.2 Irrigated Agriculture

Irrigated agriculture accounts for approximately 25,214 ha (9.3% of cultivated lands), while representing around 85% of Jamaica's total water usage (excluding environmental needs). This high demand reflects low irrigation efficiencies, estimated to be around 40%, although this varies dependent upon method of irrigation, management of the irrigation system, investment and other factors. There is scope to improve irrigation efficiencies, moving away from surface furrow methods, which in the mid 1990s accounted for 80% of the systems supplied by the NIC and 70% of the systems operated privately, including aquaculture, to more efficient drip irrigation systems.

The parish by parish distribution of agricultural lands (as of 1997) is listed in Table 3-7. Half of the total area irrigated comprises public schemes, which are managed by the National Irrigation Commission (NIC), while the other half is on individual private systems and on commercial estates, where banana, papaya and sugar cane are the major crops grown. Three-quarters of the irrigated area uses surface irrigation, 17% are equipped with sprinklers and 8% with micro-irrigation systems.

The NIC has responsibility for operating and maintaining delivery systems for six public districts: Rio Cobre, St. Dorothy, Mid-Clarendon, Hounslow, Braco and Yallahs. The networks consist of open canals and pressurized pipelines. Water is abstracted from surface diversions, small storage reservoirs and deep wells. In the private sector, in addition to sugar estates in St. Catherine, which receive much of their irrigation water from NIC, there are several commercial estates, which have implemented their own irrigation systems. Many farmers with small holdings in most parishes irrigate vegetables or fruit trees using their domestic water supply or from local surface sources, springs or stored rainwater.

NWC has estimated that in areas like Essex Valley or St. Elizabeth, more than 60% of domestic water is used for irrigation. While a wide range of crops is irrigated, 76% of all irrigated lands are under sugar cane production, followed by bananas (8%), pasture (6%), and vegetables (4%). The remaining 6% comprise papaya, orchards, coffee and other crops.

Table 3-7: Distribution of Irrigated Areas in Jamaica by Parish

PARISH	IRRIGATED AREA (HA)
Clarendon	10801
Hanover	7
Kingston	0
Manchester	3
Portland	10

PARISH	**IRRIGATED AREA (HA)**
Saint Andrew	32
Saint Ann	69
Saint Catherine	9720
Saint Elizabeth	1386
Saint James	103
Saint Mary	721
Saint Thomas	1488
Trelawny	549
Westmoreland	325
JAMAICA	**25,214**

Any improvement in irrigation efficiencies may not lead to a reduction on total water withdrawals, as any water savings could be used to bring new areas under irrigation and therefore leave the overall consumption of water resources for this sector unchanged. The NIC (NIC, 2004) estimates that irrigated lands will double by around 2025.

Improved efficiencies may also have other consequences, where inefficient irrigation is a significant source of aquifer recharge e.g. for the alluvial aquifers of the Rio Cobre and Rio Minho, and where investment in new irrigation methods could have negative impacts on the water balances of coastal aquifers.

Aquaculture is also an important user of water, and requires high quality water for the rearing of tilapia.

3.2.3 The Environment

There are clear ecological and economic reasons for explicitly including environmental flow requirements within any assessment of the economic role of water resources in the Jamaican economy. Aquatic ecosystems provide a range of benefits, in addition to water supply, recreation and "natural" water treatment in streams and wetlands. Reducing water flows in both river and groundwater ecosystems will have a negative impact not only on the flora and fauna but also on the human communities that depend on these ecosystems.

The estimates of environmental flow needs presented in Table 3-3 are based on estimates of required groundwater submarine discharges to the sea to prevent saline intrusion as well as estimates of minimum stream flow requirements to maintain aquatic ecology (60% of minimum river flows for 7 days over a 10 year period) However, it is recognised in Brace Centre for Water Resources Management (2005) and strongly endorsed here that further work is needed to refine the estimates given especially for the stream flow requirements.

3.2.4 Hydro-electric Power

Jamaica has currently installed approximately 23.8MW of HEP capacity (approx 2.0% of total electricity production), with the potential for a further 100MW of capacity. All but two of the currently operational HEP plants are run-of-river schemes and therefore their daily production is directly related to river flows. Note that HEP is a non-consumptive user of water, as once the water has passed through the turbines, it is returned to the stream from where it was diverted.

3.3 Vulnerabilities of the Jamaican Water Sector to Existing Climate

To understand the current situation with respect to water resources for Jamaica, Table 3-8 presents the estimated annual water resources situation for each of Jamaica's basins for 2005. The values presented in Table 3-8 are based on the second Draft update (Brace Centre for Water Resources Management, 2005) of the 1990 Water Resources Master Development Master Plan, which is in the process of final update and revision for publication later in 2008. Therefore the values presented in this table are subject to change.

Table 3-8: Annual Water Resource Demand Balance for each Water Management Unit (10^6 m^3/yr)

Basin/WMU	Potentially Available Water Resources	2005 Demands	Surplus / Deficit	Demand / Resource %
I – Blue Mountain South				
15-Plaintain Garden River	97.3	4.4	92.9	4.5
16-Morant River	194.3	25.2	169.1	13.0
17-Yallahs River	82.7	8.7	74	10.5
II – Kingston				
18-Hope River	74.5	87.6	-13.1	117.5
III- Rio Cobre				
19-Rio Cobre	483.7	305.2	178.5	63.1
IV – Rio Minho				
20 – Rio Minho	266.1	175.8	90.3	66.1
21 – Milk River	438.1	97.2	340.9	22.2
22 – Gut-Alligator Hole River	59.9	10.0	49.9	16.7
V – Black River				
23 – Black River	993.8	169.1	824.7	17.0
VI-Cabarita River				
24 – Deans Valley River	64.5	5.4	59.1	8.4
25 - Cabarita River	252.3	26.1	226.2	10.3
26 – New Savanna River	42.0	0.7	41.3	1.7
1 – S. Negril-Orange River	63.0	3.5	59.5	5.6
VII – Great River				
2 – Lucea River	38.3	5.7	32.6	14.9
3 – Great River	146.5	24.0	122.5	16.4
4 – Montego River	201.2	22.6	178.6	11.2
VIII – Martha Brae River				
5- Martha Brae River	239.2	56.3	182.9	23.5
IX – Dry Harbour Mountains				
6 – Rio Bueno-White River	641.8	159.4	482.4	24.8
X – Blue Mountains North				
7 – Rio Nuevo	74.1	6.5	67.6	8.8
8 – Oracabessa-Pagee River	93.2	12.0	81.2	12.9
9 – Wagwater River	132.0	14.6	117.4	11.1
10- Pencar-Buff Bay River	55.7	13.4	42.3	24.1
11 – Spanish River	56.2	14.6	41.6	26.0
12 – Swift River	30.4	6.2	24.2	20.4

Basin/WMU	Potentially Available Water Resources	2005 Demands	Surplus / Deficit	Demand / Resource %
13 – Rio Grande	107.2	37.0	70.2	34.5
14 – Drivers River	286.9	20.6	266.3	7.2

Source: Brace Centre for Water Resources Management (2005)

The estimates of potentially available water resources are based on annual average conditions under current climate. The estimates are based on the following water balance equations, assumptions and calculations for groundwater and surface water contributions respectively:

Aquifer Safe Yield = (Precipitation – Evapotranspiration) – Surface Runoff – GW Return Flow

River Safe Yield = Q90 low flow (flow that occurs at least 90% of the time)

Potentially Available Resources = Aquifer + River Safe Yields

Demands have been estimated for agriculture, domestic use, industry and tourism, as well as exports to neighbouring catchments.

An internationally accepted threshold for a water stressed catchment / area is a demand / resource percentage of 40%. (For global examples, see http://www.earthtrends.org/pdf_library/maps/watersheds/gm16.pdf. Accessed 4 August 2008). As can be seen in Table 3-8, three WMUs fall into this category: Hope River at 117.5%, Rio Cobre at 63.1% and Rio Minho at 66.1%. The next highest value is 34.5% for the Rio Grande WMU.

Note that the analysis presented in Table 3-8 does not include WMU water supply transfers. For example, as highlighted in Table 3-5, Kingston (Hope River WMU) receives significant water supply transfers from the Rio Cobre and the Yallahs WMUs. These transfers provide a total estimated annual average water supply of 67 x 10^6 m^3/yr (United States Army Corps of Engineers, 2001). With this transfer in place, the balance in the Hope River WMU moves from a deficit of 13.1x10^6 m^3/yr to a surplus of 53.9 x 10^6 m^3/yr, with a revised demand/resource percentage of 61.9%, still within the definition of a water stressed basin.

In the case of the Kingston Basin, demands are driven by municipal and industrial needs, given that Kingston, the capital of Jamaica, is located within this basin. In contrast, for the Rio Cobre and Rio Minho, it is irrigation needs that are the greater and which drive demand for water in these basins. Thus, even under average climatic conditions, a significant proportion of the Jamaican population and important parts of the Jamaican economy are vulnerable to the risk of water supply shortfalls.

The analysis presented in Table 3-8 is limited to a comparison of water resources availability and demand only within each WMU. In the case of groundwater resources availability, this is assumed to be equal to the balance of net precipitation less surface runoff and groundwater return flow (or discharge to the sea). This is considered to be overly optimistic, as it does not consider the role of other forms of groundwater discharge such as spring flows, seepages and baseflows which have important roles in the aquatic environment and hydrology of many WMUs. This interaction needs to be more fully considered as part of a more comprehensive analysis. Also, the analysis upon which the results are based on from Brace Centre for Water Resources Management (2005) lumps the alluvial and limestone aquifers together within each MWU, which is a weakness that needs to be addressed.

Also, the analysis does not factor in water delivery / engineering systems, their capacities or reliabilities, and therefore the results presented in Table 3-8 only present a preliminary analysis of basin water resources vulnerability. A further refinement of this analysis would include assessments of engineering capacities of intakes / wells / pipelines / treatment plants / service reservoirs for each water supply system.

It is also the case that the analysis presented in Table 3-8 is based on annual average conditions. The performance of water delivery systems under a range of climatic and drought conditions is also necessary. This is to assess levels of service of supply under existing climate and how these levels of service compare with the water providers own target levels of service. Such an approach requires the adoption of more complex approaches and methods of analysis, the use of enhanced water resources modelling tools as well as the time series data and other data on the engineering aspects of the water delivery systems of interest.

Despite the preliminary nature of the results presented in Table 3-8, evidence that basins are already under stress with respect to their water resources can be seen in the analysis of hydrometric and hydrogeological time series data. For example, Figure 3.11 presents a time series analysis of groundwater elevations from the important alluvial aquifer in SE St Catherine within the Rio Cobre Basin. This aquifer has been used for irrigation through to the 1980s, and from the 1990s it has switched to be predominantly used for public water supply to the "new town" development of Greater Portmore.

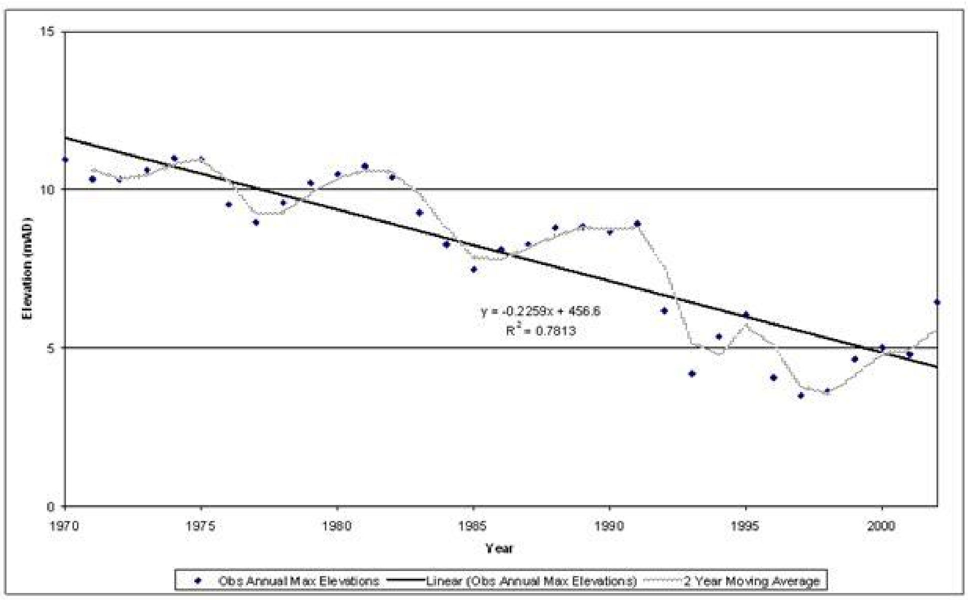


Figure 3-11: Lime Tree#2 in SE St Catherine Trend Analysis Observed Annual Maximum Series Groundwater Elevations (Data source: Water Resources Authority)

Groundwater elevations at this location are influenced by nearby production wells. To reduce these local influences, only annual maximum elevations have been plotted. These annual maximum values give an indication of what is happening regionally to groundwater elevations and thus storage within the aquifer. As can be seen, there is both a cyclical pattern as well as a long term trend of decline elevations. Thus, the annual maximum elevation at the start of the 1970s was above 10mAD, which by 2000 had declined to around 5mAD. During this 30 year period the annual maximum series shows increases in elevation during wetter periods, to be followed by declines in elevation during average and drier periods. Nevertheless, the key feature is the long term decline in groundwater elevations, indicating that abstractions from the aquifer are taking place at a greater rate than the long term recharge, indicating decline in groundwater storage and consequent groundwater elevations. This is a coastal aquifer, and therefore continuation of such trends into the future increases the risk of saline intrusion.

In the neighbouring Rio Minho basin, although there has been some recovery in water quality since the 1960s with the introduction of licensing, current analysis, based on 1990s datasets, has highlighted a decline in aquifer water quality. This is illustrated in wells for both public water supply and irrigation in Figures 3.12 and 3.13 respectively (Haiduk, pers. comm.)

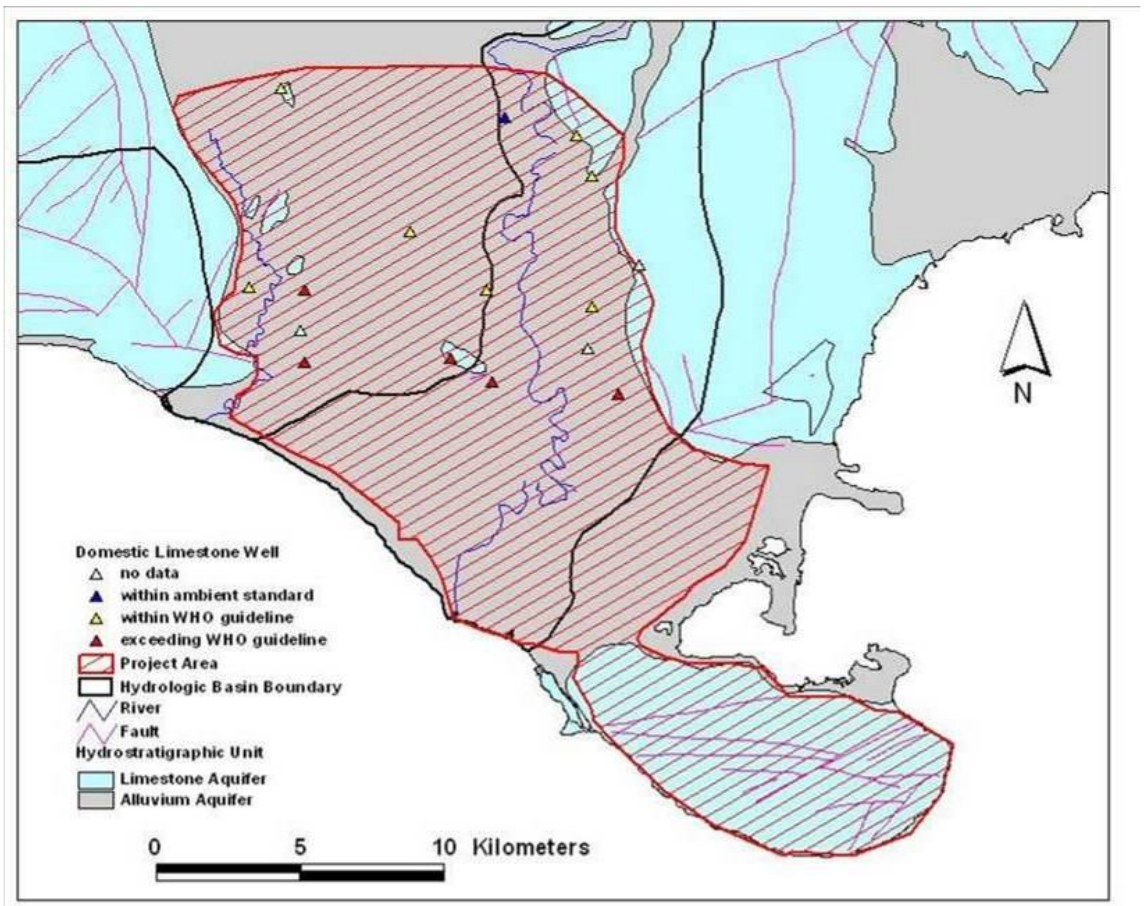


Figure 3-12: Current Water Quality Status of Limestone Public Water Supply Wells in the southern Rio Minho Basin (Haiduk, pers. comm.)

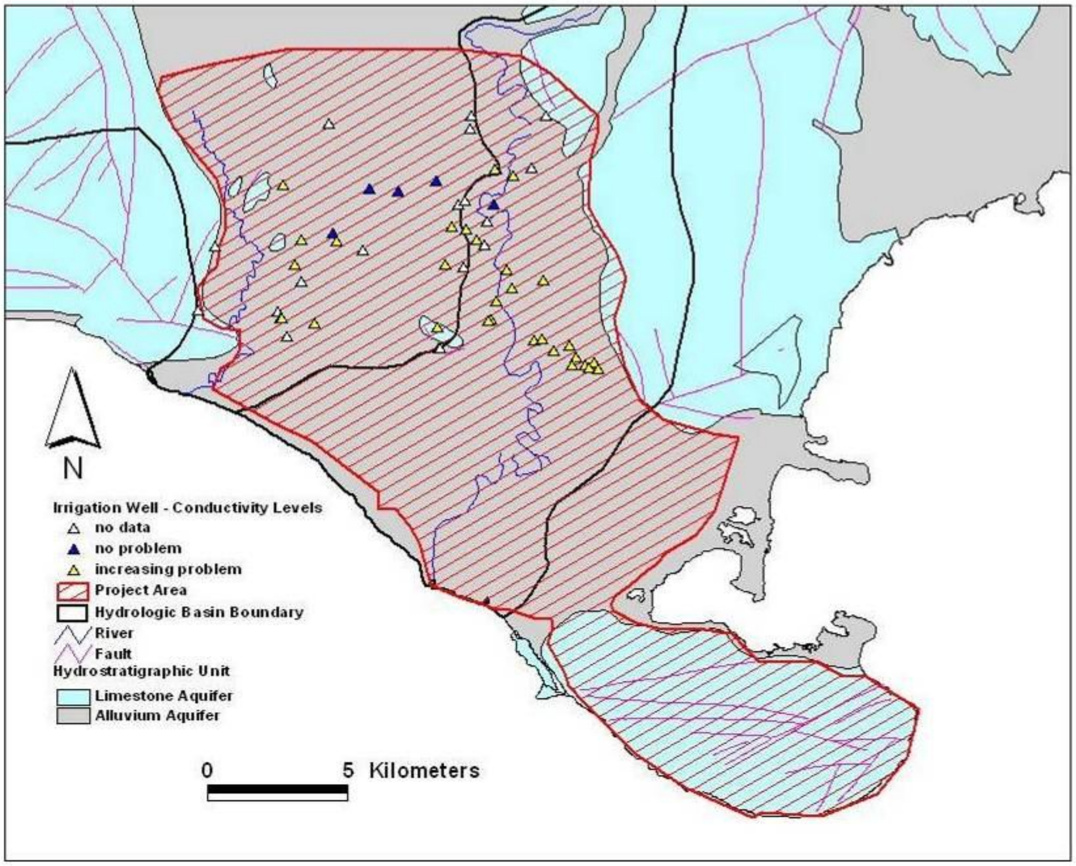


Figure 3-13: Current Water Quality Status of Limestone Irrigation Wells in the southern Rio Minho Basin (Haiduk, pers. comm.)

For the public water supply wells, five of the 17 wells display chloride levels above the WHO guideline. These wells are located at the most southern boundary of the limestone well field. In terms of irrigation, 64 wells tap the limestone aquifer within the project area. A number of wells have been abandoned due to poor water quality and the present network of wells although displaying increasing problems with water quality cover the irrigated areas. Conductivity is one of the parameters used to determine the suitability of irrigation water. Groundwater falling within a range from 0 – 750 mS/cm is considered unproblematic for irrigation. The range 750 mS/cm – 3000 mS/cm causes increased problems of salinity and above 3000 mS/cm severe problems. None of the wells in the WRA database indicate conductivity levels above 3000 mS/cm, although as can be seen in Figure 3.13, a majority of the wells display increased trends in conductivity, and therefore are at increasing risk from further water quality deterioration.

3.3.1 Public Water Supply

Issues of low levels of service of water supply to the Jamaican population are not just limited to the most vulnerable WMUs discussed earlier. As commented in the parish by parish review of NWC services in Table 3-5, there are a large number of smaller communities who rely on springs and run-of-river sources for their water supply, and which during periods of drought suffer from shortfalls in supply and reduced reliability. In many cases these problems are related to a lack of surface water storage in these localities, where source yields are driven by drought flows, and reservoir storage is not available to provide water resources during times of drought, for example, communities in Clarendon, St. Mary and St. Thomas.

In parallel with the reduced availability of water resources during drought periods, there are also problems resulting from lack on investment in water supply infrastructure. This is in terms of both development of new infrastructure as well as maintenance of existing systems. The NWC and the Rural Water Supply Company are seeking to improve their performance in these areas. A number of projects and initiatives under development and at implementation, aim to improve performance and either maintain or enhance the level of service offered to customers, within the constraints of the existing climate. The most recent plans and projects implemented include:

- Broadgate Water Supply Scheme, St Mary: Laying of new pipelines to improve the water supply for 1,850 persons
- Redwood Water Supply Scheme, St Catherine: Construction of intake pumping station, storage tank, installation of pipelines and bridge crossing to supply water to 1,650 persons
- Huddersfield / Mango Valley Water Supply Scheme, St Mary: Included laying of distribution pipelines, the construction of a re-lift station and installation of a reservoir. The system is planned to serve a population of 12,000 persons.
- Rural Water Supply Project Phase II: Refurbishment, improvement and extension of four supply schemes and introduction of leakage detection and network management programmes in each of the four areas.
- Rural Water Programme: This project is aiming to improve the sanitary and health conditions by increasing the coverage of potable and sanitation services in poor rural areas. The project consists of construction of potable systems, community and private sector participation and institutional strengthening for the Ministry of Water & Housing.
- KMA Water Supply Project: This project aims to improve service standards and meet increased water demand in South East St Catherine and Greater Spanish Town. The project includes rehabilitation of water supply facilities, including pipeline replacement, refurbishing water treatment plants and pumping equipment, water resources development and an institutional strengthening component.
- North Western Parishes Service Improvement Project: This includes a meter installation programme of 30,000 meters in western parishes of Jamaica. Other components of the project include water treatment plant rehabilitation, pipeline installation and system rehabilitation including upgrading infrastructure and leak detection and repairs. The outcome of the project should be increased customer service levels and reduced non-revenue water.

The public water supply system is also vulnerable, like all sectors of Jamaica, to the passing of tropical storms and hurricanes. Table 3-9 summarises the estimated costs to the NWC from recent tropical storm and heavy precipitation periods since 2002. Direct costs are those related to direct damages to plant and equipment, while indirect damages are related to loss of income.

Table 3-9: Estimated Losses to NWC Resulting from Recent Tropical Storms / Hurricanes

Tropical Storm / Hurricane	Direct Losses (J$)	Indirect Losses (J$)
May 2002 Storms	54,805,000	30,000,000
Hurricane Ivan	90,000,000	488,000,000
Hurricanes Dennis & Emily	Total Losses = 400,000,000	
Hurricane Wilma	47,400,000	N/A

Sources: Economic Commission for Latin America and the Caribbean (2002), Economic Commission for Latin America and the Caribbean (ECLAC) et al 2004, Planning Institute of Jamaica (2005a), Planning Institute of Jamaica (2005b) respectively

Problems commonly encountered include silting of settling tanks and filters, damage to pumps and electrical equipment, scouring of pipelines, blocked canals, landslide affecting pipelines, and flooded well fields and stations.

Where Jamaica Public Service bring in partial or national shut downs of the power grid, then only those NWC systems that have their own stand-by generators or those which are gravity driven are the most likely to stay operational with the passing of a tropical storm or hurricane. Water quality in many of the distribution systems can also be compromised, with a resultant threat to public health, as well as having impacts on household budgets where additional expenditure on bottled drinking water may be required.

3.3.2 Irrigated Agriculture

Irrigation systems operated by the National Irrigation Commission (NIC) are also vulnerable to damage by tropical storms and hurricanes. For example, NIC infrastructure was affected by both Hurricanes Dennis and Emily (2005) to the tune of J$30.4 million. Damage related to Hurricane Dennis included: flooding to pumping stations in Clarendon, St. Catherine and Trelawny; damage to access roads and structures in Clarendon, St. Catherine and St. Elizabeth; collapse of sections of the Caymanas siphon in St Catherine; lightning damage to offices; and deposition of silt and debris on open canals in St. Thomas, St. Catherine, Clarendon, St. Elizabeth and Trelawny. For Emily, damage involved: dislocation to sections of pipeline; flooding to some pumping stations along with roads and farmlands in St. Elizabeth; dislocation of 20 meters of pipeline in Trelawny; and flooding of pump houses in the Black River Upper Morass close to Santa Cruz. (Planning Institute of Jamaica, 2005a).

3.3.3 Industry

Productive sectors of the economy also suffer from the loss of water supply, either under drought conditions, which are more longer term in nature, or due to interruption in supply due to tropical storms / hurricanes. The latter are shorter in duration and may only last 1-2 weeks, for example, 13 days after the passage of Hurricane Emily approximately 380 NWC water systems (serving about 93 per cent of customers) were operating (PIOJ, 2005).

3.3.4 The Aquatic Environment

Impacts of the existing climate and climatic variability on Jamaica’s aquatic environment reflect both the occurrence of climate events such as tropical storms and hurricanes and droughts as well as human activities that increase the sensitivity of the environment and thus vulnerability of the environment and people.

Inadequate settlement patterns and land use practices have greatly altered the natural precipitation-runoff relationships so that hydrographs tend to rise more quickly and flood flows are more frequent. Accelerated erosion accompanies the rapid runoff as natural protective resources become increasingly degraded. Settlement also occurs in hazard prone solution basins and floodways which are often compromised in their ability to discharge floodwaters because of blocked sinkholes or heavily silted channels.

Figure 3-14 illustrates poor land use and settlement activities.

Coffee Plantation on steep sided hill slope

Deforestation on hill slope

Source:Trees for Tomorrow Project (2004)

Figure 3-14: Examples of Poor Landuse Practice and Settlement Activities in Jamaica

The occurrence of tropical storms and hurricanes can have a range of impacts on the aquatic environment. With the factors referred to above, these impacts are directly felt by sectors of the Jamaican population. Examples of these are summarised in Table 3-10 and illustrated in Figure 3-15.

Table 3-10: Examples of Impacts from Tropical Storms / Hurricanes on the Aquatic Environment

Attribute	Impact	Examples
Rivers / Surface Water	• Changes in river course • Sediment erosion and deposition	During Hurricane Ivan, river bank erosion and collapse was particularly marked in the Hope River Valley in Kingston where extensive settlements (legal and squatter) occupy the banks and terraces of the river in northeastern St Andrew
Groundwater	• Groundwater flooding	Widespread groundwater flooding, including properties, at Content in Manchester in 2002
Water Quality	• Increased turbidity • Pollution	Destruction of sewage treatment facilities at Yallahs following Hurricanes Dennis & Emily, with raw sewage entering Yallahs River.

Silt plume near the mouth of the Wag Water River moving in a north westerly direction towards Robins Bay following Hurricanes Dennis & Emily.

Untreated Sewage effluent flowing into Yallahs River from damaged pond following Hurricanes Dennis & Emily.

Figure 3-15: Examples of Tropical Storm / Hurricane Impacts on the Jamaican Aquatic Environment

(Source: Planning Institute of Jamaica (2005a))

3.4 Analysis of Vulnerability to Future Climate Risks for the Jamaican Water Sector

This section of the report presents the findings of the analysis undertaken to assess the risks for Jamaican water resources under future climate change and climate variability.

3.4.1 Methods and Data Availability

The results of analysis looking at the current water resources availability versus demand situation on a basin by basin basis were presented in Table 3.8. The approach adopted in this relatively simple analysis forms the basis of assessing the potential impact of climate change on these balances and from there looking at potential demand side solutions to address any increase in deficits that can be attributed to climate change. The proposed methodology is outlined in Figures 3.16 to 3.18.

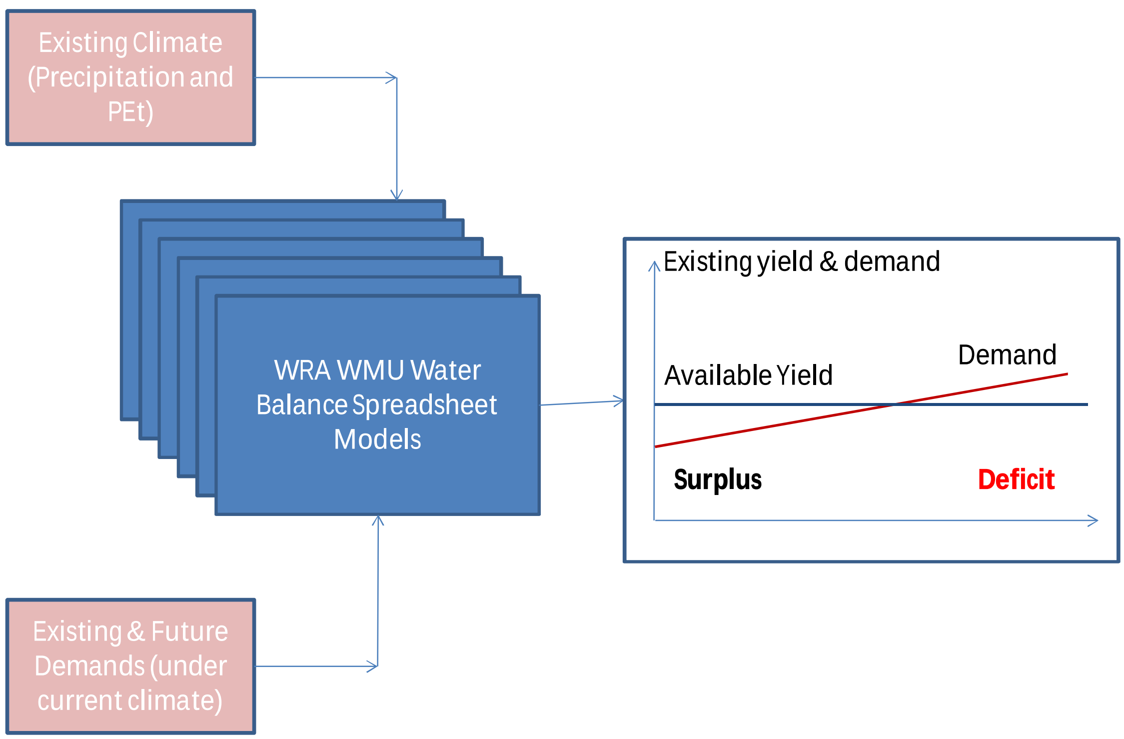


Figure 3-16: Assessment of Existing Climate Supply-Demand Balances

Figure 3.16 outlines the first stage in the analysis, which uses the existing basin (and for more detail, WMU) spreadsheet models to assess the supply demand situation under existing climate with existing and future demand estimates. This allows the tracking of the change in the supply-demand situation from, as an example, a situation of surplus to deficit as projected demands increase in the future. Note however that no account is explicitly made here for uncertainly in either the yield or demand estimates.

In Figure 3.17, the same Basin / WMU water balance spreadsheets are taken forward, but in this next stage, the inputs are future climate estimates (expressed as % changes in precipitation), for the time slice (2030s, 2050s, or 2080s for example) and scenario of interest, with associated estimates of water demand either assumed unchanged or revised across the WMU and sectors of interest for the same time slices and under the same scenarios. Note that for these estimates of scenario changes in water resources availability, it is assumed that the internal relationships between, for example, precipitation and evaporation, as well as net precipitation and surface water runoff remain unchanged.

Where it is assumed demands are unchanged under future climate, then the impact of the analysis is likely to lead to a reduction in potentially available water resources, and the bringing forward of the "tipping point" of moving from a situation of surplus to deficit. Where it is additionally estimated that demands are likely to increase under this scenario, then this tipping point will move even further forward.

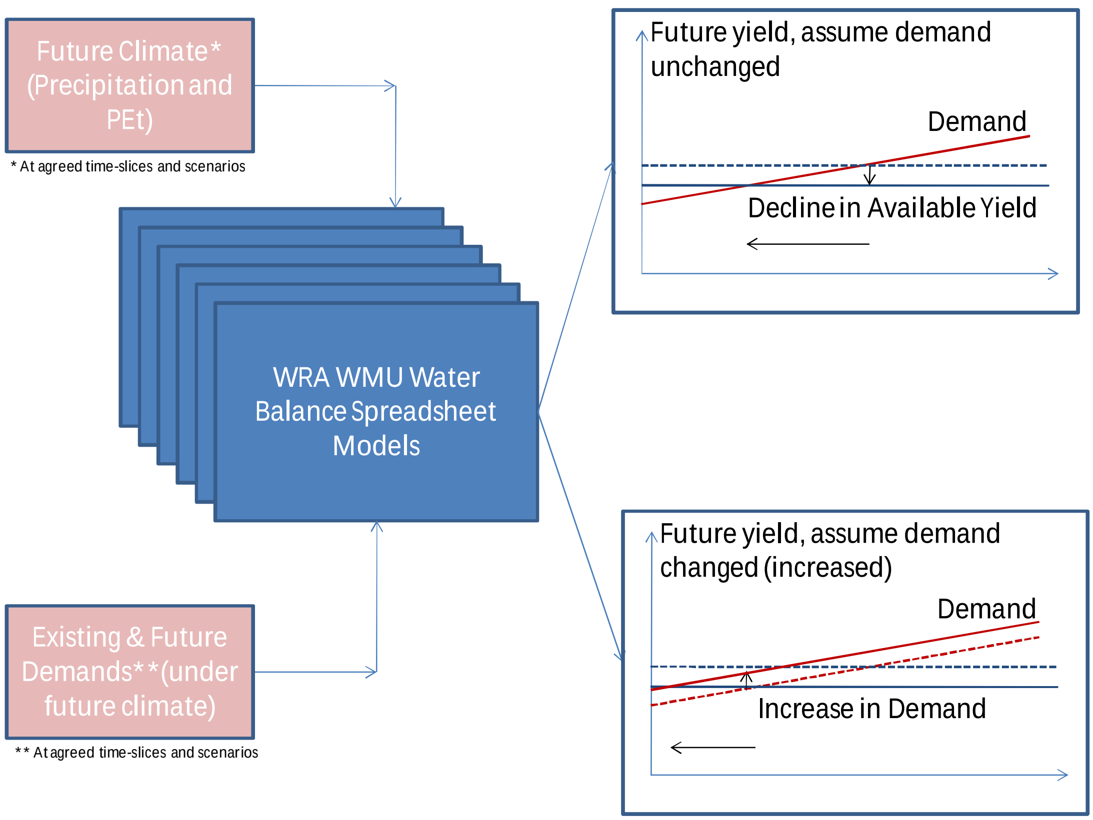


Figure 3-17: Assessment of Future Climate Supply-Demand Balances

Note that at this stage, no adaptation measures are included. This is the next stage in the analysis, as represented by Figure 3.18. However, given that the balances are based on potentially available water resources and do not include the engineering interventions and assets that bring water from the sources to the users, only demand side measures at the WMU scale can be explored here. This could include looking at the reduction in demands from improved irrigation efficiency, both in delivery as well as application on fields, and their impact on reducing deficits and WMU balances.

However, further development on the supply options could be explored in this framework. For example, it is possible to look in more detail at water supply zones within each WMU and assess their (engineering) performance against existing demand. In this way, it would be possible to include supply side factors within the supply-demand balance, taking these forward to look at the balances under climate change, and in doing so provide a framework to introduce possible engineering and other improvements to address reduced surplus or deficits under climate change scenarios.

This approach only focuses on climate change and changes to annual average conditions. Impacts of changes to climatic variability cannot be assessed using this approach. For example, investigating the impacts of changes to drought frequency and severity on water resources availability and delivery to users can only be discussed in a qualitative manner at this time until more complex modelling approaches are developed. Nevertheless, with knowledge of the locations of existing water supply schemes reliant on springs or run-of-river sources, some preliminary assessment of those communities still most at risk from both existing and future climatic variability can be made, and measures developed to address and reduce these risks.

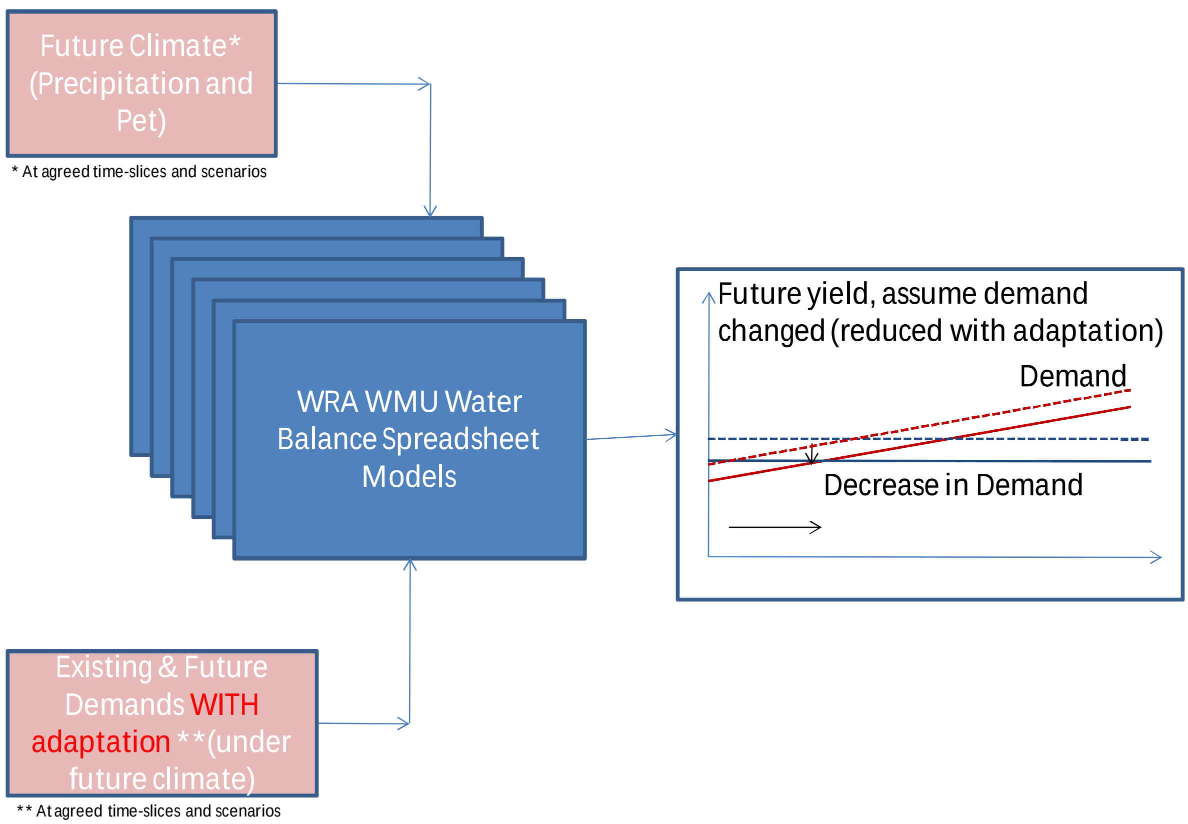


Figure 3-18: Assessment of Future Climate with Adaptation Supply-Demand Balances

3.4.2 WMU Water Availability Demand Balances under Climate Change

The methodology presented above has been used to assess the impact of climate change using the WMU analysis and results presented in Brace Centre for Water Resources Management (2005). With the publication of the final version of the Water Resources Development Master Plan Update the values presented here are subject to change. As commented above, in developing these water supply-demand balances, derived relationships from the 26 WMUs from the Brace Centre for Water Resources Management (2005) between precipitation and evapotranspiration, and net precipitation and annual runoff and 90 percentile flows are assumed to be unchanged in developing the water supply estimates of potentially available water resources.

Using this approach, water resource availability versus demand estimates for the three critical WMUs of Hope River, Rio Cobre and Rio Minho are presented in Table 3-12 for the 2015, 2030, 2050 and 2080. The balances include estimated imports and exports to provide a more complete picture of the water supply status of each WMU compared with the analysis presented in Table 3-8. Note that demand estimates for 2030 have been assumed to apply to the 2050s and 2080s. Estimated percentage changes in precipitation from the climate modelling results presented in Section 2.6 were used here, and are presented in Table 3-11 for all of the hydrological basins of Jamaica, based on overlaying the PRECIS model grids onto Jamaica's Hydrological Basins. For the years 2015 and 2030, simple interpolations has been used based on the estimates provided for the 2050s and 2080s.

Table 3-11: Best Estimate Changes in Annual Average Precipitation Across Jamaica for 2050s and 2080s

PRECIS Model Regions	Hydrological Basin	2050s % change	2080s % change
Region 1	Carabita	0	-30
Region 2	Rio Minho, Black River, Martha Brae	-10	-30
Region 3	Kingston, Rio Cobre	-10	-20
Region 4:			
Portland	Blue Mts, North	No estimate	-40
St. Thomas	Blue Mts. South	No estimate	-20
Region 5	Great River	-10	-40
Region 6	Martha Brae, Blue Mts, North	-10	-30
Region 7	Blue Mts, North	-10	-30

The results presented in Table 3-12 show the Hope River remaining in surplus through to 2080. However this is based on an assumed constant demand from 2030 onward, as well as continuing supply of the inter-WMU transfer from the Rio Cobre and Yallahs River. In the case of the Yallahs River, based on the indicative results from the streamflow SDSM results, yield from this source are at risk from possibly significant decline. For the Rio Cobre WMU, the balance remains in surplus until the 2015, after which by 2030, the situation tends to an increasing deficit, estimated to reach -100.6x10^{6}m^3/yr by 2080. Given this trend, it would be reasonable to assume that the 32.5x10^{6}m^3/yr transferred from the Rio Cobre to the Hope River would come under increasing competition to meet local water demands, and thus the situation for Kingston tends to be worse than that depicted in the analysis presented in Table 3-12.

In the case of the Rio Minho WMU, the results presented in Table 3-12 indicate a surplus in the water balance until the 2050s, after which a deficit of -67.6 x10^{6}m^3/yr is estimated for 2080.

Table 3-12: Estimated Water Resources Availability – Demand Balances for the Kingston, Rio Cobre and Rio Minho Basins (10^{6}m^3/yr)

WMU		**Period**				
		Current	**2015**	**2030**	**2050**	**2080**
Hope River	Total Available Resources	74.2	70.9	65.9	57.6	42.6
	Import	67.0	67.0	67.0	67.0	67.0
	Demand	87.6	92.1	96.8	96.8	96.8
	Export	0	0	0	0	0
	Balance	**53.6**	**45.8**	**36.1**	**27.8**	**12.8**
Rio Cobre	Total Available Resources	483.6	471.5	453.3	422.9	362.3
	Import	0.0	0.0	0.0	0.0	0.0
	Demand	305.2	389.2	430.4	430.4	430.4
	Export	32.5	32.5	32.5	32.5	32.5
	Balance	**145.9**	**49.8**	**-9.6**	**-40.0**	**-100.6**
Rio Minho	Total Available Resources	266.1	257.3	244.2	222.3	134.7
	Import	9.0	9.0	9.0	9.0	9.0
	Demand	175.8	195.9	203.0	203.0	203.0
	Export	8.3	8.3	8.3	8.3	8.3
	Balance	**91.0**	**62.1**	**41.9**	**20.0**	**-67.6**

Sources: Brace Centre for Water Resources Management (2005) & US Army Corp Engineers (2001)

As commented above, for the Hope River WMU / Kingston, the results perhaps show an overly optimistic situation, given the assumed continuing supply of water from other basins. One of the main sources of this import is the Rio Cobre basin, which as shown, is projected to be moving into a deficit situation which will result in increasing competition for water resources. Therefore, it is important that the Kingston Basin seeks to reduce its reliance on these existing imports and either develop new resources (e.g. desalination of Ferry Springs) /imports from neighbouring basins or introduce significant efforts to address the projected growing demands. This includes measures within the domestic, industrial and commercial sectors to reduce per capita water use, as well as taking a proactive stance to reduce unaccounted for water (a major component of which is leakage). As commented earlier, the NWC is adopting such measures island-wide with a metering programme, as well as the introduction of measures to address unaccounted for water.

For the Rio Cobre, the demands are mainly agricultural. At the time these demand estimates were prepared, the area under sugar cane cultivation was significantly larger, and it is very likely that with both this decline and the recent introduction of more efficient irrigation methods that the demand estimates for this basin will be very much reduced. However, it is important to note that the introduction of more efficient irrigation methods may lead to a reduction in irrigation based recharge and therefore a reduction in total available resources. Although demands are mainly from agriculture, non-agricultural demands are likely to increase especially in the southern part of the basin associated with new highway development and the zoning of land either side of the highway for development. For the Rio Minho, the situation is comparable, with agricultural remaining the main sector for water demands, but with an increasing urban public water supply demand from new growth.

Therefore, with the publication of the Water Resources Development Master Plan Update in late 2008, this analysis will require review and revision. With the expected advances in both resource and demand estimates, this will allow a more thorough basis on which to develop, investigate and assess the feasibility of adopting WMU wide demand side measures to counter both existing and projected deficits under climate change. This will support the required analysis that is also needed to investigate supply side measures.

The projections of water resources availability and demand that are presented in Brace Centre for Water Resources Management (2005) were prepared before the GoJ, through the Jamaica Bauxite Institute (JBI), granted Jamalco a Special Exclusive Prospecting License (SEPL) to assess the extent of bauxite deposits in the Parish Trelawny in 2006. Following the granting of this license, concerns have been raised regarding the potential risk to the environment of the Cockpit Country and to key water resources, given that it is understood that the Cockpit Country is an important of source of recharge for a number of the island's major rivers, including the Martha Brae to the north, the Hector's River and Black River systems to the south, and the Rio Bueno to the east. It has been stated by the JBI that no mining will take place for at least 20 years in Trelawny, and that a policy decision was made in the early 1990s that no bauxite mining or alumina processing would be done within the core area of the Cockpit Country, in keeping with the boundary of the proposed National Park[7]. However, this does leave open the possibility of development outside this core area. As discussed in Section 3.1.6, bauxite mining has had negative impacts on water quality, and is also a major water consumer in Parishes where it is currently located. The hydrology and hydrogeology of the Cockpit Country is not fully understood. The full magnitude of any impacts from the development of bauxite reserves in this part of Jamaica presents a high level of risk and uncertainty.

3.4.3 Impacts on Water Resources / Water Supply from Increased Climate Variability

As shown in Table 2.1, there is strong modelling evidence to suggest that by the 2080s there will be an increase in the frequency of dry seasons across spring (MAM), summer (JJA) and autumn (SON) with an annual increase in % dry seasons of 39% (comparing 1980-1999 with 2080-2099).

Section 2.2.3.2 also presents results which suggest an increase in the intensity of stronger tropical cyclones but a decrease in the number of weaker storms, within an estimated increase in North Atlantic tropical cyclone activity of 34% between the start and end of the 21st Century. However, more recent research has

7 NO PLANS TO MINE IN THE COCKPIT COUNTRY, Parris A. Lyew-Ayee, Executive Director, The Jamaica Bauxite Institute, November 27, 2006

been less conclusive on changes in hurricane frequency and severity and links with climate. Some studies have suggested that if the frequency of tropical storms remains the same over the next century, there will be an increase in the number of more intense category 5 storms (http://www.gfdl.noaa.gov/~tk/glob_warm_hurr.html accessed 13 July 2008).

Thus, the regional climate projections are indicating a general increase in the frequency of extreme events such as droughts, floods and increased intensity of heavy rain events.

Results from the specific Statistical Downscaling methods reported in Section 2.5.4 follow these general trends with respect to wet-day %, wet spell length and dry spell length for PRECIS regions 3 and 5. These results are reproduced here in Table 3-13.

Table 3-13: Best Estimate Changes in Precipitation Variability Across Jamaica for 2050s and 2080s

PRECIS Model Regions	2050s % change	2080s % change
Region 5		
Wet day %	-24	-44
Wet spell length	-7	-10
Dry spell length	32	80
Region 3		
Wet day %	-2	-7
Wet spell length	-3	-6
Dry spell length	1	4

Clearly these results indicate the potential for major geographical variations across Jamaica with respect to changes in climatic variability which requires further analysis on the basis of more data sets.

This increased climate variability is likely to have a number of impacts on, for example, water supply:

1. Increasing length of dry season will increase the vulnerability of those communities who are supplied by single spring or river sources. Lower annual average precipitation linked with a longer dry season is likely to reduce the safe yield from these sources.

2. Increased frequency of intense rains also has an impact on water supply, as these rains are likely to result in watershed flows associated with high sediment loads. Increased sediment loads will place increased requirements on water treatment facilities to treat water to an adequate standard before entering supply. Therefore, upgrading of treatment facilities may be required, as well as the need to introduce higher cost treatment processes (capital investment with higher operating costs).

3. Changes in the climate regime is likely to impact the hydrological regimes across basins, including impacts on groundwater recharge. On a long term annual average basis, decreased precipitation with increased temperatures and evapotranspiration will reduce potential groundwater recharge. It is also the case that if the precipitation that does occur is concentrated in a smaller number of events, then a greater proportion of this may not be available for recharge, but will be taken up to address increased soil moisture deficits, as well as leading to the greater proportion of direct

runoff. Further watershed based hydrological studies are required to assess the impacts of climate change on Jamaican basin hydrological / hydrogeological regimes and water balances.

4. The projected increased intensity of hurricanes will obviously increase the potential losses of infrastructure with the water sector, as well as revenue after the event and during the recovery period.

There are also wider watershed and catchment management issues associated with increased climate variability. As commented above, increased frequency of more intense precipitation events has an impact on sediment erosion, movement and transport within basin river systems. Poor land use and agricultural practices can increase the vulnerability of watershed slopes to soil erosion and sediment transport. Therefore, it is important that the work within the IWCAM project is developed to identify best management practices (BMPs) in these areas and methods and models of transfer of these BMPs to other basins within Jamaica. This is clearly important with respect to non-irrigated agriculture, where increases in the frequency of more extreme climatic and hydrological events will have a potentially disproportionate impact on this sector than irrigated agriculture.

As commented in Section 3.2.2 irrigated agriculture accounts for only 9.3% of cultivated lands, and is principally focused on the production of crops and their products for export. Non-irrigated crops are important for the wider rural community in Jamaica and in the provision of locally grown crops and foodstuffs for the local Jamaican market. This is an important sector with respect to food security, but it remains vulnerable to existing climate and climatic variability. Given the likely increase in climatic variability, the vulnerability of this sector is likely to increase unless measures are adopted to improve its resilience and adaptive capacity to these climatic driven hazards.

In the case of HEP generation, as commented in Section 3.2.4, there is the potential to increase Jamaica's HEP production to 100MW. There are significant financial resources involved in developing such schemes, with any decision to develop a project based on financial as well as hydrological analysis. Given the long term nature of such investments, potential changes in the hydrological regimes under climate change present another uncertainty and this is likely to decrease the attractiveness of such schemes for developers.

3.4.4 Changes in Flooding Vulnerability

Within each of the main flooding regions of Jamaica identified in Table 3.1, the following impacts, and changes in vulnerability, are likely to result from forecast climate change

- Eastern Jamaica (Blue Mountains): Likely increase in frequency of high intensity precipitation events will increase frequency of occurrence of landslides and floods.

- Central Jamaica: No consensus on change in frequency of occurrence of tropical storms and hurricanes under climate change. However, likely that severity will increase, thus threat from flooding due to these events is likely to increase.

- Western Jamaica (Karst regions): Likely increase in frequency of high intensity precipitation events will increase frequency of occurrence of floods.

- Coastal Areas: Sea level is projected to increase by between 0.18m to 0.59m by the 2090s across the SRES scenarios against 1990 elevations (IPCC, 2007a). Others have estimated an increase in global mean sea level of between 0.5m and 1.4m over the same period. (Rahmstorf, 2007). This increase, with the likely increase in the severity of hurricanes and tropical storms, will lead to an increase in the potential storm surge elevations, thus putting a greater area and populations at risk from coastal flooding. Those coastal areas of Jamaica most at risk from sea level rise are presented in Figure 3-20. In this figure, a simple analysis has been undertaken, which shows areas falling within the 0.6m and 1.4m contours above existing mean sea level. As can be seen, these areas include significant population centres such as portions of Kingston and a large area of Portmore.

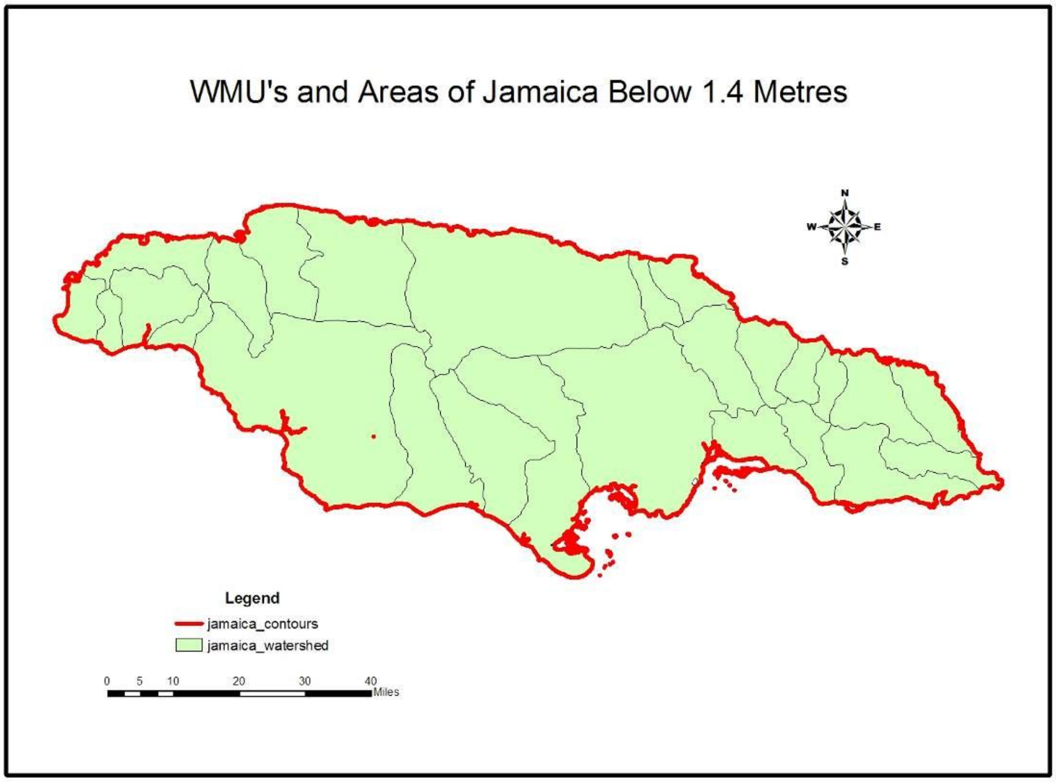


Figure 3-19: Areas of Jamaica at 0.6mASL and 1.4mASL

Given the likely impacts of projected climate change on flooding risk, there are a number of key measures that need to be taken to minimise both existing and future vulnerabilities to flood risk. Many of these are related to moving people and property from the paths of these events before they occur, as well as having and implementing the appropriate planning tools and mechanisms in place to stop development in flood risk areas.

3.4.5 Vulnerability to Sea Level Rise

Coastal aquifers remain a significant source of water supply for both the agricultural and non-agricultural sectors, especially in the Rio Cobre and Rio Minho Basins. Groundwater was in the past an important source of water supply in the Kingston Basin, but over abstraction resulted in problems of saline intrusion. Water quality problems were compounded in the Kingston Basin by sewage contamination of the aquifers.

As commented above, the projected increases in sea level within the Caribbean and around the coasts of Jamaica varies from 0.18 m. to 0.59 m by the 2090s (IPCC, 2007a). Others (Rahmstorf, 2007) have given higher magnitudes of 0.5 m to 1.4 m, against 1990 sea level. Given the coastal location of many of Jamaica's wells, for agriculture, public water supply and industrial use, such increases in sea level increase the potential risk of saline intrusion into the coastal aquifers and thus the vulnerability of these wells in terms of negative water quality impacts. Figure 3.21 shows the locations of Jamaica's wells with respect to those areas falling with the 0.6mASL and 1.4mASL contours. This clearly demonstrates the vulnerability of many of the coastal wellfields to sea level rise, saline intrusion and impacts from storm surges.

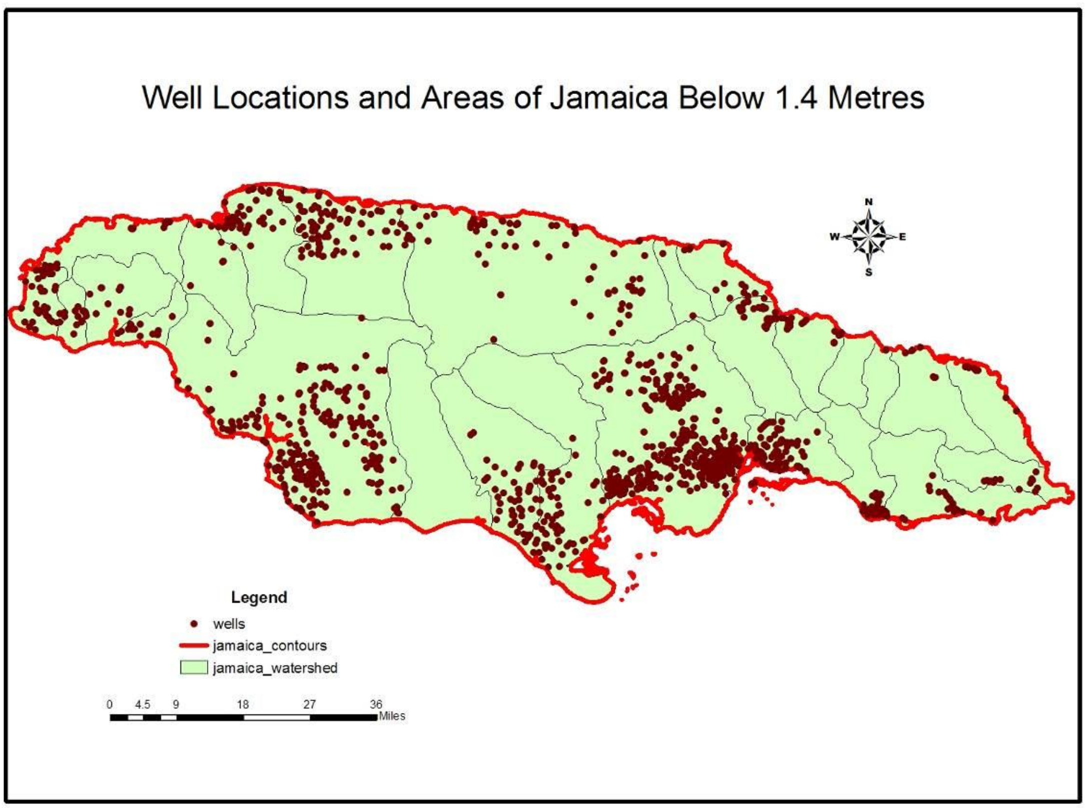


Figure 3-20: Wellfield Locations and Areas of Jamaica at 0.6mASL and 1.4mASL

There is a history of poor water resources management in these coastal aquifers. For example, abandonment of wells for public water supply, in the alluvial aquifer of the lower Rio Cobre basin due to saline intrusion as a consequence of over abstraction.

The Mainstreaming Adaptation to Climate Change Programme (MACC) has provided funding for the implementation of a pilot vulnerability and capacity assessment project (VCA) in the water sector in Jamaica. This project has selected as the study area the Vere Plains of southern Clarendon (Haiduk, pers. comm. 2008). The objectives of the study are to identify:

- How a predicted sea level rise of 0.5 m and 1 m would move the saline front inland and change groundwater quality;
- The response strategies including policy intervention that would be required to minimize effect if any; and
- The requirements for monitoring precipitation intensity in south Clarendon.

The project area is illustrated in Figure 3-22, and shows the locations of pumping wells in both the limestone and alluvial aquifers within the plains. Within the project area, wells tapping the southern section of the limestone aquifer have been abandoned due to high salinity, and there remain wells within this part of the project area with salinity levels exceeding the WHO aesthetic guideline concentrations for sodium and chloride.

Work on this project has stalled, but it will be completed by the end of September 2008. This delay is unfortunate, as the findings of this project would have provided significant and useful information on the risks and vulnerability to groundwater resources in Jamaica from sea level rise and brought forward technical and policy recommendations to develop adaptation strategies and programmes to address, manage and reduce vulnerability that would have been included within this report.

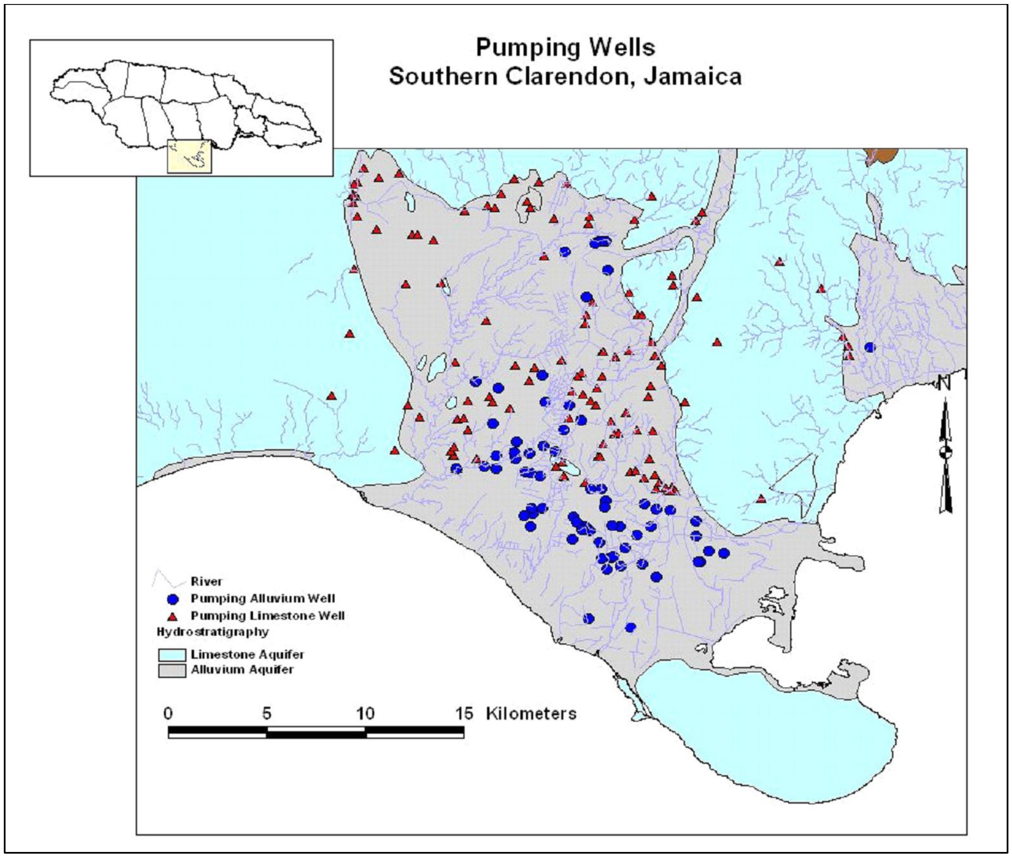


Figure 3-21: MACC VCA Project Area

(Source: Haiduk, pers. comm. 2008)

3.4.6 Impacts on River Low Flows

Impacts on river low flows from climate change and increased climate variability can be inferred in a preliminary manner. With respect to impacts from climate change and mean climatic conditions, some preliminary results are presented in Table 3-14 looking at potential future changes to the 90 percentile low flow (Q90), expressed as a percentage of existing mean annual flow for each basin. These results are based on the basin / WMU water supply-demand balance calculations that were summarised in Section 3.3. Here the same internal relationships between net precipitation and Q90 were applied to look at estimated changes in Q90 from the existing values through to 2015, 2030, 2050 and 2080 under the same changes in annual average precipitation from the climate modelling studies, and as stated earlier, are subject to revision with the publication of the updated Water Resources Development Master Plan in late 2008. Note that estimates for some of the smaller WMUs are not presented as they tended to zero Q90 flows when using the simplified approach on which this analysis is based.

All basins show a decline in the Q90 flow expressed as % of existing mean annual runoff. Changes are relatively small until 2050, after which the impacts of the projected declines in annual average precipitation start to be seen in these results. For example, for the Hope River WMU, the results tend to zero low flows by 2080, while for the Rio Cobre the results indicate a decline in the Q90 flows from this WMU from 36% to

28% of existing mean annual flow by 2080. In the case of the Yallahs WMU, the change is from 12% to 6% of existing mean annual flow by 2080. These results also offer some support to the SDSM analysis for the Hope River, Rio Grande and Great River presented earlier in Section 2.4.2.

These results, and analysis upon which they are based, would be expected given the estimated decline in mean annual precipitation from the climate modelling results, and the simple relationships developed between net precipitation and Q90. Nevertheless, given both the reduction from the climate modelling in mean annual precipitation, and also consistent results showing a decline in precipitation in the months of June-July-August, changes in low flow regimes for Jamaican rivers under climate change and increased variability are to be expected.

Table 3-14: Estimated Changes in Basin / WMU Q90 Flows, expressed as % Existing Mean Annual Flow

Basin/WMU	2005	2015	2030	2050	2080
I – Blue Mountain South					
15-Plaintain Garden River	8%	8%	7%	7%	5%
16-Morant River	23%	22%	21%	20%	16%
17-Yallahs River	12%	11%	10%	9%	6%
II – Kingston					
18-Hope River	11%	9%	7%	4%	0%
III- Rio Cobre					
19-Rio Cobre	36%	36%	34%	32%	28%
IV – Rio Minho					
20 – Rio Minho	13%	12%	12%	11%	8%
21 – Milk River	14%	13%	13%	12%	9%
22 – Gut-Alligator Hole River	65%	n/a	n/a	n/a	n/a
V – Black River					
23 – Black River	37%	36%	35%	33%	25%
VI-Cabarita River					
24 – Deans Valley River	33%	n/a	n/a	n/a	n/a
25 - Cabarita River	53%	53%	53%	53%	29%
26 – New Savanna River	3%	n/a	n/a	n/a	n/a
1 – S. Negril-Orange River	14%	n/a	n/a	n/a	n/a
VII – Great River					
2 – Lucea River	1.4%	1.4%	1.3%	1.2%	0.5%
3 – Great River	16%	15%	14%	13%	7%
4 – Montego River	10%	10%	9%	8%	4%
VIII – Martha Brae River					
5- Martha Brae River	35%	34%	33%	30%	21%
IX – Dry Harbour Mountains					
6 – Rio Bueno-White River	39%	38%	37%	35%	26%
X – Blue Mountains North					
7 – Rio Nuevo	27.1%	n/a	n/a	n/a	n/a

Basin/WMU	2005	2015	2030	2050	2080
8 – Oracabessa-Pagee River	27%	25%	22%	18%	0%
9 – Wagwater River	9%	8%	8%	7%	4%
10- Pencar-Buff Bay River	11%	11%	11%	10%	5%
11 – Spanish River	15%	14%	14%	12%	7%
12 – Swift River	11%	11%	10%	9%	4%
13 – Rio Grande	10%	10%	9%	9%	6%
14 – Drivers River	24%	24%	23%	21%	13%

Reductions in low flows in a river system, as shown in Table 3-14, indicate the placing of additional stress on the aquatic environment. For example, a reduction in Q90 flows implies shallower water depths and reduced stream flow velocities. This may reduce oxygen concentrations and raise water temperatures, resulting in stress being applied to aquatic animal species. Clearly these are preliminary observations, and further studies are required looking at the potential timing of stream flow changes (reductions) and vulnerable life stages of key aquatic species.

3.5 Increasing the Adaptive Capacity of the Water Sector under Climate Change

The water sector in Jamaica is vulnerable to the existing climate and climatic variability. This can be seen with the impact of flooding events, either localised or across large parts of the country linked with tropical storm events / hurricanes, as well as droughts related to global / regional climatic phenomena such as El Nino/Southern Oscillation (ENSO).

Projected changes in Jamaican climate by the end of the century will result in the increased frequency and severity of dry spells / droughts, the increased intensity of tropical storm events / hurricanes, as well as a change in annual average climatic conditions with decreased annual average precipitation, increased evaporation and likely increased wind speeds.

To reduce the vulnerability of the water sector to these likely changes in climate requires the adoption of a pro-active approach to both integrated watershed and water resources management. There are already a number of initiatives and plans / programmes in place that can form the core of this adaptation to climate change. These include the IWCAM project as well as the continuing work that is being undertaken by the Forestry Department through the implementation and continuing development of the National Forestry Plan.

Although flood hazard maps do exist for a number of watersheds, further modelling and mapping exercises are required to increase the coverage of these maps and the promotion of their existence to the relevant national and parish planning agencies and bodies. This is especially important with respect to the planning and location of key national assets given the likely range of sea level rise during this century coupled with tidal surges associated with tropical storms / hurricanes.

This enforcement, set within a wider planning context, must be based on the development of a National Physical Plan for Jamaica.

There is also a need to regularly review engineering design procedures to ensure that both existing and future structures such as bridge crossing and culverts have been designed and built with enough capacity to pass flood waters at agreed magnitudes.

Within the area of water supply planning and delivery, an integrated approach has been proposed here that looks at both water resources availability as well as demand. However, further work is needed to bring within the approach the engineering aspects and constraints related to delivery of water from source to customer at this planning level. This also needs to move away from an approach that looks solely at annual average conditions, but develops into looking at system performance under agreed drought conditions for a range of climate change scenarios. Under such an approach, it would then be possible to focus on a range of potential measures / programmes of measures that may be required to address supply-demand deficits projected for these scenarios.

Such an approach is conditional on the availability of hydrological / groundwater models that can be used to provide estimates of source yields under existing climate. Climate change impacts on yield estimates can then be assessed by perturbing inputs using results from the climate modelling studies. Therefore, there is a need for investment in the development of these models, which is conditional on the availability of the technical capacity within the relevant organisations and institutions. This is likely to require the pooling of available resources, both technical and financial, but does offer the opportunity of an agreed set of modelling approaches and tools across the key water sector stakeholders. These models can be used in both a planning as well as operational mode, using the outputs from climate models looking to the 2030s and beyond, and also shorter term predictions of likely climate in the next 1-2 years respectively.

At present, even without the modelling approaches suggested above, support for measures to increase water use efficiency must continue. This is both for the agricultural sector as well as for public water supply.

Monitoring is a key aspect to understanding what is happening within the watershed. Therefore, investment in the meteorological / hydrological / hydrogeological monitoring networks must be a priority. This includes quantity as well as quality. It is important that a co-ordinated approach across agencies is adopted to maximise return on this investment and avoid duplication of effort. It is also important that the collected data, once it has been through the necessary Quality Assurance/Quality Control checks is made available to all stakeholders. The WRA has a GIS web-based database system that can be accessed through its website that provides an existing platform for stakeholders to view and download these kinds of data. The continued investment and growth of this service must be supported, with, for example, incorporation of data held by other government bodies such as the Met. Service (precipitation and evapotranspiration) into this platform.

Unless and until the main water sector government institutions and agencies (WRA, NIC, Met. Office, Forestry Dept., relevant functions of NEPA) are brought together within a single Ministerial responsibility, there is a need for these agencies, in partnership with others such as the NWC, to present a unified approach / coalition on key water sector strategic issues to their respective ministers. This is to assist with the development of co-ordinated GoJ policy with respect to the water sector and the development of adaptation policies, plans and programmes to manage the impacts of climate change.

There may be an implied assumption that the adoption of the measures to increase the adaptive capacity of the water sector outlined above will assist directly and / or indirectly with a similar increase in the adaptive capacity of the aquatic environment / flora and fauna. This may not be the case, and therefore it is important that those bodies and organisations with such specialist knowledge are included within the key stakeholder group in the development of the water sector adaptation policy to ensure that the role and importance of the aquatic environment is explicitly considered.

Much of what has been presented so far will involve the investment of significant funds by the Government of Jamaica, or the accessing of funds as low interest loans or grants from bi-lateral or multi-lateral lending agencies. Such applications for funding will require supporting economic evidence on the benefits that such investments will bring to Jamaica. Therefore, it is crucial that mechanisms are developed and put into place that will provide the necessary socio-economic tools on which to assess the potential range of measures and programmes of measures that would form the adaptation strategy.

4 INSTITUTIONAL REVIEW

4.1 Institutional Map

The institutional map takes account of all agencies public and private which relate to the several functions and resources considered a part of the water sector.

A wide range of institutions are involved in water resources management. These include:

(i) Cabinet
(ii) Ministry of Water and Housing
(iii) Water Resources Authority
(iv) NEPA
(v) NWC
(vi) NIC
(vii) Forestry Department\
(viii) Parish Councils
(ix) Ministry of Health and Environment
(x) ODPEM
(xi) Ministry of Local Government
(xii) NWA
(xiii) Private Sector

4.1.1 Cabinet

Section 9(1) of the Constitution establishes a Cabinet for Jamaica. The Cabinet consists of the Prime Minister and other Ministers as the Prime Minister may from time to time consider appropriate. Cabinet has key responsibility for approving legislation for submission to Parliament as well as Policy documents such as the Water Sector Study.

The Constitution of Jamaica provides that the Cabinet is the principal instrument of policy and is charged with the general direction and control of government. By virtue of Constitutional provisions, the Prime Minister and other Ministers are appointed to serve in the Cabinet and assigned responsibility for various subjects and departments of Government. Ministries are organized, staffed and resourced to provide the requisite support to Ministers to plan and implement policy decisions in relation to the assigned subjects and departments. Planning and implementation of Government policy is also undertaken by statutory bodies falling under the portfolio responsibility of Ministers.

Under section 69 (2) of the Constitution, the Cabinet is the principal instrument of policy charged with the general direction and control of the Government of Jamaica and shall be collectively responsible therefore to the Parliament.

4.1.2 The Cabinet Committees

Cabinet has established seven advisory committees to strengthen and support its policymaking and planning processes. Each is chaired by a member of the Cabinet. They are as follows: The Development Council, Human Resources, Committee Infrastructure, the Land and Environment Committee, the Inter-

Ministerial (Policy) Committee on Administrative Reform, International Relations and Trade Committee and the Legislation Committee is primarily responsible for deciding the Government's legislation programme for each financial year and for reviewing Bills and referring them to Cabinet for approval and subsequent tabling in Parliament. Policy issues relating to water would be considered by the Land and Environmental Committee. New legislation affecting the water sector has to be approved by the Legislation Committee.

4.1.3 Ministry of Water and Housing

The Ministry of Water and Housing has responsibility for policy development for the water sector. The Ministry is also involved in coordinating the activities involved with water management.

A National Water Policy was developed primarily by the Ministry of Water and its institutions and approved by Cabinet in January, 1999. It forms the policy framework within which the Water Sector Strategy & Action Plan and the Water Resources Strategy & Action Plan are being developed. It is envisaged that the analyses employed in the development of the respective strategies and action plans may result in the recommendation of refinements to the National Water Policy.

The Ministry of Water is the single institution responsible for the promulgation of a National Water Policy, with the authorization of the Cabinet and Parliament. The first Ministry of Water was established in 1998 with a view to focusing attention on the provision of acceptable levels of water and sewerage services islandwide within the short to medium term.

4.1.4 Ministry of Agriculture

The Ministry of Agriculture currently has responsibility for the National Irrigation Commission. The Ministry will therefore be integral to any policy decision affecting irrigation water. The Forestry Department falls under the purview of the Ministry.

4.1.5 Ministry of Transport and Works

The proposed new institutional arrangement for flood water control will result in the National Works Agency being responsible for the implementation of Flood-water Control Plans.

4.1.6 Water Resources Authority

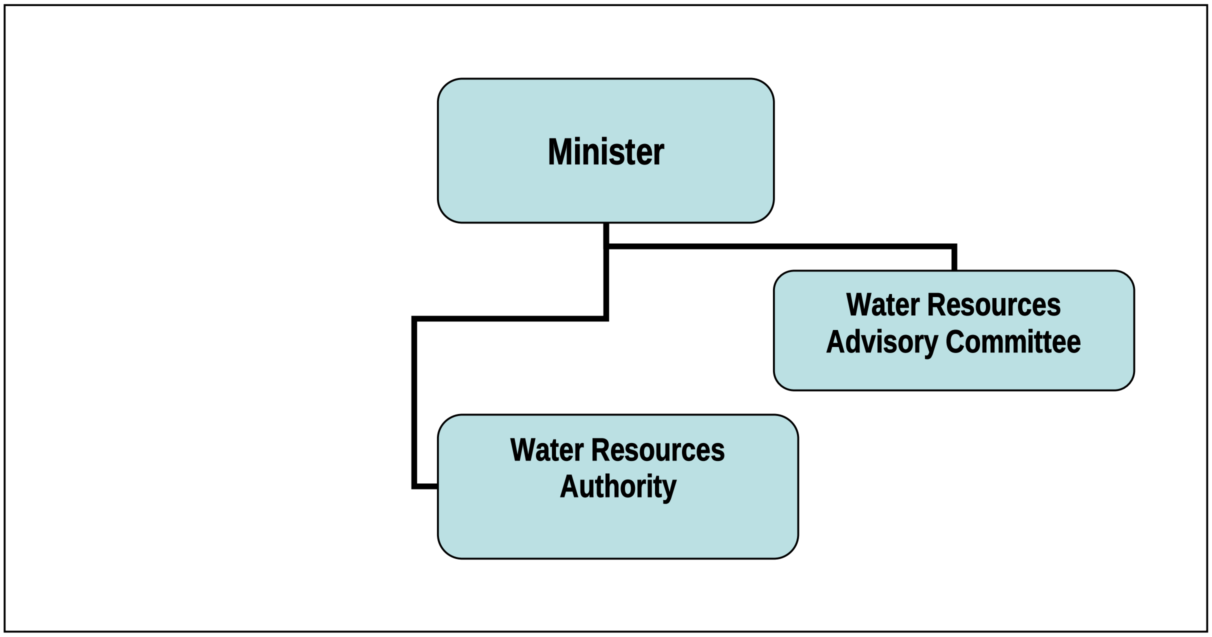
WRA's core mandate is to regulate, allocate, conserve and generally to manage Jamaica's water resources. In order to discharge its mandate WRA is empowered to:

a) Obtain, compile, state and disseminate water resources data.
b) Exercise planning functions in relation to the Master Plan and the Water Quality Control Plan.
c) Allocate water
d) Control the quality of water

WRA's power to allocate water is of central importance to its role and function in the water sector. In this regard WRA exercises a coordinating role over NWC and NIC through its allocation power.

WRA serves mainly as a technical advisor to Government and Government Agencies. WRA does little investment in the water resources sector as this is done by NWC and NIC.

The Water Resources Act (1995) sets out the basic organizational structure that governs the operation of the WRA as follows:-



WRA seeks to reform and improve the current mandate by:

(a) Introduction of technical performance standards, which will be used to evaluate annually the effectiveness of the hydrological data program for each hydrological basin and the general performance of the WRA. This has been implemented and is being used to evaluate the organization's performance.

(b) Rehabilitation and expansion of the hydrological data network to provide adequate and reliable data for assessing the water resources of each hydrological basin and overall water availability. This project continues to be under funded each year and the Authority is continuously playing catch up with its monitoring network. The monitoring network is critical to the success of all water projects and the sustainable management of water resources.

(c) Development and implementation of a National Water Quality Program to provide information on trends and status of ground and surface water quality, delineation of areas where pollution is occurring and the development of actions to mitigate contamination.

(d) Revision and promulgation of the Water Resources Development Master Plan. Cognizance will be taken of the water supply plans of the National Water Commission and the National Irrigation Commission. The Inter-American Development Bank has agreed to provide grant funds for the execution of the upgrade of the Master Plan.

4.1.7 The National Environment and Planning Agency (NEPA)

The National Environment and Planning Agency was created through the merger of the former Town Planning Department and the Land Development and Utilization Commission and the Natural Resources Conservation Authority in 2001.

The establishment of this Executive Agency sought to ensure the protection and efficient use of limited human and physical resources; a more integrated approach, including public participation, to planning for sustainable development; resolution of overlaps in formulation and enforcement of environmental and planning policies and legislation to ensure effective overall management of land. This institutional framework was designed to help resolve conflicts between environmental and development interests when considering appropriateness of development proposals. One objective was to significantly reduce the time period to review and process applications for environmental, subdivision and development approval.

NEPA as the leading environmental and planning agency has a key role in the sustainable use of water resources. It also plays a central regulatory role in water quality and the control of water pollution. NEPA has an enforcement branch which is responsible for the monitoring and enforcement of all pollution issues including matters relating to water quality. NEPA oversees all inter-agency matters affecting water quality and would be responsible for enforcing the statutes affecting water quality.

NEPA is responsible for the administration of the following Acts: Natural Resources Conservation Authority Act; Watershed Protection Act; Beach Control Act; Wildlife Protection Act; Town and Country Planning Act; Local Improvements Act; Land Utilization Act.

NEPA and the Water Resources Authority have responsibility for developing and monitoring standards relating to water quality. Some of these standards have already been promulgated, while others are still being developed. A Memorandum of Understanding (MOU) exists between NEPA, WRA and the Ministry of Health on water quality.

4.1.8 National Water Commission

The main sectoral institution responsible for water and sewage operations in Jamaica is the National Water Commission (NWC). NWC was formed in 1980 through a merger of the Kingston Water Commission (KWC), and the National Water Authority (NWA) which was responsible for water services provided by the Parish Councils (local government) throughout the country. This amalgamation resulted in the merging of some major systems islandwide under one authority. NWC's mandate is set out in the National Water Commission Act, in which it is given the task to provide water supply services islandwide. The exception is the small gravity fed rural water supply systems, which were transferred back to the parishes in 1990. NWC is also responsible for the collection, treatment and disposal of urban sewerage systems. NWC's mandate is intended to ensure the application of full cost recovery principles, and the implementation of economically viable investments.

NWC has grown rapidly and was successful in extending water supply service coverage to 82% of the population by 1998. The number of accounts doubled between FY 1984 and FY 1994, partly due to the merger with the parish council systems. During the same decade, production volume increased by 43%. Sales, however, have not grown significantly due to the high levels of unaccounted for water.

Sewerage coverage has remained relatively low. Only about 24% of households are connected to sewerage systems, while the majority of the population is served by individual sanitation systems. Also, in recent years, NWC has been forced to economize on the operation and maintenance of these systems primarily due to financial constraints. This has resulted in a deterioration of these systems, giving rise to increasing pollution of fresh and coastal waters.

4.1.9 National Irrigation Commission

The National Irrigation Commission Ltd. (N.I.C.) which is an agency within the Ministry of Agriculture was established in 1986 and became operational in May 1987.The NIC has legislative responsibility for the commercial operation of all public irrigation systems - Rio Cobre, St. Dorothy, Mid-Clarendon, Hounslow, Braco and Yallahs. These systems provide irrigation for some 13,781 hectares (15%) of the irrigable land in Jamaica. Revenue shortfalls have historically been made good by GoJ subventions. A National Irrigation Development Plan and Irrigation Investment Programme was prepared in 1998 by the NIC.

Several large private farms operate their own irrigation systems invariably for the exclusive use of the individual farms i.e. sugar estates in St. Catherine, Clarendon, St. Elizabeth, Trelawny, St. Ann and banana estates in St. Mary and St. Thomas. Some 11,433 hectares is irrigated by privately owned irrigation systems representing 13% of the irrigable land in Jamaica. Private companies registered under the Companies Act of Jamaica own these farms.

4.1.10 National Works Agency

The NWA assumed the responsibility of the now defunct Public Works Department. NWA has the mandate to plan, build and maintain a reliable, safe and efficient main road network and flood control system. NWA also has responsibility for coastal maintenance and river training.

4.1.11 Forestry Department

The Forestry Department, established under the Forestry Act (1996), has the overall responsibility to directly manage Government owned forest lands and to advise and assist private landowners on the management of private forest lands. It is mandated to conserve and enhance forests, water, soil and other forest related natural resources on a sustainable basis.

The Forestry Department has prepared and published the National Forest Management and Conservation Plan. This document explicitly outlines one of the key values of forestry to Jamaica as supporting the water resources functions of forested watersheds, as well as soil conservation, protection of biodiversity and carbon sequestration. The Plan includes the development of a number of strategies to support the Plan's objectives. With respect to water resources, the most relevant strategy relates to Forest Protection. This includes a number of activities:

- forest inventory
- development of guidelines on forest land use
- identification of critical emphasis areas
- development of conservation and protection strategies

- declaration of Forest Reserves, Forest Management Areas and Protected Areas
- restoration of mining disturbed forests.

The Plan includes an implementation programme and budget for a number of activities and projects. It was adopted by the GoJ in 2001 and has a 5 year implementation programme. Updating the National Forestry Plan will commence later this year and is due for completion in 2009. It will explicitly include climate change issues and responses for Jamaican forestry.

The Forestry Department has also undertaken a number of detailed catchment/watershed based studies, with its Trees for Tomorrow project, looking at strengthening the Department's abilities to plan and manage forests and develop and implement soil conservation measures appropriate to Jamaica's environment. To assist the accomplishment of this aim, the Rio Minho, the Martha Brae and the Buff Bay/Pencar watersheds were chosen as Watershed Management Unit (WMU) models for further study. From this work, two reports (Trees for Tomorrow Project, 2002 & 2004) were produced which summarized the main physical-morphometric characteristics and the modification of the land-use conditions of the watershed, and how this has influenced their hydrological responses, investigated linkages between forest cover and watershed yield as well as recommending appropriate land treatments for erosion control.

The Forestry Department is also charged with a legal responsibility for watershed management for the purpose of minimizing erosion. Because erosion is particularly intensive during floods, the management of the Forest Reserves endeavours to maximize water retention and reduce the flood peak as a specific objective of the programmes of the Forestry Department.

The IWCAM project is seeking to develop a pilot watershed management programme that includes the active participation of the local community, including local industry, in fostering good land and water use management practices (changing behaviour) that will reduce vulnerability to climatic based events such as flooding, enhance sustainable economic development and in doing so increase the resilience of the local community to climatic based (and other) natural hazard events. This project is wide ranging and ambitious, but should be actively encouraged and supported by the Government of Jamaica. Assuming the successful outcome of the project, a programme for its implementation within other sensitive watersheds across Jamaica should be planned and funded.

The Forestry Department also has an important role to increase the ability of the Jamaican water sector to adapt to climate change. The National Forest Management and Conservation Plan (Forestry Department, 2000) is about to be revised and updated. This has to be supported and encouraged. At the same time, the Forestry Department is developing the technical planning tools linking forestry / land use and hydrological models within a GIS environment. This framework can be used to optimise forest coverage to enhance the hydrological benefits that forestry can offer in terms of, reducing flood runoff and enhancing groundwater recharge. This work clearly needs to be encouraged and supported, with consultation among other relevant organisations such as NEPA / the IWCAM project, WRA and NWC. For example, within watersheds where run of river abstractions / springs provide the sole water supply for rural communities; land use and forestry practices that discourage surface runoff and encourage groundwater recharge would be of interest to those local communities as well as the NWC, where they are the water provider.

4.1.12 The Meteorological Services

The Meteorological Services has as one of its key functions, the provision of accurate and timely warnings and advice on the occurrence and impact of naturally occurring hazardous phenomenon as well as the influence of atmospheric conditions on technological hazards such as oil spills and fires.

Based at the Meteorological Headquarters, the Climate Branch is responsible for maintaining a current database of the climate of Jamaica and for the utilization of this date in informing productive sectors of the country. It consists of a Data Acquisition Section that sets up and maintains an island-wide network of precipitation and climatological stations; a Data Processing Section that gathers, archives and analyses the climatological data with a view to monitoring and assessing the climate of the island; and an Applied Meteorology Section that processes the needs of clients, which include crop water requirements, design criteria for hydrologists and engineers, and climatological information for resolving weather related legal and insurance issues.

Proposals have been put forward for the institutional and legal strengthening of the Meteorological Services. The proposed institutional strengthening would include the provision of expert advice to agriculture and other development projects as well as the provision of forecasting services to aviation, monitoring the daily state of the atmosphere and forecasting the development, track and intensity of severe weather systems as well as drought.

In addition, the Meteorological Services would be expected to provide technical guidance to public sector agencies on the use of meteorological information, and the application of meteorological information to such areas as land use planning, water resource assessment, and other sporting or commercial activities, as well as the impact of climate change on economic development and the social impacts, especially in regards to public health and safety have become critical operational issues that require special consideration.

There are also proposals by the Meteorological Services for a Meteorology Act. The main objectives of this Act would be to promote and coordinate all activities in the field of meteorology and allied sciences in Jamaica, and should carry out such functions as providing a service to civil aviation, cooperation with other agencies and services to provide efficient and accurate severe weather warning system, provide meteorological information and advise to national agencies as well as collecting, analyzing archiving and publishing all meteorological data, participating in work of appropriate international organizations, particularly the World Meteorological Organization and the International Civil Aviation Organization, as well as participating in work in applied meteorology , agricultural meteorology, hydrology and associated research of direct interest to meteorology, along with cooperation with all relevant scientific institutions.

4.1.13 Office of Utilities Regulation (OUR)

The OUR was established by the OUR Act of April 1995. The Act was amended in 2000 to provide the agency with the power for the regulation – economic regulation – of electricity, telecommunications, public passenger transport and water and sewage. Currently the OUR has full responsibility for regulating the NWC. Based on the Act, OUR will (i) receive and process all applications for a license to provide any utility service; (ii) enquire into the nature and extent of the utility services provided by an approved organization; (iii) determine the rates or fares which may be charged; (iv) monitor the operations of an approved organization to enforce provisions of the law; and (v) specify financial penalties, which may be incurred by a licensee for breach of any terms of the license.

OUR objectives are to: (i) establish and maintain transparent, consistent and objective rules for the regulation of utility service providers including NWC; (ii) promote the long term, efficient provision of utility services, e.g. OUR is monitoring an existing regulatory framework with NWC on agreed monitoring indicators; (iii) provide an avenue of appeal for consumers; (iv) work with other related agencies in the promotion of sustainable environment; and (v) act independently and impartially in all matters including setting tariffs.

The OUR has adopted measures to guarantee the protection of the consumer of the services it regulates, the most relevant being the establishment of a public consultation process for the key regulatory procedures that guarantees transparency in the issued regulation. Tariff requests from NWC as well as quality standards for the services provided by the utility are subject to public consultation. A second key element of the process is the establishment of "Levels of Compensation" by which a customer can be compensated for failures in the service provision. The quality standards adopted after a public consultation are part of the performance indicators adopted for the midterm and final evaluation of the project. The standards are divided into two groups, overall standards (OS) and guaranteed standards (GS).

The OUR is independent from the sector ministries and is attached to the Office of the Prime Minister. It finances its activities from the regulatory fees on the regulated utilities and processing fees from the license applications. The Office is comprised of a Director General who heads the Office and two deputy directors, one for electricity and water and the other for telecommunications. The Governor General appoints the director general for a period between three and seven years and he cannot be removed from office unless clear misconduct is demonstrated. The Prime Minister appoints the deputy directors on the same terms as the Director General.

The regulatory process in the water sector comprises a series of activities that concludes with the establishment of (i) a set of tariffs for a determined period, and (ii) a regulatory framework – quality standards associated to a determine tariff level – for the regulated utility (NWC). In 1999 OUR defined a set of 14 "quality of service standards" that have been included in successive regulatory frameworks. The regulatory framework as well as the tariff requests of NWC is subject to a public formal consultation process around the country.

4.1.14 Office of Disaster Preparedness and Emergency Response

The Office of Disaster Preparedness and Emergency Management (ODPEM) is required by law to develop and implement disaster preparedness policies, plans and mitigation measures in relation to all disasters including flooding. In this regard, its programmes have included the preparation of flood plain maps and the establishment/ operation of flood warning systems. Because the WRA collects flood flow data and has the technical capability to conduct flood analyses (and the ODPEM does not), the flood plain maps and the establishment/operation of flood warning systems have been undertaken by the WRA under its legal mandate to provide technical assistance to GoJ agencies on request. The Office of Disaster Preparedness and Emergency Response has been responsible for a number of initiatives including the following: development of National Disaster Management Plan and Policies; completion and maintenance of a National Disaster Catalogue and Hazard Database; establishment of Community Flood Warning Systems. The Meteorological Service issues public warnings of the threat of flooding and provides the precipitation data for flood analysis. The work being done by the ODPEM/WRA has introduced a pro-active approach to floodwater control in contrast to re-active approach of the NW A (and its predecessors).

4.1.15 Rural Water Supply Ltd.

This company is an Agency of the Ministry of Water and Housing and focuses on developing water supply solutions for Jamaica's rural communities, both for public water supply as well as for local irrigation needs. It was established in 2005, with the merger of the Carib Engineering Company and the NWC's Rural Water Programme. Its aim is to ensure that all Jamaicans have access to piped water by 2010.

The company seeks to include private sector and local community support, as it is these communities that will have responsibility for managing and maintaining the systems once they have been put in place by the company.

It is currently supervising the Rural Water Supply Project, which Project is funded by the Inter-American Development Bank (IDB) and the Government of Jamaica, aims to improve the basic sanitary conditions by increasing of potable water and sanitation services in poor rural area. The project is due to complete in February 2008.

4.1.16 Parish Councils

The Parish Councils have a major role to play as suppliers of water. The Department of Local Government would be responsible for coordinating these functions of the parish council in this regard.

Responsibility for local government is vested in 12 parish councils and the Kingston and St. Andrew Corporation, which represent the amalgamation of two parishes. Since 1947, all of the councils (called parochial boards until 1956) have been fully elective, although the members of the House of Representatives from each parish are ex-officio members of the councils. Elections are normally held every three years on the basis of universal adult suffrage.

Local government authorities are responsible for public health and sanitation, poor relief, water supply, minor roads, and markets and fire services. Revenues come largely from land taxes, supplemented by large grants from the central government.

4.1.17 Ministry of Health and Environment

The Ministry of Health and Environment is responsible for developing and implementing health policies and legislation to promote appropriate sanitation practices; establishes and monitors health indicators for sanitation, enforces public health laws, provides public education on sanitation and hygiene. The National Environment and Planning Agency (NEPA) is an agency under the Ministry of Health and Environment that determines and monitors environmental standards for water supply and sanitation.

4.1.18 Private Sector

There is a growing involvement of the private sector in the water resources sector. The declared intention of the Government as enunciated in the Water Sector Policy, is to permit wider involvement of private interests in the water sector. Already there are four private sector entities supplying water to the public.

4.1.19 Agencies holding responsibilities

Several agencies have responsibilities relevant to the water resources sector and these are given in the table below.

TABLE 4-1: AGENCIES WITH RESPONSIBILTY WITHIN THE WATER SECTOR

GOVERNMENT AGENCY/ MINISTRY	MANDATE	VISION STATEMENT	LEGISLATION	POLICY/PLAN	CAPACITY	CURRENT ROLES
National Water Commission (NWC)	Responsible for providing potable water and wastewater services for the people of Jamaica.	The Vision of the NWC is to be recognized as one of the best providers of water and wastewater services in the world, based on superior service, efficiency, viability, integrity, innovation and teamwork.	***National Water Commission Act***	- Water Sector Policy	NWC produces more than 90 % of Jamaica's total potable water supply with more than 1,000 water supply facilities and over 100 sewerage facilities island wide; More than 70% of Jamaican households are supplied via house connections and the remaining 30% obtains water from standpipes, water trucks, wayside tanks, community catchment tanks and direct access to rivers and streams; 30% of Jamaica's population is served by sewerage facilities operated by the NWC. NWC supplies some 190 million gallons of potable water each day across Jamaica.	
Water Resources Authority (WRA)	Responsible for the management, protection, and controlled allocation and use of Jamaica's surface and underground water resources.	To ensure the sustainability of Jamaica's water resources through continual assessment and proper management, promotion of conservation and protection, and optimal development of these resources; to ensure rational	***Water Resources Act***	-Water Sector Policy -Water Resource Master Plan		

TABLE 4-1: AGENCIES WITH RESPONSIBILTY WITHIN THE WATER SECTOR

GOVERNMENT AGENCY/ MINISTRY	MANDATE	VISION STATEMENT	LEGISLATION	POLICY/PLAN	CAPACITY	CURRENT ROLES
		and equitable allocation of the nation's water resources and to reduce conflicts among water users.				
National Irrigation Commission (NIC)	To manage, operate, maintain and expand such existing and future irrigation schemes and systems as may now or hereafter be established by the Government of Jamaica or by any department or agency. NIC's main role is therefore to distribute irrigation water to the agricultural sector in Jamaica.	To develop potential sources of irrigation water, and to manage these together with existing resources, by the provision of effective and efficient delivery systems up to farm-gate, geared towards the enhancement of Jamaica's agricultural development.	***Irrigation (Amendment) Act***	-National Irrigation Development Master Plan - Water Sector Policy	Serves approximately 25,000 hectares or 10% of Jamaica's cultivated lands	1. Delivering irrigation water to farm gates 2. Developing water users groups/associations in order to encourage farmer involvement and foster on-farm water management 3. Maintaining irrigation infrastructure 4. Developing new irrigation systems
National Environment and Planning Agency	Watershed protection and management, environmental monitoring and enforcement, promoting industry compliance for the consistent meeting of effluent and waste standards by companies, development of a system of national parks and protected areas, coastal zones management, environmental education,	That Jamaica's natural resources are being used in a sustainable way and that there is broad understanding of environment, planning and development issues, with extensive participation amongst citizens and a high level of compliance to relevant legislation.	***The Natural Resources Conservation Authority Act*** ***The Town and Country Planning Act*** ***The Land Development and***	-Jamaica National Environmental Action Plan (JaNEAP) 1999-2002 -National Physical Plan -Policy for Jamaica's System of Protected Areas		

TABLE 4-1: AGENCIES WITH RESPONSIBILTY WITHIN THE WATER SECTOR						
GOVERNMENT AGENCY/ MINISTRY	**MANDATE**	**VISION STATEMENT**	**LEGISLATION**	**POLICY/PLAN**	**CAPACITY**	**CURRENT ROLES**
	increasing public awareness of environmental issues and promoting the use of environmental impact assessments.		***Utilization Act*** ***The Beach Control Act*** ***The Watershed Protection Act*** ***The Wildlife Protection Act***	- 1997 -Biodiversity Strategy and Action Plan (Draft) -Watershed Management Policy (Draft) -Beach Policy for Jamaica (Draft) -Environmental Management Systems Policy and Strategy (Draft)		
National Works Agency (NWA)	Responsible for the management of the island's public works infrastructure. Main function of NWA include: • Maintenance of the national road network and associated structures gazetted to its care. • Maintenance and/or replacement of					

TABLE 4-1: AGENCIES WITH RESPONSIBILTY WITHIN THE WATER SECTOR						
GOVERNMENT AGENCY/ MINISTRY	**MANDATE**	**VISION STATEMENT**	**LEGISLATION**	**POLICY/PLAN**	**CAPACITY**	**CURRENT ROLES**
	bridges, and maintenance of other civil engineering facilities, including drainage and flood protection structures. • Design and maintenance of building structures associated with the Ministry and responsibilities regarding other government buildings as follows: * Provision of architectural and structural engineering services. * Provision of electrical and mechanical maintenance services. The NWA is also charged with the responsibility for proactive and reactive responses to emergency situations arising from the forces of nature. These include:					

TABLE 4-1: AGENCIES WITH RESPONSIBILTY WITHIN THE WATER SECTOR						
GOVERNMENT AGENCY/ MINISTRY	**MANDATE**	**VISION STATEMENT**	**LEGISLATION**	**POLICY/PLAN**	**CAPACITY**	**CURRENT ROLES**
	* Attention to sea defenses and river training works. * Provision of a radio and telephone network independent of the commercial networks. * Clearing of blocked roads, land slippages etc. * Providing assistance in disaster management through technical advice and engineering support to coastal defenses and river training					
Office of Disaster Preparedness and Emergency Management (ODPEM)	Develops and implements policies and programmes for the purpose of achieving and maintaining appropriate state of national preparedness as well as encouraging and supporting disaster preparedness and mitigation measures in all parishes in association with local Government authorities, community	Committed to taking proactive and timely measures to prevent or reduce the impact of hazards on the Jamaican people, its natural resources and economy, through collaborative efforts with national regional and international agencies.	***Disaster Preparedness and Emergency Management Act***	Hazard Mitigation Policy		

TABLE 4-1: AGENCIES WITH RESPONSIBILTY WITHIN THE WATER SECTOR						
GOVERNMENT AGENCY/ MINISTRY	**MANDATE**	**VISION STATEMENT**	**LEGISLATION**	**POLICY/PLAN**	**CAPACITY**	**CURRENT ROLES**
	based organizations and private and voluntary agencies.					
Ministry of Water and Housing	Provide the island with an adequate supply and suitable quality of water for domestic, commercial and agricultural purposes. Monitor weather conditions in order to issue reliable and timely advisories islandwide . Increase the Ministry's capability to respond to disasters and emergency incidents, and reduce the effects of hazards and disasters through the application of mitigating measures		***Housing Act***	Jamaica Water Sector Policy Housing Policy		
Ministry of Transport and Works	To contribute to the economic growth and social development of Jamaica by securing resources and providing effective policies, planning, standards and regulations for: the provision of safe and sustainable transport systems for the movement of people and goods and		***Road Safety Act***	• National Transport Policy • Jamaica Water Sector Policy • Construction Industry Policy		

TABLE 4-1: AGENCIES WITH RESPONSIBILTY WITHIN THE WATER SECTOR						
GOVERNMENT AGENCY/ MINISTRY	**MANDATE**	**VISION STATEMENT**	**LEGISLATION**	**POLICY/PLAN**	**CAPACITY**	**CURRENT ROLES**
	the achievement of efficient, high quality and timely architectural engineering and technical works.					
Ministry of Health and Environment (new ministry, website not yet established)	Under the former Ministry of Local Government and Environment (Source JIS): -Air Quality and Control -Beach Control and Coastal Management -Marine Conservation and Protection -Meteorology -Disaster Preparedness and Emergency Management -Watershed Management -Wildlife Protection - Minor Water Supplies - Solid Waste Management	Vision statement not yet available for the new ministry				

4.2 SWOT ANALYSIS

STRENGTHS- INTERNAL	WEAKNESSES- INTERNAL
• Generally adequate and surplus water resources • High access to potable water (>71%) • Recognition of the link between sanitation and water supply • Demand Side Management Awareness • Established institutional framework for administration of elements of the water sector • Established water resources monitoring programme (quantity and quality) • Existing institutional framework • Water Sector Policy exists • Sector Policy and Framework focusing on all aspects of water (WRMP/NIDP/RWMP/WSP) • Institutional Framework exists • Water Resources Master Plan (Draft 2005) • Water Resources Act (1995) • Forestry Plan/ Forestry • Established communication links between main actors in water sector (Some common membership of boards). • Mechanism exists for enhancement of links between water resources management and environment management. MoU between NEPA, WRA and Ministry of Health. • Jamaica signatory/ party to several international conventions (Montreal Protocol, Kyoto Protocol) • Climate Studies Group at UWI- internationally recognized • Trained cache of meteorologists • Trained cache of hydrologists • Water consumed by main economic drivers – small percentage of total demand. • Most agriculture appears tolerant to predicted climatic variability (temperature and precipitation)	• Fragmented legislation in drainage sector • Poor enforcement of regulatory framework • Inadequate or no enforcement of planning and environmental legislation • Lack of strong focus/ centre on climate change within GoJ • No climate change policy • No National development policies do not now existing policies incorporate climate change considerations. • Lack of incorporation of the pivotal role of water in planning and development • Several pieces of legislation dealing with Water Sector • Overlapping legislation. Especially important regarding enforcement. • Communication between the two tiers of government not always in sync. Note responsibilities and ownership of "fees" generated. • "Conflict" between upstream and downstream users of water and pollution of sources. Blurb on "polluter pay principle". • Inconsistency in supporting water monitoring programmes. Link to funding and funding mechanisms. • Flood control legislation not adequately mainstreamed into sector. • Lack of coordination of water and sanitation programmes, human settlements development and urban and regional planning • "Timidity" re response to social pressure. Relate to Land use and tariff collection. • Use of local professional staff vs dictates of funders and international protocol. Difference in rates paid etc. • Dominance of "Supply Drive" in mind set of political bosses. • Targeting of technologies to reflect physical/geological differences not sufficiently appreciated. Discuss re rainwater harvesting and selection of appropriate faecal waste disposal mechanism. • Draft Water Plan in existence since 1990. Not considered by parliament as mandated in the Water Resources Act of 1995. • Poorly maintained parish council water systems • Fragmentation of water supplies especially for the rural population • Lack of consistent water quality monitoring programme to detect changes over time • Lack of proper maintenance and monitoring of water sector infrastructure • Inadequate design and maintenance of drainage systems in urban drainage and even less in rural communities • Lack of coordination of water and sanitation programmes, human settlements development and urban and regional planning • Limited reservoir capacity • Lack of rainwater harvesting

	• Aged Infrastructure causing leaks • Siting of waterworks • Washout of pipelines from landslides and flooding • Water resource availability does not coincide with major demand centres • Inadequate distribution network • Inoperable sewage treatment plants • Attrition of professional staff • Non- tariff water/ unaccounted for water • Data gathering related to water is inadequate for several socio-economic parameters • High energy consumption in works • Lack of public awareness of potential impacts of climate change • Financial resources for adaptation strategies a challenge • Lack of adequate funding
OPPORTUNITIES - EXTERNAL	**THREATS- EXTERNAL**
• Development of new climate change policy • Improved ODPEM • New Disaster Management Act • A water policy exists which needs to be updated, improved and expanded • Implementation of draft Met. Act • Strengthening of the capacity of Met. Office to deal with climate change matters. • National Drainage Policy • Improved enforcement of planning and environmental legislation • Inclusion of IWRM in national development plans • Co-ordinate national efforts in watershed management, forestry development programmes and climate change • Establish links between UWI Mona Climate Studies Group and stakeholders • Inclusion of climate change considerations in national development plans • Water Resources Plan now being revised and updated. Opportunity to be used to implement it in accordance with the Water Resources Act (e.g. Consideration and approval by Parliament). • Water Resources acts calls for annual update to parliament. Use opportunity to mainstream climate change aspects. • Use can be made of climate forecasts to plan water management • Lack of integrated planning • International funding to deal with adaptation to climate change for water resources and water supplies • High Global attention to water and sanitation • Stated commitment of local government to improving water quality • Increased private sector participation in water and sanitation services • New modalities for rural water management involving communities	• Overlapping institutional mandates • Enforcement lacking • Lack of political consensus on policy and implementation • Deforestation and increased runoff and erosion • Watershed Degradation • Expanding urbanization into upper watershed areas • Informal Settlements and poor waste practices • Poor agricultural practices • Contamination of water from agricultural practices, etc. • Contamination of resources from sanitation washout during flood events • Climate Change - impacts on natural hazards (flood, drought, hurricanes) and coastal aquifers • Projected increased variability in rainfall • Coastal location of sources and infrastructure at increasing risk from sea level rise • Agriculture vulnerable to predicted extreme weather events • Hotel sector particularly vulnerable to coastal zone inundation • Rising energy costs • Criminality and theft of infrastructure and water

• Implement demand management • Increased conservation of water (reuse, recycle) • Development of economic analysis (Cost Budget Analysis) to support access to funding for adaptation programmes	

4.3 Governance

Governance relates to the decisions that define the expectations, grant power and verify the performance of the responsible bodies. Governance also incorporates consistent management, cohesive policies, processes and decision-making for the water sector. The major responsibility for Governance is the Ministry of Water and Housing in association with the relevant GOJ agencies such as the Water Resources Authority, the National Water Commission, the National Environment and Planning Agency and the Meteorological Services.

4.4 Institutional Recommendations

- Strengthen the Meteorology Office by providing additional staff and where necessary technical expertise to discharge its functions in climate change adoption.
- Establish a climate change desk in the OPM .
- Strengthen the ODPEM to deal with new issues emerging from climate change.
- Strengthen the Water Resources Authority to deal with new issues emerging from climate change.
- Clarify agency responsible for planning for coastal works (including beach and shoreline erosion).

5 POLICY AND LEGISLATIVE REVIEW

5.1 Existing Legal Instruments

A large number of national legislation apply to water resources. Similarly there are disparate institutions responsible for water resources. The legal framework process of distilling this wide array of legislative instruments into a coherent framework still has to be done.

There are also major gaps in the legislative framework. For example there is no Meteorological Act and the legislation in relation to disaster management needs substantial revision.

5.1.1 Water Resources Act (1995)

The Water Resources Act established the Water Resources Authority (WRA) as the principal water resources regulatory agency in Jamaica. The enactment of the Water Resources Act, 1995, provided the legal basis for the management, conservation, protection and allocation of all water resources. The core functions of the WRA are to deal with a range of matters including the power to: (a) obtain, compile, store and disseminate data concerning the water resources of Jamaica; (b) exercise planning functions in relation to the National Water Resources Development Master Plan and Water Quality Control Plans; (c) allocate water resources;

The Water Resources Act provides that the WRA shall continue to have responsibility for management of water resources; maintenance of a timely updated and comprehensive water resources database; raw water quality and monitoring assessments; planning and approval for water resources development; issuing and enforcing permits for well drilling and water abstraction; and public education, as appropriate.

Sections 14 and 15 of the Act provides for the establishment of a Water Resources Advisory Committee to advise the Minister on water resources matters. The organizational structure specified by the Water Resources Act, has not yet been fully implemented as the Water Resources Advisory Committee has yet to be appointed. The Act requires the Minister to consult with this Committee prior to declaring an Emergency Area and a Water Quality Control Area, and prior to the approval of the National Water Resources Development Master Plan and a Water Quality Control Plan.

Section 16 of the Water Resources Act provides for the preparation of a National Water Resources Development Master Plan to guide the regulation of the water resources of the island. The main elements of the Master Plan are as follows: Inventory of water resources potential; Inventory of existing water production and use; Inventory of present and future water demands; Plan for the allocation of water resources to satisfy the present and projected demands; Design of a programme of appraisal, research and resource management to inform the implementation of the Master Plan. Over the period 1985/90 a National Water Resources Development Master Plan was prepared by the WRA (then the Underground Water Authority). This Master Plan of 1990 has not been submitted to the Minister for approval as required by section 16(1) of the Act and therefore does not have the force of law.

Under section 17(1) of the Water Resources Act, the abstraction and use of water in Jamaica and the construction of any works for such abstraction and use are governed by the provision of the Water

Resources Act. Section 17(1) also contains an override clause, which provides that nothing in any existing enactment shall be construed as derogating from any provision made by or pursuant to the Water Resources Act. Section 17(2) defines an “existing enactment” as an enactment which is in force on the appointed day.

Section 19(1) of the Water Resources Act establishes the licensing regime for the abstraction and use of water. Under section 19(1) no person shall abstract or use water or construct or alter any works for the abstraction of water except under an in accordance with a licence granted by the Authority. Two exceptions to the licensing regime are created by section 19(2). These are:

a) Where the person has a right of access to the source of water
b) Where the water is required only for domestic use.

5.1.2 The Natural Resources Conservation Authority Act (1991)

The Natural Resources Conservation Authority Act provides for the management, conservation and protection of the natural resources of Jamaica. The term 'natural resources' is not defined but in practice a wide and liberal interpretation has been given to this term.

The Natural Resources Conservation Authority Act (hereinafter called "NRCA") was enacted in 1991 to provide a framework for the effective management of the physical environment of Jamaica. The NRCA is given wide functions and duties including to develop, implement and monitor plans and programmes relating to the management of the environment and to formulate standards and codes of practice for the improvement and the maintenance of the quality of the environment.

The Natural Resources Conservation Authority Act also provides for a) the designation of protected areas (section 33); (b) environmental impact assessments (section 10); the promulgation of Ministerial orders to protect the environment (section 32). The Act also empowers the establishment of standards for environmental protection (section 4(1) (d)), the management of waste (section 38), the management of national parks, marine parks (section 5), other protected areas and public beaches (section 4).

Although water resources are not significantly defined in the Act, It IS redefined to include marine (section 4 (1) (c), 4 (2) (c), 5 (2) (c)) and surface and ground (section 12 (1) (a)) waters. The Act (sections 9 (2) and 9(4)) requires persons undertaking "any enterprise, construction or development" to only do so "in accordance with a permit issued by NRCA and if the "enterprise, construction or development will or is likely to result in the discharge of effluents then a licence to discharge is required (section 12 defines the conditions under which a licence is required). In essence NRCA's responsibilities with respect to water relate to monitoring and controlling the use of waters dot become polluted.

5.1.3 Watershed Protection Act (1963)

The Watershed Protection Act (1963) is the law governing watersheds and is administered by NEPA. The primary focus of the Act is the conservation of water resources by protecting land in or adjoining the watershed. The Act is intended to ensure proper land use in vital watershed areas, reduce soil erosion, maintain optimum levels of ground water, and promote regular flows in waterways.

NEPA is responsible for the administration of the Act. Watershed areas are declared under section 5 by a Ministerial order on the recommendation of NRCA. Powers are conferred on NRCA to make regulations designed to achieve proper efficient and economic utilization of lands in watershed areas. No regulations have been made either before or after NRCA was assigned responsibility for watersheds. Provision is made for the appointment of Watershed Protection Committees to assist NRCA. NRCA may enter into arrangements with owners of private lands in relation to the carrying out of improvement works to ensure the protection of watersheds.

5.1.4 Public Health Act (1985)

The Public Health Act establishes a Local Board of Health for each parish in the island (see section 5). By section 6, the Local Boards of Health are empowered, *inter alia,* to carry out all activities which appear to them to be requisite, advantageous or convenient in the interest of public health. The Local Boards of Health are authorized by section 7 to promulgate regulations for a wide variety of matters e.g. nuisances. A key role of the local Boards of Health is to monitor water quality within their respective areas. The Ministry of Health is also responsible for water quality monitoring and water quality data throughout the island.

5.1.5 National Water Commission Act (1980)

Section 3 of the National Water Commission Act establishes the National Water Commission (NWC). NWC is charged with the responsibility (within the limits of its resources) to provide and improve water supply services throughout the island. NWC is also required to prepare and submit to the Minister proposals for an efficient, coordinated and economical water supply system capable of meeting the water needs of the Island. In addition NWC is authorised to prepare and submit for Ministerial approval details of schemes for the development of water resources and the supply of water in particular areas. NWC is empowered to borrow and to issue securities for raising money which it is authorised to borrow.

5.1.6 Flood Water Control Act (1958)

Under section 3(1) of the Flood Water Control Act the Minister may by order declare any area to be a flood water control area. By section 3(2) when declaring a flood water control area, the Minister shall appoint undertakers of the scheme. The undertakers to be appointed are restricted to three categories: (a) any Government department; (b) any Government agency; or (c) any statutory body or authority. Section 4(a) provides that the undertakers shall prepare and submit to the Minister a provisional flood water control scheme. In addition by section 4(b) the undertakers are authorized to do all things necessary to give effect to any confirmed flood water scheme. (See below the draft Water Resources (Amendment) Act which once enacted will repeal the Flood Water Control Act.)

5.1.7 Irrigation Act (1973)

Section 4(1) the Irrigation Act allows the Minister to licence a company to be the Irrigation Authority for the Act. Section 4(3) allows the licence to make provision for (1) irrigation and drainage charges; (2) charges in relation to the use of land or the use of any watercourse.

Section 5 of the Irrigation Act sets out the functions of the Authority. These include:

a. making investigations and surveys and doing such work as necessary for the preparation and submission to the Minister of provisional irrigation schemes;

b. doing all matters to give effect to any confirmed irrigation scheme;

c. subject to directions given by the Minister, to manage, control and operate, any irrigation works;

d. carry out investigation as required by the Minister into any matter affecting or relating to an irrigation area or regarding irrigation work.

Section 6 permits the Authority to drain land and to carry out irrigation, reclamation drainage works. Section 7 allows the Authority to direct the occupier of lands in an irrigation area to maintain and clean drains. Part 2 of the Act (see sections 8-15) sets out the procedure for the preparation, confirmation and modification of irrigation schemes. By section 8(3) (b) every provisional irrigation scheme must indicate whether the proposed scheme has been approved by the Water Resources Authority. Section 9 requires that there be notification of the provisional irrigation schemes in the Gazette and in three issues of a daily newspaper.

Paragraph 3 of the Irrigation Authorities (Vesting of Functions in the National Irrigation Commission Limited) Order, 1990 (LN 25/90) vests in the National Irrigation Commission the powers of the Irrigation Authority under the Act.

The Irrigation (Amendment) Act, 2003 was introduced to implement some of the proposals in the Water Sector Policy which recognized the participation of water user's associations in the management and operation of the new irrigation systems identified for construction under the National Irrigation Development Plan. The Act seeks to make provision for the Irrigation Authority to licence water users' associations to carry out irrigation functions. This brings the Irrigation Act in harmony with the Water Sector Policy.

5.1.8 Water Supply Act (1958)

The Water Supply Act was enacted prior to the establishment of the NWC. At the time of its enactment there were many diverse water systems in Jamaica. The Water Supply Act sought to facilitate cooperation and collaboration among the various suppliers of water (in the Act they are referred to as statutory water undertakers).

A statutory water undertaker includes NWC or Parish Council. This Act would therefore facilitate NWC or a Parish Council to make arrangement for the supply or water with another statutory undertaker or a private person.

Section 5 of the Water Supply Act allows a statutory water undertaker to make arrangements with other persons (whether statutory water undertakers or not) for the supply of water in areas outside limits of supply.

Under section 2 of the Water Supply Act a "statutory water undertaker" is defined as meaning the National Water Commission, the Kingston and St. Andrew Parish Corporation (KSAC), and any Parish Council.

Section 3 of the Water Supply Act allows the Minister by order to provide for (a) the joint furnishing by two or more statutory water undertakers, by agreement, of a supply of water; (b) the constitution, by agreement, of a joint undertaking of two or more statutory water undertakers for the purpose of exercising all or any of their functions in regard to the supply of water; (c) the transfer, to a statutory undertaker of the undertaking on part of the undertaking of any other statutory undertaker.

5.1.9 Parish Water Supply Act

The Parish Water Supply Act applies to parishes outside of Kingston and St. Andrew. Under the Parishes Water Supply Act, any Parish Council can apply to the Minister responsible for water to construct waterworks or to enlarge or improve any existing waterworks. When the Minister approves the construction etc. of waterworks the Minister may define the limits for the supply of water.

Under the Act each Parish Council is authorized to construct waterworks and to alter or regulate the course of any non-navigable river, or any stream or watercourse and to take water from any river, stream or watercourse. However, where any person sustains damages in consequence of the alteration or regulation of any stream or water course, such damage will be compensated in accordance with the provisions of the Land Clauses Act. The Act enables the Parish Council with the approval of the Minister to fix water supply rates.

Section 8 allows a Parish Council to acquire lands fort he purposes of water supply. Under section 10, the lands acquired under section 8 are vested in the Commissioner of lands but each Parish Council has the entire occupation, management and control of any waterworks constructed as well as the public water supply. Under section 16, each Parish Council, may with the approval of the Minister, fix the water rates and charges to be used throughout the district.

Section 22 allows each parish council to sell and dispose of and deliver water from the water works in any district in the parish at such prices and times as the parish council may determine. Section 23 allows the parish council to charge for the supply of water from public tanks.

Section 32 allows every Parish Council to make by laws:

(a) for the prevention of the waste of water;
(b) for regulating the use of any waterworks or waterways;
(c) for regulating the sale and delivery and supply and use of water in a parish.

Under section 4 of the Parishes Water Supply Act it is lawful for any Parish Council to apply to the Minister for the construction of water works. By section 6 each Parish Council is authorized to construct such waterworks and make such waterways as may be deemed necessary or advisable. In addition section 6 empowers any Parish Council to alter or regulate the course of any non river navigable river, or any stream or water course in order to effect and supply of water to persons within the particular parish.

By section 6 once authorized each Parish Council is empowered to construct such waterworks and make such waterways as may be necessary and also to carry out the appropriate repair, improvement of such waterworks. In addition the Parish Council is empowered to alter or regulate the course of any non-navigable river, stream or watercourse or to take water from any such river, stream or watercourse in such manner as it considers necessary. There is provision for compensation to be paid for damages sustained by any person in consequence of the alteration or regulation of the river, stream or watercourse under the Act must vest in the Commissioner of Lands and must beheld by him to secure the repayment by the Parish Council of sums advanced to facilitate the construction of works. However, the Parish Council remains in control of the works constructed, the public water supply and the lands, rights and easements acquired for the purposes of the works. It may, as it considers necessary for the purposes of its functions, alter, with the approval of the Minister, any street, road or lane.

A Parish Council is entitled under section 22 to sell and dispose of and delivery water from any waterworks in the district in such manner as the Parish Council may determine. Section 24 allows a Parish Council in charge of public water supplies to provide free supply of water.

5.1.10 Kingston and St. Andrew Water Supply Act (1911)

Under the Kingston and St. Andrew Water Supply Act, the Commissioners (effectively the National Water Commission) may establish and construct across Ferry River selected dams and other waterworks to obtaining additional water supplies for Kingston and St. Andrew.

In addition, the Act allows the Commissioners to take water from Wag Water River, the Iron River, the Plantain River and the Grange River and to construct dams and waterworks for the additional water supply for Kingston and St. Andrew. The Act prohibited the Commissioners from taking or diverting from the rivers any water in excess of five million gallons per day during the months of January, February, July, August and September.

5.1.11 Town and Country Planning Act (1948)

The objective of this Act is to ensure the orderly development of land. This is achieved through Development Orders which are legal documents used by the planning authorities to inter-alia provide for protection of amenities and conservation and development of the resources of the prescribed area. Development Orders are the main means of control of land use in Jamaica.

Development Orders may be made under the Town and Country Planning Act. The Development Order will make provision for the matters mentioned in the Second Schedule. Among the matters included in the Second Schedule are the provisions for amenities. These include reservations of lands as open spaces, reservation of lands for Fame and bird sanctuaries and for the protection of marine life. Also included are reservations for the protection of marine life. Also included are reservations for the protection of forest, woods, trees etc.

At present the entire island is not covered by Development Orders. Existing orders are not updated regularly. In areas covered by a Development Order planning permission is required from the local authority or from the Town and Country Planning Authority if the area is “called in” or if the development does not conform to the zoning in the Development Order e.g. Change of use, retention of use, outline application, determination and petrol stations. In considering development applications the planning authorities take into account the Development Order and other material consideration.

Substantial amendments were made to the Town and Country Planning Act in 1999 to provide for effective enforcement. The required changes to provide a more comprehensive control over planning in Jamaica will be incorporated into the NEPA Act.

The Act also provides for the making of Tree Preservation Orders (Section 25) whereby a local authority may seek to preserve trees or woodlands in their area and prohibit wilful damage or destruction of trees, or require the replanting of trees. The Act provides for notification of, designation, and the right to submit objections to the declaration of such an Order including provisions for compensation. These Orders are not widely used.

Coordination with the Local Government authorities, otherwise known as the Parish Councils, is being strengthened. Traditionally these entities are not considered among environmental agencies. They however, have numerous responsibilities related to environmental management, including land use and subdivision controls, solid waste management, cleansing, local physical planning and municipal parks. They also have responsibility in the area of water supply within their parishes.

Government's policy on Local Government is based on the conviction that despite the shortcomings of the existing system, a strong and vibrant system of Local Government is essential to creating a society in which all citizens enjoy real opportunities to fully and directly participate in and contribute to the planning, management and development of their local communities, and by extension, of the nation. If this is fully applied to water it would mean that such involvement is not only desirable, it is also an excellent means of safeguarding and deepening the democratic process while promoting equal rights and social justice. It is also proving and channelling these towards the solution of local problems as well as those of the nation as a whole.

Additionally, the Government perceives both Local Government and Community Development as being complementary processes by which it can achieve its focal objective of empowering citizens to enjoy greater self-management over their own affairs and take initiatives towards, and responsibility for, determining and solving their own problems. A major focus of Government's policy is therefore to deepen the integration between these two processes.

In the context of water, prior to 1980 water resources were managed mainly by Parish Councils. With the enactment of the National Water Commission Act, the majority of water is supplied by NWC but the parishes still retain responsibility for water supply, especially for social water in the rural areas.

Local authorities (parish council and city councils) exercise wide functions over various amenities (including water) which affects the lives of citizens on a day-to-day basis. In many cases, the provision of amenities presents opportunities for local authorities to earn income from the fees and charges imposed by law for the services they provide.

5.1.12 Office of Disaster Preparedness and Emergency Management Act (1998)

This Act established the Office of Disaster Preparedness and Emergency Management (ODPEM) to develop and implement policies and programs to achieve and maintain an appropriate state of national and sectoral preparedness for coping with emergency situations. Under the Act disaster is defined to mean the occurrence or threat of occurrence of an event caused by an act of God or otherwise, which results or threatens to result in inter alia, damage top property, damage to property, damage to the environment on a scale which requires emergency intervention by the state. Disaster preparedness includes an activity undertaken in anticipation of a disaster, hazard or other emergency situation. Though this Act is very general in its application, the Office of Disaster Preparedness and Emergency management in conjunction with the Natural Resources Conservation Authority has formulated guidelines for disaster relief and response. Jamaica is a member of the Caribbean Island Oil Pollution Preparedness Response and Co-operation Plan. This is a tiered response procedure designed to assist island states and territories within the region with oil pollution incidents that are beyond their capacities.

5.1.13 Urban Development Act (1968)

Established UDC with authority to require, manage, or dispose of land within or outside of designated UDC areas, and to act as the sole planning authority within its designated areas. Also develops domestic water supplies and Wastewater treatment facilities.

Although the UDC is its own Planning Authority within its designated areas, it is still subject to the NRCA Act (see sections 8 and 30 of the NRCA Act).

5.1.14 Parochial Water Charges Act

The Parochial Water Works Charges Act (Cap. 27) provides that the Parish Council of a parish shall charge for water supplied by the parish. The Minister may by order approve of the free distribution of water for a period to be named in the order. The free distribution of water may be made either to the general public or to such persons or classes of persons as may be designated by the Minister.

Under section 2 of the Parish Council Water Works Charges Act, "Waterworks" means any tank, well, reservoir and any other receptacle for water or means of providing a supply of water.

The Kingston and St. Andrew Water Supply Act is administered by the National Water Commission under section 3, dams and other works may be constructed for water supply for the parishes of Kingston and St. Andrew. Section 6 allows the use of water from the Wag Water River. By section 10 all powers exercised under this Act require the approval of the Minister.

All water supply systems with distribution pipe sizes equal to or greater than 102 mm Id and/or all sewerage system associated with the development of 10 or more lots are required to secure a permit from the NEPA prior to their construction. Water Supply and Sewerage systems associated with private land developments are also required to obtain Town Planning Authority/Parish Council planning approval. NEPA and the Parish Councils reply on the advise of the ECD with respect to the appropriateness and adequacy of the respective designs. NEPA has also established and are enforcing compliance to trade effluent standards (including treated sewage effluent quality).

5.1.15 Forest Act (1996)

This Act sets out the role and function of the Forestry Department and the Conservator of Forests.

The Forest Act (1996) provides a broad mandate for the Forestry Department, recognizing the importance of preserving forests intact for biodiversity, watershed protection and ecotourism in addition to meeting the country's needs for timber and related forest products on a sustainable basis.

The Act vests responsibility in the Conservator of Forests for developing and maintaining an inventory of forests and lands suitable for the development of forests. The Forestry Department is required to make an assessment of forestry lands to determine their potential for maintaining and enhancing biodiversity. Provisions have been made in the Act for the controlled utilization of forest resources in a rational manner.

Jamaica has over 150 gazetted forest reserves. Under the Act private lands may be acquired for declaration as forest reserves. One of the purposes of forest reserves is to protect and conserve endemic flora and fauna.

The Act calls for the creation of forest management plans, which stipulate the allowable annual cut where appropriate, conservation and protection measures and the roles of other Government departments. The purpose of forest management plans is to ensure the protection and conservation of forests, soil, water, wildlife, and forest products.

5.1.16 Wild Life Protection Act (1945)

The Wild Life Protection Act, continues to be central to conservation and sustainable use of Jamaica's biological resources. Key provisions relate to:

(a) protected species are listed with provisions making it an offense to have in one's possession the whole or any part of a listed animal, living or dead;
(b) game sanctuaries and reserves may be declared with provisions for preventing hunting, egg collection or possession of guns or weapons;
(c) hunting activities controlled (seasons, permitted species, limits, licenses, etc.);
(d) fishing in rivers controlled through types of gear permitted;
(e) pollution of rivers which may kill fish not permitted;
(f) use of dynamite or other explosive substances banned in fishing activities; and
(g) authorization of game wardens (honorary, volunteer positions) to assist in enforcement and compliance activities related to the Act.

5.2 Supporting Regulations

Apart from the various Acts there are a variety of statutory provisions governing the water sector.

5.2.1 Water Resources Regulations (1995)

The Water Resources Regulations, 1995 (made under the Water Resources Act), deals with a variety of matters. First, Part II establishes a regulatory framework for licences to abstract and use water. Secondly, Part III contains various provisions for the protection of underground water including the regulation of well-drilling; thirdly, Part 4 contains several provisions enumerating the powers of the Authority e.g. power to enter premises and take samples. Part 5 deals with a variety of matters including the procedure upon the receipt of a licence application; the registration or recording of easements as well as the keeping of information relevant to well drilling for water. Part 6 deals with general matters including providing for a licence holder to supply of information to WRA. The final part deals with transitional provisions relating to persons holding licences of right (i.e. were holders of licences etc. on the date when the Water Resources Act come into effect).

In addition there are regulations made under the now repealed Water Act and Underground Water Control Act which are retained (see section 51 of the Water Resources Act). There are also a variety of regulations under the Irrigation Act. The Natural Resources Conservation (Permits and Licences) Regulations, 1996 (made under the Natural Resources Conservation Act) are of critical importance in relation to the granting of permits and licences to carry out prescribed activities.

5.2.2 Parishes Water Supply Regulations

The Underground Water Control (Abstraction) Regulations, 1961 (LN 90/62) (preserved by section 51 of the Water Resources Act) deals with the information to be supplied by persons abstracting underground water. By Regulation 3(2) the records to be kept include: (1) the quantity of water abstracted each day; (2) the rest level and the pumping level for a stated abstraction rate; (3) certified copies of any chemical or bacteriological analysis of the water made on its behalf.

5.2.3 Parishes Water Supply Subsidiary Regulations

Under the Parishes Water Supply (St. Catherine) (Limits) Order, 1974 (LN 105N74), the limits of water supply distribution for the parish of St. Catherine shall comprise the whole parish. The Parishes Water Supply (St. Catherine) By-laws, 1974 (LN 105C/74) deal with the issue of water rates for water supplied to the consumer by the St. Catherine Parish Council.

5.2.4 National Water Commission Regulations

The National Water Commission (Water Supply Services) (Rates and Charges) Regulations, 1985 (L.N. 242c/85) provides that the NWC shall keep and provide in the service area a constant supply of water, sufficient for the domestic, commercial and industrial use of occupiers of property in any part of the service are (see regulation 3). By regulation 4 a person in possession of property in a service area may apply to NWC for the supply of water in such manner subject to such conditions as NWC may determine.

By regulation 14 of the National Water Commission (Water Supply Services) (Rates and Charges) Regulations, 1951, where there is a deficiency in the supply of water owing to drought or other cause, NWC may by notice prohibit, either absolutely or such to such conditions as may be specified, the use of water supply for a wide range of purposes e.g. irrigation or watering of gardens, lawns and ponds.

The Regulations also permit NWC to reduce or discontinue the supply of water where there is drought, or any contingency affecting its supply or works due to repairs etc. In addition, where there is a deficiency in the supply of water due to drought, NWC may institute various prohibitions and restrictions regarding the use of water such as prohibiting watering of gardens, filling tanks, swimming pools etc, washing cars or any activity which may require the use of a considerable or excessive quantity of water.

5.2.5 Public Health Regulations

The Public Health (Tourist Establishment) Regulations, 2000 (L.N. 71/2000) establishes a regulatory framework for the health of tourist establishments. Under regulation 31 every tourist establishment shall be provided with an adequate and continuous supply of potable water from a sanitary source, which could be from NWC, the Parish Council of the area or any other source approved by the Medical Officer of Health. The Regulations also address the issue of water quality in tourist establishments.

5.3 Pending Legislation

5.3.1 Water and Sewerage Services Act

The Cabinet has already approved the drafting instructions of the Water and Sewerage Service Act (WSSA) for the legislative power and the enactment of this Act is still pending. The key outcomes of this reform are to formalize the independence and autonomy of the NWC as a commercial led company and the full autonomy of the OUR as sector regulator. It is important to note that the GOJ and NWC are already taking actions towards the goals of the proposed legislations. Under this Act, NWC would cease to have any regulatory functions and the NWC Act will be recast, so as to establish the NWC solely as a service provider. A decision is still pending as to whether a new Act will be written to create a National Water Corporation or to recast the existing Act. In both cases, NWC will formally act with a more commercial focus and with more autonomy from the MOWH, even though this situation is de facto occurring. The instruction for the WSSA also defines a role for the private sector in the provision of water services, the role of policy maker for the MOWH and that of OUR as regulator of the service.

5.3.2 Water Resources (Amendment) Act, 2008

In January, 1999, Cabinet approved the Water Sector Policy, which outlines the framework for the continued development of Jamaica's water sector. The Water Sector Strategy and Action Plan completed in October 2000, was developed to effectively implement the programmes and activities that would realize the objectives of the Policy.

A decision was taken to assign responsibility for the regulation of flood-water control to:

a) The Water Resources Authority established under the Water Resources Act, as regards planning for flood-water control, and
b) The National Works Agency, as regards implementation of flood-water control plans.

The draft Water Resources (Amendment) Act, 2008, seeks to amend the Water Resources Act in order to give effect to that decision.

The draft Water Resources (Amendment) Act, 2008 repeals the Flood-water Control Act, as a consequence of the transfer of the control of flood-water regulation to the Water Resources Authority and the National Works Agency under the Water Resources Act.

The amendment of the Water Resources Act would allow for interagency consultation prior to the implementation of any river training or flood control structures.

5.3.3 Protected Areas Systems Plan

The Forestry Department, the Fisheries Division, the Environment and Planning Agency (NEPA), and the Jamaica National Heritage Trust are responsible for protected areas declared under various legal instruments in Jamaica. These include the Forest Act, the Beach Control Act, the Fishing Industry Act, the Natural Resources Conservation Authority Act, the Wildlife Protection Act and the Jamaica National Heritage Trust Act.

The Convention on Biological Diversity (CBD), to which Jamaica is a party, obligates Parties to conserve, sustainably use biodiversity, and equitably share the benefits arising from the use of biodiversity. One of the means of meeting these obligations is by establishing protected areas.

Many of the Parks and Protected Areas are managed jointly between NEPA and a Non-Governmental Organisation, through a Delegation Instrument.

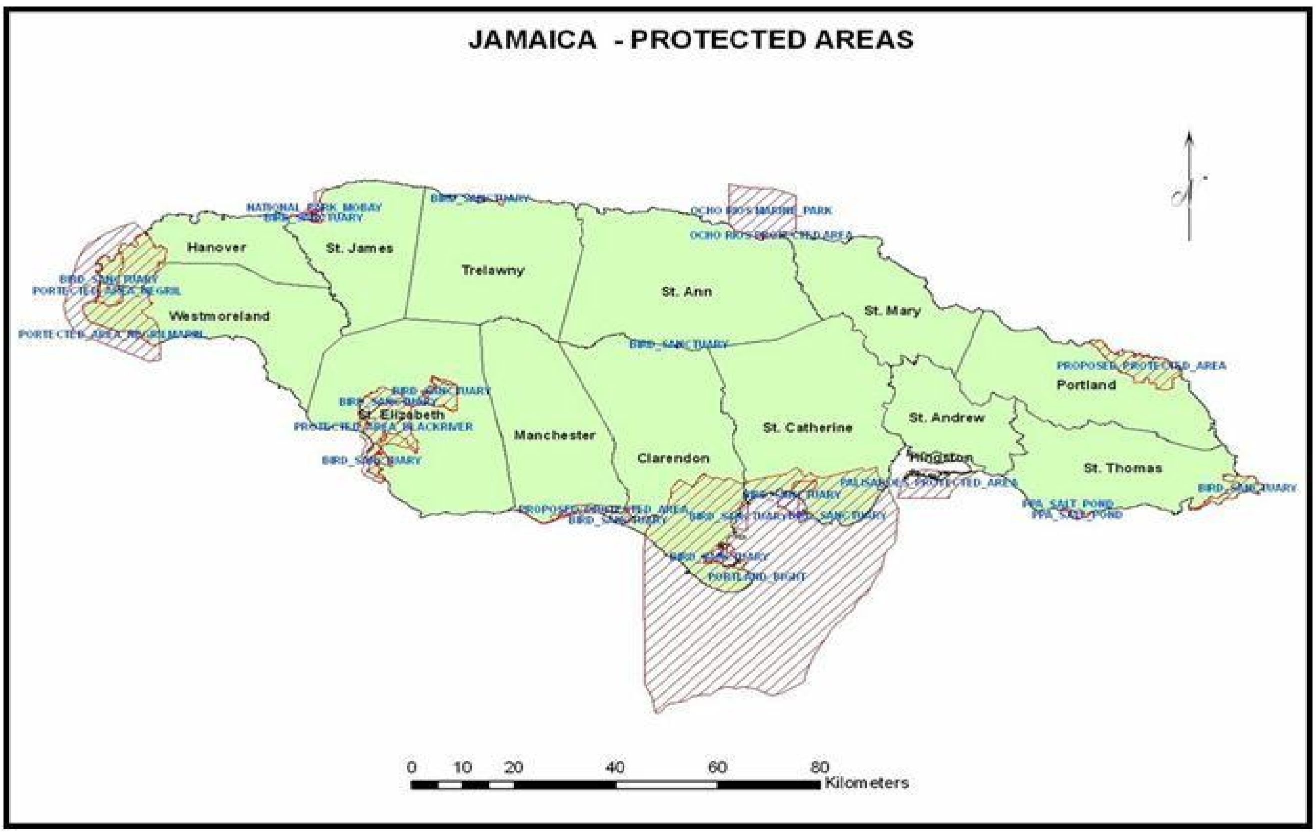


Figure 5-1: Distribution of Selected Protected Areas throughout Jamaica

(Source: http://www.jamaicachm.org.jm)

5.4 Existing Policies and Guidelines

5.4.1 Watershed Policy

National Environment and Planning Agency (NEPA) has produced a National Watershed Policy to address the most severe constraints to watershed management and to seek to employ strategies to ensure the sustainable use and development of watersheds. The policy states the essential elements of a national watershed management initiative. It seeks to define opportunities for the people, for the government and non-government organizations and for the international community to participate in the sustainable management and conservation of watersheds of Jamaica in the interest of water supply and biodiversity. There are twelve guiding principles to the Policy, among which are included:

- Long term watershed management
- The design, planning and implementation of watershed management interventions
- Special attention to people in watershed areas and their environment
- Integral protection and production functions for land and water resources
- Assessment of land use impacts and rehabilitation of damages
- Compromise rather than confrontation and complimentary rather than contradictory in resolving conflicts of interest
- Co-operation among agencies and the public to manage watersheds effectively

5.4.2 Water Sector Policy

In 1999 the Cabinet approved the Water Sector Policy to enable the provision of adequate water and sewerage services to the nation. The main objectives of the Policy are universal access to water by 2010, improvement in the efficiency of the NWC, and expansion of central sewerage facilities. The main elements of the policy are to:

(i) reorganize the water institutions;

(ii) ensure services availability of a minimum quantity in a cost effective manner;

(iii) ensure minimum standards of service to the population;

(iv) use and provide water efficiently;

(v) mobilize additional sources of funding;

(vi) introduce cost recovery mechanisms; and

(vii) develop an effective and efficient regulatory framework to protect customers, investors and the environment.

After the Cabinet approved the Water Sector Policy a Water Sector Strategy was also completed.

5.4.3 Forest Policy, 2001 (updated Forest Land Use Policy, 1996)

The Forest Policy was completed in March of 2001 and approved by Cabinet in July of that year. The preceding Policy dealing with forest issues, the Forest Land Use Policy of 1996 was revised as a result of the realization that is needed to be updated to fall inline with t he tenets of the National Forest Management and Conservation Plan of 2001. The Forest Policy attempts to ensure the sustainable management of the island's forests by concentrating on certain priority areas namely the conservation and protection of forest areas, the sustainable management of the island's forest lands and by extension its watershed areas. It goes further to outline the strategies and tools required for implementation as well as incorporating the state run agencies whose mandates include forestlands management. This list included but was not limited to the Forestry Department, the National Environment and Planning Agency, the Commissioner of Authority. The Policy recognized that planning and monitoring of the sector is a necessity and concludes that this can best be achieved through the implementation of the National Forest Management and Conservation Plan.

5.4.4 National Forest Management and Conservation Plan (NFMCP)

The NFMCP was approved by Cabinet in March 2001. Though similar in some respects to the Forest Policy, the NFMCP sought to provide a more detailed outline of all facets of forestry in Jamaica. The Plan was divided into three sections; the first part provide a background to Jamaica's forestry sector examining land use and ownership issues, the forestry productive sector, and the various forest management constraints that affect the functioning of the Forestry Department. Part Two addressed the forest values to society, while Part Three dealt with the strategies for implementation of the NFMCP. Implementation of the plan will require the involvement of the public in general and more specifically the communities bordering the forested areas, forest research, forest protection and forest production.

5.5 Assessment of Effectiveness of Policies

There are no current policies which directly focused on climate change. Neither the Watershed Policy nor the Water Policy deals with climate change.

5.6 Recommendations for New Policies

5.6.1 Policy and Legislative Recommendations

1. That a climate change policy be developed by the Government – that the Policy be presented to Cabinet for approval.
2. An outline of the possible scope of a climate change policy is set out below.
3. There needs to be a link between the climate change policy and the water policy.
4. Revise the Watershed Policy and the Water Policy to take into account climate change considerations
5. That the draft Disaster Management Act be enacted at an early date.
6. That the proposals for the enactment of a Meteorological Act be implemented.

7. Stricter enforcement of physical planning laws and regulations is also necessary to ensure that life and property is not placed at risk from both pluvial, fluvial and coastal flooding and flood events.

5.6.2 Outline of a Climate Change Policy

Policy Goals and Objectives

The aim of Climate Change Policy is to foster and guide a national process of addressing the short, medium and long term effects of climate change in a co-ordinated, holistic and participatory manner in order to ensure that, to the greatest extent possible, the quality of life of the people of Jamaica and opportunities for sustainable development are not compromised.

The objectives of the Policy would be to:-

1. Foster the development of processes, plans, strategies and approaches to:
    - Avoid, minimize or adapt to the negative impacts of climate change on Jamaica's natural environment including ecosystems, species, genetic resources, ecological processes, lands and water;
    - Avoid, minimize or respond to the negative impacts of Climate Change on economic activities;
    - Reduce or avoid damage to human settlements and infrastructure caused by Climate Change;
    - Avoid or minimize the negative impact of climate change on human health;
    - Improve knowledge and understanding of climate change issues in order to obtain broad-based support for, and participation, in climate change activities;
    - Conduct systematic research and observation on Climate Change related factors in order to improve forecasting and to supply the necessary planning and response measures.
2. Foster the development and application of appropriate legal and institutional systems and management mechanisms for planning for and responding to climate change;
3. Foster the development of appropriate economic incentives to encourage public and private sector adaptation measures.

Policy Principles

The Government in collaboration with other relevant entities will:

- Fulfil to the extent possible, its commitments under the United Nations Framework Convention on Climate Change, to which Jamaica is party;
- Participate to the fullest extent possible in negotiations on various aspects of the Convention, its protocols, and articles insofar as these will meaningfully impact on the ability of Jamaica to address issues relating to climate change or on its development in general;
- Collaborate as appropriate and feasible, with other regional and international states and organisations which pursue confluent agendas in climate change;

- Endeavour to ensure that society, at all levels and in all sectors is adequately informed on climate change and its implications for the nation and the role that it must play in this respect;
- Endeavour to obtain, to the extent feasible, the involvement and participation of all stakeholders at the national level in addressing issues related to climate change;
- Endeavour to ensure that such involvement and participation occurs on an appropriately coordinated basis which minimizes duplication of effort and conflict and which ensures efficient use of resources and the creation of positive synergies;
- Endeavour to foster or create an institutional, administrative and legislative environment which engender/supports the effective implementation of climate change adaptation activities;
- Promote and support research and information gathering at the national, regional and international levels on aspects of climate and its impacts as they pertain to Jamaica.
- Ensure that adequate planning (physical, socio-economic etc.) is undertaken on a continual basis to address the impacts of climate change. Such planning should be undertaken, not in isolation but in the wider context of sustainable development;
- Endeavour, to the extent possible and necessary, to develop national human and institutional capacity in all aspects of climate change research, response, planning, etc.;
- Create an enabling environment for the adoption of appropriate technologies and practices that will assist in meeting national and international commitments with respect to the causes and effects of climate change;
- Procure/allocate financial and other resources, as appropriate and feasible, to ensure that Climate Change is addressed in the manner required;
- Recognizing that the resilience of the natural environment is key to coping with climate change, do all possible to enhance and maintain environmental quality;
- Recognizing that economic resilience is key to coping with climate change, do all possible to promote the development of a strong and diversified economy.

Application

This policy shall guide the work of all governmental, statutory, non-governmental and civic entities which are involved in, or which may seek to become involved in addressing Climate Change issues as they affect Jamaica.

The policy should provide a clear policy framework to guide adaptation in the following key areas:

a) high-quality climate change information, including improved regional climate predictions, particularly for precipitation and storm patterns;

b) land use planning and performance standards to encourage private and public investment in buildings, capital and infrastructure that are resilient to climate change as well as the protection of vulnerable utilities and facilities;

c) long term climate-sensitive policies such as natural resource and coastal protection, disaster and emergency preparedness, and relocation of vulnerable human settlements;

d) financial safety nets to help the more vulnerable sections of society, who are the least likely to afford protection;

e) develop and put in place mechanisms and/or interventions to ensure more efficient use of Jamaica's natural resources. This includes better management of water resources and the application of improved agricultural practices to enhance food security.

f) develop policies to protect vulnerable communities e.g. housing policies that would prevent the exposure of communities to flood hazards;

g) develop and implement information, education and communication programs to keep relevant audiences abreast of climate change, adaptation actions and mitigation measures.

5.7 Recommendations for Upgrading of Policies

Both the Watershed Policy and the Water Policy are in need of upgrading to reflect current concerns regarding climate change. Policies regarding the coastal zone and wetlands also need to be revised to incorporate climate change concerns.

5.8 International Conventions

International law is much different from domestic law. Domestic law describes the rights and obligations of persons and their relationship to each other and the government. Domestic legal systems almost always include general methods for enforcing laws and adjudicating disputes.

International laws set out the powers and obligations of nations. Usually only nations, not individuals, may seek enforcement of the laws. Though there is an International Court of Justice, unlike a domestic court, it has no authority to force parties to appear before it or to abide by its decisions. Often international law is established through mutual agreements or treaties, and individual treaties may spell out specific means of enforcement or resolution of disputes. These dispute resolution mechanisms may be open only to Nations party to the agreement and not to their citizens in their own right.

Sometimes international accords are not intended to be directly enforceable. Nations will sometimes sign non-binding statements of policy or principle. These may serve as a step towards future treaties, as policy guides for international organizations, or as persuasive references in policy debates involving the signing governments. Violations of the principles, however, have no defined consequences.

Nevertheless, both binding and non-binding international law may make itself felt in domestic situations. A nation may pass domestic laws to implement a treaty or international standard of behaviour. Or, a nation may simply conform its actions to the course of international aw without specific new domestic laws. For example, a country might render promised technical assistance to another without needing a change of domestic law to comply. Accords may occasionally make themselves felt through non-governmental action. For example, non-governmental organizations (NGOs) around the world have embraced the Forest Principles signed at the 1992 Rio "Earth Summit". Even industry groups have adopted codes of practice reflecting the Forest Principles.

Under Jamaican law a treaty does not become law in Jamaica until local (i.e. Jamaican) legislation is passed to implement the treaty. Thus even though the Government of Jamaica may have ratified a treaty such a treaty cannot be enforced in Jamaica unless there is Jamaican legislation implementing the treaty.

Examples of Implementation	
CITIES	Endangered Species (Protection, Conservation & Regulation of Trade) Act
Ramsar	No implementing Legislation
UNCLOS	Exclusive Economic Zone Act Maritime Areas Act.

Examples of Non-Implementation	
Convention on Biodiversity	No implementing legislation
Climate Change Convention	No implementing legislation
Kyoto Protocol	No implementing legislation

5.8.1 Climate Change Convention

The main objective of this Convention is to stabilize the level of greenhouse gases in the atmosphere, to avoid triggering rapid climate change. By signing it each party pledge to work for the reduction of greenhouse gas emissions, the protection of greenhouse gas sinks and reservoirs, and the mitigation of any effects of climate change. Each country has to make national inventories of its emissions of those greenhouse gases not regulated under the Montreal Protocol (which governs chlorofluorocarbons and related chemicals affecting the stratospheric ozone layer).

5.8.2 Kyoto Protocol

The Kyoto Protocol represents the first binding reduction target under the United Nations Framework Convention on Climate Change (UNFCCC). Under the Protocol, developed countries (Annex I Parties) agreed to reduce their emissions of greenhouse gases (GHGs) by at least 5% below 1990 levels (Art. 3.2). Individually, each Annex I Party agreed to a specific reduction target to achieve to overall goal.

The Protocol includes a number of flexibility mechanisms that are intended to provide alternatives to domestic emission reductions. These mechanisms include emissions trading (Arts. 4 and 17) (either on a case by case basis or by creating an emission bubble, such as the European Union) and joint implementation of emissions reductions between Annex I Parties and economies in transition (Art. 6). They also include a clean development mechanisms (Art. 12), which allows Annex I countries to work with non-Annex I Parties to achieve credits in non-Annex I countries and use the reductions to offset emission in the participating Annex I country.

Finally, the Protocol provides an opportunity to offset emissions beyond the country specific target by removing GHGs from the atmosphere through sinks (Arts. 3.3. and 3.43). Possible sinks include forests and soils. The details on how these flexibility mechanisms will operate have yet to be worked out.

5.8.2.1 Structure

The Protocol consists of a short preamble, 28 articles and two annexes. The preamble simply places the protocol within the context of the UNFCCC. Annex A lists the six greenhouse gases that are subject to the Protocol as well as a list of major sectors that contribute to emissions. Annex B lists the country specific emission reduction targets for Annex I countries.

Articles 1 to 3 include definitions and an overview of the overall obligations taken on by Parties. Included in these articles are the emission reduction obligations, obligations to developing countries, and provisions for sinks as a way to offset emissions (Arts. 3.3 and 3.4). Articles 4, 6, 12, and 17 provide for flexibility mechanisms, including the emissions bubble (allowing countries to meet their target as a group rather than individually), joint implementation, the clean development mechanism, and emissions trading.

Articles 5, 7 and 8 provide for determination and reporting of member countries' emissions by source and removals by sinks. Article 18 addresses the issue of compliance. The remaining articles deal with the general administration of the Protocol.

5.8.2.2. Obligations

Most of the obligations of the Protocol rest with Annex I countries. They include the country specific emission reduction targets in Annex B for the first commitment period of 2008 to 2012. This means countries have to reduce their emissions to the accepted emissions reduction target averaged over the five-year commitment period. If a country cannot meet its target in 2008, it still has four years to make up the difference.

To ensure proper accounting of emissions and trading, reporting obligations are included under Articles 5, 7 and 8. These provisions are intended to ensure a balance between national sovereignty in allowing countries to determine how they will meet their obligations for emissions reductions and international oversight to ensure that the terms of the protocol will be met. They include an obligation to show demonstrable progress toward the emission reduction target by 2005 (Art. 3.2). Other related obligations include a requirement to estimate emissions in accordance with accepted methodologies, and a requirement to keep and make public an annual inventory of GHG emissions by source and GHG removal of sinks (Art. 7).

Obligations of Annex I Parties to developing countries are set out in Articles 2.3, 3.14, 10, and 11. Article 2.3, in combination with Article 3.14 requires Annex I countries to strive to minimize adverse effects on other Parties. This includes the issue of adaptation to the adverse effects of climate change such as sea level rise and extreme weather events. It also extends to economic, social and environmental impacts of mitigation actions. Articles 10 and 11 provide for technology transfer and capacity-building in developing countries, including the provisions of new and additional financial resources. The specifics in terms of amounts of funding and processes for technology transfer and capacity-building are still under negotiation.

Non-Annex I countries take on very few obligations under the Protocol (Art. 10), and those taken on are essentially restatements of obligations under the UNFCCC. They include the development of national inventories of anthropogenic emissions by source and removal by sinks of greenhouse gases not controlled by the Montreal Protocol on Substances that Deplete the Ozone Layer (1987). Article 10 also makes general reference to an obligation to develop national and possible regional programmes to mitigate and adapt to climate change. Finally, all Member States are obliged to cooperate in research, technology transfer, education, training, and to communicate on action taken under the Protocol.

5.9 The Convention on Biological Diversity

Threats to biological diversity have increased almost everywhere in the world during recent decades, mainly as a result of the destruction of natural habitats. Requirements for the conservation of biodiversity have therefore developed far beyond what was envisaged when the first conservation conventions were concluded.

The Convention defines biological diversity as "the variability among living organisms from all sources …; this includes diversity within species, between species, and of ecosystems." That means biological diversity encompasses the genetic variation to be found within a single kind of plant or animal; the variety of different kinds of plants and animals in a given place and their relative abundance; and the variety of natural aggregations of plants and animals, such as temperate pine forests, temperate oak forests, temperate forests dominated by mixes of particular species, the many distinct kinds of tropical forests, various grasslands, and so forth.

The Convention's objectives are to help conserve biological diversity, to promote sustainable use of its elements; and to ensure fair participation in the benefits that may derive from utilization of genetic resources. The agreement sets out an international consensus on these issues and thereby creates a legal framework that will contribute to the preservation of biological diversity.

Consistent with basic international law, the Convention reiterates that States have the sovereign right to exploit their natural resources pursuant to their own environmental policies, but with the responsibility to ensure that activities within their jurisdiction or control do not cause damage to the environment of other states or of areas beyond the limits of national jurisdiction. Article 4 states that the requirements of the Convention apply not just within a State's borders, but also to all actions under the State's control, inside or outside of the State's physical jurisdiction and regardless of where their effects are felt.

The Convention requires each signing State to formulate management plans and national strategies for the conservation and sustainable use of biological diversity or to adapt the existing strategies for this same purpose, and integrate the conservation and sustainable use of biological diversity into relevant sectoral or cross-sectoral plans, programs, and policies.

As part of a global approach to conservation, the Convention on Biological Diversity accordingly places far greater emphasis upon the conservation of ecosystems than upon the protection of species as such. Under Article 6 dealing with the in-situ Conservation, parties are required, as far as possible and as appropriate, to: establish a system of protected areas or areas where special measures need to be taken to conserve biological diversity; develop, where necessary, guidelines for the selection, establishment and management of protected areas and areas where special measures need to be taken to conserve biological diversity; promote the protection of ecosystems, natural habitats and the maintenance of viable populations of species in their natural surroundings; promote environmentally sound and sustainable development in areas adjacent to protected areas with a view to furthering protection of these areas; and rehabilitate and restore degraded ecosystems and promote the recovery of threatened species, inter alia, through the development and implementation of plans or other management strategies.

The Convention contains no obligation for parties to protect the areas which are most important for the conservation of biological diversity. Annex I to the Convention only provides guidance for area selection in the form of an indicative list of components of biological diversity important for its conservation and sustainable use.

The conservation of ecosystems is also promoted through general obligations for the identification and monitoring of important components of biological diversity (Article 7). Parties are required to identify processes and categories of activities which may have significant adverse impacts on the conservation and sustainable use of biological diversity. Environmental impact assessment obligations are set out in Article 14.

5.10 Convention on Wetlands of International Importance Especially as Waterfowl Habitat, Ramsar, 1971 (Ramsar Convention)

Ramsar, which has been in force since 1975 aims to stem the progressive encroachment on and loss of wetlands, now and in the future. While Ramsar focuses on wetlands that are important for migratory waterfowl, it recognizes the overall value of wetlands, including their fundamental ecological functions and their economic, cultural, scientific and recreational value. Ramsar defines wetlands broadly to include freshwater, brackish and saltwater marshes, including marine waters up to six meters deep at low tide, and any deeper marine waters contained within the wetland area, as well as adjacent islands and coastal areas.

Ramsar parties are to designate the least one national wetland of international importance when signing the Convention or when depositing its instrument of ratification or accession; many parties have designated more than one. Designation of these areas should be an element of the process of identifying priority components of biodiversity under Article of the Convention (see Part II, Action Item 6). Under Ramsar, parties are also required to establish wetlands nature reserves and cooperate in the exchange of information for wetlands management.

5.11 Protocol Concerning Specially Protected Areas and Wildlife in the Wider Caribbean (SPAW Protocol)

The Cartegena Convention was drafted in 1983, with Jamaica signing in 1990, but has not yet formally ratified. This regional convention encourages the establishment of protected areas to conserve rare and fragile ecosystems occupied by vulnerable species, as well as the protection of endangered species and sustainable use of wildlife. While the emphasis is on the marine environment, it does include provision for protection of terrestrial species such as the Jamaican Iguana and Amazona parrots.

Jamaica signed the SPAW Protocol under the Cartagena Convention on January 18, 1990 in Kingston, Jamaica, but has yet to ratify it. Jamaica has however made a commitment to ratify the Protocol.

5.12 United Nations Convention to Combat Desertification in those Countries experiencing Serious Drought and/or Desertification, Particularly in Africa, Paris (1994)

The Convention aims to promote effective action through innovative local programs and support of international partnerships. The Convention requires the implementation of national and regional action programs, which should emphasize popular participation, and the creation of an enabling environment designed to reverse land degradation. Jamaica became a party to the Convention by accession on 12 November 1997.

5.13 Comparative Developments

There have been both policy and legislative development in several countries in regard to climate.

5.13.1 Policy

St. Lucia has climate change policy in place. In Guyana, Belize and Fiji work is well underway in finalizing their Climate Change Policies.

5.13.2 Legislation

Alberta, Canada has enacted a Climate Change and Emissions Management Act (Chapter C-16.7). The UK has enacted the Climate Change and Sustainable Emergency Act, 2000. The South Australia's State has promulgated the Climate Change and Greenhouse Emissions Act Bill.

While all these Acts primarily focus on the control or reduction of greenhouse gas emissions the South Australia's Act also includes provisions designed to facilitate the early development of policies and programs to address climate change.

5.14 Non-Binding International Agreements

5.14.1 United Nations Conference on the Sustainable Development of Small Island Developing States, Bridgetown, (1994)

The United Nations Conference on the Sustainable Development of Small Island Developing States was held in Barbados in May 1994. The participants to the UN Conference on Environment and Development (the Earth Summit) had recognized the particular needs of these countries and their dependence on marine and coastal resources, as well as the threats they faced due to climate change and sea-level rise. Consequently, Chapter 17 of Agenda 21 specifically called for the convening of this Conference. Its objectives were to examine the nature and special vulnerabilities of thee States and to define a number of specific actions and policies relating to environmental and development planning to be undertaken by these States, with help from the international community. After more than a year of negotiations, the Parties adopted the Barbados Programme of Action for the Sustainable Development of Small Island Developing States.

5.15 In Summary

A wide range of agencies are involved in the water sector. The Water Resources Authority has the responsibility for the regulation, control and management of the nation's water resources. The Water Resources Act (1995) established the Water Resources Authority (WRA) as the sole agency with responsibility for the regulation of water resources availability, including inter alia, the collection of water resources data (except precipitation), assessment, allocation, planning and management. Its main instrument of control is the issue of well drilling permits and abstraction licenses for both surface and ground water sources.

The National Water Commission (NWC) has responsibility for the public supply of drinking water and sewage treatment. The NWC operates within the policy context of the Government of Jamaica's goal of universal access to potable water by the year 2010 and the establishment of sewerage systems in all major towns by 2020. The National Irrigation Commission (NIC) has responsibility for the supply of water for agricultural and irrigation uses while the Rural Water Supply Company has the responsibility for the execution of small rural projects.

The liberalisation of Water Services Sub-sector to include the participation of Private Enterprises as set out in the National Water Policy (1999) has resulted in housing developers who develop their own water supply system to support their respective housing developments opting to operate private water systems rather than handing over to the NWC, as was previously required.

The National Irrigation Commission (NIC) is authorized to provide irrigation water nationally. Across the island it operates the Rio Cobre, St. Dorothy, Mid-Clarendon, Hounslow, Pedro Plains, Braco and the Yallahs Irrigation systems. The NIC is presently promoting the handover of these systems to Water Users Associations (i.e. the farmers themselves).

The National Water Commission Act (1980) gave the NWC authority over the water supply districts prescribed by the Minister under the National Water Authority Act (1963) and those of the Kingston and St. Andrew Water Commission. However in practice the NWC has interpreted its mandate to extend beyond those areas specified by Statute, to all areas except those supplied by the Parish Councils.

Finally, the National Environmental and Planning Agency (NEPA), implements environmental protection laws and regulations and monitors water and wastewater quality. The institutional structure is relatively recent and the actors in the sector are evolving. They are also cognizant of areas of overlap in responsibilities and seek to coordinate in these areas.

In 1999 the Cabinet approved the Water Sector Policy to enable the provision of adequate water and sewerage services. The main objectives of the Policy are universal access to water by 2010, improvement in the efficiency of the NWC, and expansion of central sewerage facilities.

Adapting to the impacts of climate change poses a difficult challenge for developing countries such as Jamaica. It is important that the government provides a clear policy framework to guide adaptation in the following key areas:

(a) high-quality climate change information, including improved regional climate predictions, particularly for precipitation and storm patterns;

(b) land use planning and performance standards to encourage private and public investments in buildings, capital, and infrastructure that are resilient to the effects of climate change, as well as protection of vulnerable utilities and facilities;

(c) long-term climate-sensitive policies such as natural resource and coastal protection, disaster and emergency preparedness, and relocation of vulnerable human settlements.

It is considered that both the policy and the legislative framework are inadequate for purposes of adapting to climate change. The key changes proposed are as follows: -

- significant strengthening of the Meteorological Office is an urgent necessity;
- institutional strengthening of the WRA, NEPA to deal with the implications of climate change;
- upgrading the Water Policy and the Watershed Policy
- preparation and approval of a Climate Change Policy
- enactment of a Disaster Management Act
- enactment of a Meteorological Act
- effective enforcement of planning and environmental legislation.

6 ECONOMIC REVIEW AND ANALYSIS

6.1 Introduction

In this section the economic context of the development of a national water sector adaptation strategy to address climate change is presented.

The term economic context is limited to include:

1) The relationship between the economy (i.e. GDP), the water sector and the current best estimates of supply and demand for water resource users who impact importantly on the economy. Threat scenarios to the social condition posed by climate change, as exemplified by issues related to residential water are also discussed.

2) The resource allocation to the water sector as indicative of both the relative importance attached to water by the Government and the likely funding constraints to adaptation strategies.

Recommendations for appropriate adaptation strategies will be introduced as appropriate.

Unless otherwise indicated the currency used in this section is Jamaican dollars.

The Planning Institute of Jamaica, in its role as the main planning agency in Jamaica, is leading and facilitating a collaborative process of planning through year 2030 called Vision 2030 Jamaica: National Development Plan. When finalised it is expected to represent an integration of thirty-two draft Sector Plans prepared by respective Task Forces. In December 2007 a preliminary draft report entitled "Situational Analysis of Jamaica's Water Sector" was published. To create a desired interface with this important though evolving report, text boxes have been inserted which contain extracted statements from this document.

Since adaptation strategies have as a principal rationale, the support and protection of the human condition, an important corollary to the impact of climate change on water resources is its induced impact on this condition. However this is a very wide net, and could legitimately include all aspects of human culture given that access to water underpins culture. A convenient proxy value for measuring the macro economic condition is the GDP and this is the main link to the economic impact of climate change used. There are also some useful development indices which assist in measuring qualitative notions of development and well being. Nevertheless, the challenge for adaptation strategies to climate change is largely the absence of a compelling cause and effect framework for interpreting, much less measuring, how climate change will impact these economic and social values, and hence the human condition.

The impact of climate change is generally perceived as being incremental, somewhat predictable and relatively long term in relation to changing conditions. Very broad predictions of global change are 'downscaled' for interpreting regional change. Hence visioning to 2080 and even beyond by extrapolation of accepted climatic relationships, is a generally standard approach. The effective planning horizon for economic change is generally much shorter term, mainly 5 to 10 years and sometimes 20 years, and this is particularly true in developing economies, Jamaica being no exception. The interface between climate change and the economy is therefore not a comfortable one, and this challenges the fashioning of a meaningful policy supportive framework.

The National Communications Support Unit of the Global Environmental Facility has been supportive of addressing this challenge and in encouraging the development of socio economic scenarios for vulnerability and adaptation assessments. However as a general comment, these approaches while offering a consensus based approach and relying heavily on per capita relationships as the basis for identifying and projecting the interface of the economy with climate change, still manage to remain remote and somewhat disconnected to the realities of how political directorships make decisions for change. The time constraint of this study did not permit engaging these pioneering approaches fully, but elements of the approach have worked their way into the review. The main approach taken is to look at the current interface between the economy and water, and on the basis of predicted changes to water resources, suggest the consequences for the economy that are implied.

6.2 The Relationship between the Economy and Water

Jamaica's consumption of water is in the order of 1,312 $10^6 m^3/yr$ million cubic metres per annum. None of this amount is imported, and an inconsequential amount is exported. Our exploited water resources support a GDP characterized by these economic groupings and relative dependency on generated water.

Table 6-1: Contribution to GDP and Water Consumption by Sector

¤ GDP CONTRIBUTORS	% CONTRIBUTION TO GDP	% TOTAL WATER CONSUMPTION
Manufacturing incl. Food	13	1
Mining and Construction	16	5
Irrigated Ag	3	33
Other Agri (Non Irrigated)	2	-
Hotels	7	0.3
Other services	65	1
Residential	-	21
Environment	-	39
Less Financial Adjustments	(7)	-
Total GDP	100	100

Source: Brace Centre for Water Resources Management (2005)
*The contribution of irrigation agriculture to GDP is taken as the equivalent of export agriculture

The economy's relationship to exploitable water resources is one in which those sectors contributing 94% of GDP (manufacturing, other services, and mining and construction) consume about 7% of exploited water resources. Conversely, the environment, irrigated agriculture and residential water account for 93% of total water consumption and contribute about 7% of GDP.[8] The proportion of exploitable water resources (total available resources) consumed in the generation of GDP would therefore be is an even smaller percentage.

A preliminary inference would be that, whereas water is indispensable to economic production, the overall loss of water resources arising from climate change would need to be of a significant order to significantly

8 Residential is a non quantified subset of the GDP grouping Households which itself contributes about 10% of the Services Sector (which includes tourism).

impact economic production. This preliminary conclusion is now examined more closely, firstly by looking at sectoral vulnerabilities.

Table 6.1 suggests that the sectors of the economy most vulnerable to loss of exploitable water resources arising from climate change would be the irrigated agricultural and the residential sub sectors. Collectively these two sub sectors absorb 54% of exploited water consumption.

The Situational Analysis Vision 2030 JNDP.(Draft)

- In 2006 Agriculture Forestry & Fishing Sector accounted for 33% GDP and 75% of fresh water use.
- Any decrease in quantity of water to this sector would have serious adverse effect on the Jamaican economy
- Commercial Fish Farming is a major user of fresh water. In 1997 it produced 3 times the amount of fish landed from the sea.
- Many agricultural practices contribute to watershed degradation. It is largest non-point source of water pollution. Nutrient run off from fertilizers leads to eutrophication in rivers lakes and the sea. Land degradation and poor land use practices affect water resources including availability and quality .
- Unsustainable land use practices abound in Jamaica.

6.2.1 Irrigated Agriculture

The National Water Resources Master Plan for Jamaica (2nd Draft) (Brace Centre for Water Resources Management, 2005) puts the economic context succinctly. Half of the potentially cultivatable land in Jamaica is currently cultivated (270,000 ha) but only 9.3% of the country's cultivated lands are presently under irrigation (25,360 ha). The impact of irrigation on cultivation is further diminished in that 60% of water actually withdrawn for irrigation is not used directly by crops. Much of non crop applied irrigation is due to inefficiencies and wastage. Of irrigated crops, reference to Table 6-2 reflects that the crops with the highest irrigated acreage are sugar, bananas and pasture collectively accounting for 90% of irrigated acreage.

Table 6-2: Irrigated Areas By Crops (Ha)

PARISH	SUGAR	BANANAS	PASTURE	ALL OTHERS	TOTAL
St. Thomas	-	953	20	443	1416
Kingston	-	-	-	8	8
St. Catherine	8103	12	1043	562	9720
Clarendon	9180	236	90	395	9901
Manchester	1102	93	21	97	1313
St Elizabeth	365	-	150	558	1073
Westmorland	136	20	40	30	226
Hanover	-	-	-	7	7
St James	24	-	-	38	62
Trelawny	413	-	-	136	549

PARISH	SUGAR	BANANAS	PASTURE	ALL OTHERS	TOTAL
St. Ann	112	33	-	147	292
St. Mary	--	627	-	61	688
Portland	-	52	-	53	105
Totals	**19,435**	**2026**	**1364**	**2535**	**25360**
Percent of total	***77***	***8***	***5***	***10***	***100***

Source: Brace Centre for Water Resources Management (2005)

Of the estimated 7% direct contribution to GDP of irrigated agriculture these three crops account for the greater proportion. However it would be misleading to conclude that the importance of these crops to the GDP is in relation to this small percentage since the value added by processing as in the case of sugar cane being manufactured into sugar, significantly increases its actual contribution. This underlines an important difficulty in correlating water consumption to GDP since at nearly all levels there is 'value added' at various transactional stages to complicate the interface.

There are other difficulties in arriving at the full picture. These can be briefly summarized:

- that sugar cultivation and manufacture are both important contributors to rural employment means that its contribution to national income generation would be considerably understated by seeing this contribution only in terms of irrigated agriculture.

- the contribution of other irrigated agricultural produce, mainly vegetables, fish and fruit which consume about 5% of total irrigated water, likely contribute significantly more directly to the economy via employment and foreign exchange earnings than does a crop like pasture.

- Non irrigation crop production probably accounts for a significant proportion of food produced for domestic consumption and would also be an important contributor to rural household incomes. Inferentially, some measure of its importance can by adduced by subtracting the value of export agriculture (mainly supported by irrigation) from the value of total agricultural production (mainly non irrigated farming). On this basis average annual domestic agricultural is about $8.65b annually whereas agricultural exports are about $3b annually.

An analogous situation exists in tourism and in fact in most other sectors of the economy If for example we were able to trace out and value the importance of environmental water flows to the economy, a major causal relationship with climate change and the economy and issues of wellbeing such as food security and poverty would be established.

Notwithstanding these limitations, there is some justification for starting with available data and examining the inferences it allows. For if, as the example of sugar suggests, primary agricultural production is impacted by climate change then presumably secondary production is also threatened even if the relationship is far from linear.

Four parishes account for 82% of all land under irrigation and are significant producers of the three main irrigated crops: St. Thomas & St. Mary (bananas), St Catherine (sugar and pasture land) and Clarendon (sugar).

An assessment of the current and future economic prospects for these crops is required, linked with the threat that climate change poses to water resources for irrigation of these crops. Results from this assessment will lead directly to the issues for adaptation strategies including considerations of crop diversification and/ or crop modification for both traditional export and domestic crop production. Reference to Table 6.3 gives some indication of the trend in important economic agricultural produce over recent years. The data includes the crops under irrigation.

Table 6-3: Production of Select Agricultural Crops 2003-2007

PRODUCE [9]	**UNITS**	**2003**	**2004**	**2005**	**2006**	**2007 (PROV)**	**ANNUAL % GROWTH**
Cane milled	Tonnes (000)	1,776	1,993	1,368	1,745	1,968	5.5
Bananas (export)	Tonnes (000)	39,936	27,657	11,560	32,428	17,473	11
Cattle Slaughter	Heads	66,532	52,379	49,624	28,451	23,413	(22)
All other crop production	Tonnes (000)	491,473	414,790	391,707	467,802	427,305	(12)

Source: Planning Institute of Jamaica (2008)

Over the five year period 2003 to 2007 the crops primarily supported by irrigation water have had relatively flat or inconsistent production performance. Sugar, banana and pasture based livestock production have been trending downwards over several years. Similarly expressed in constant prices these industries have been variable in their contribution to GDP.

Planning scenarios for increased production in these crops rests mainly on improved export markets and cost containment as follows: for sugar in ethanol production, for bananas in processed products (flour & snacks) but mainly in more competitive banana cultivation for export, and for the livestock sector, aggressive import substitution strategies for the revival of the sector. Beyond the near to medium term where the outlook remains uncertain, there is little basis for assuming significant growth of output in these sectors.

The National Irrigation Plan (1997) speaks very positively to the bringing of more cultivable land under irrigation. Utilizing some 7 crops, fifty one projects have been identified by the National Irrigation Plan and envisage 15,000 hectares of new irrigation over a 17 year period. The total gross value to GDP at full plan implementation is projected at J$9.4 billion. However market justification for this out turn, over the next 17 year period, has not been given, and some scepticism is warranted when the contribution of agriculture to GDP has been declining by about 2% per annum in real terms over the last 5 years. Aggressive import

[9] Cattle slaughter rate is used as a crude indicator of pasture production and other crop production includes both irrigated and non irrigated crops.

substitution policies that encourage domestic production and a marked increase in both labour and capital to output productivity would need to be the basis of meeting this target.

The important basins with which water resources are associated for irrigation water for the named crops are, Blue Mountain South and Blue Mountain North (bananas) Rio Cobre (sugar and pasture) and Rio Minho (sugar).

Two of these four basins (the Rio Cobre and the Rio Minho) carry the main demand for irrigation water, the estimated water balances for all 4 basins in 2005 and 2025 is shown below. 2025 is selected mainly because data from WRA is available up to that period, but it also probably represents the borderline limit of practical economic forecasting unless mainly predicated upon per capita population relationships.

Table 6-4: Estimated Irrigation Demand in year 2025 ($10^6 m^3/yr$)

BASIN –WMU	DEMAND FOR IRRIGATION WATER 2025	PROJECTED WATER BALANCES (AFTER IRRIGATION WATER ACCOUNTED FOR) 2025
I - Blue Mountain South	16.0	92.7 324.7
X – Blue Mountain North	7.5	704.7
III- Rio Cobre	270.4	53.3
IV- Rio Minho	269.7	400
Total	**563.6**	**1482.7**

Source: Annexes A2.3 and A5.3. Brace Centre for Water Resources Management (2005)

What the data reflects is that with respect to those crops absorbing 90% of irrigated water, the projected water balances in the basins mainly supporting these crops, reflects a sufficiency of exploitable water through year 2025. In fact WRA estimates that the total irrigation water requirements when satisfied, will absorb 654 $10^6 m^3/yr$ of water and still leave average surplus water balances of 3,578 $10^6 m^3/yr$ after municipal, industrial (goods and services) and environmental water have been accounted for.

One qualification to this analysis is that water transfers between basins have not been factored. Net transfers redistribute water in relation to national priorities. A second qualification is the disproportionate and distorting impact the Blue Mountain North Basin water balance has on the overall projected water balance at 2005.

In the mid range of the 2005 to 2080 climate change time horizon, i.e 2030-2050 the supply challenge therefore continues to remain a distribution challenge rather than a water resource one. Subsequent to 2050 this is shown to engage both fairly critically. Adaptation strategies that do not now factor significant improvements to water distribution infrastructure are likely to compromise future economic growth and social development significantly.

Because both irrigation and non irrigation agriculture are dependent on surface and ground water resources (though mainly groundwater) estimated changes in Q90 flows will give some indication of the likely impact for important basins and water management units supporting irrigation agriculture.

Table 6-5: Estimated Changes in Basin/WMU Q90 Flows, expressed as a% Existing Mean Annual Flow

BASIN/WMU	2005	2030	2080
I – Blue Mountain South			
15-Plaintain Garden River	8%	7%	5%
16-Morant River	23%	21%	16%
17-Yallahs River	12%	10%	6%
III- Rio Cobre			
19-Rio Cobre	36%	34%	28%
IV – Rio Minho			
20 – Rio Minho	13%	12%	8%
21 – Milk River	14%	13%	9%
22 – Gut-Alligator Hole River	65%	n/a	n/a
X – Blue Mountains North			
7 – Rio Nuevo	27.1%	n/a	n/a
8 – Oracabessa-Pagee River	27%	22%	0%
9 – Wagwater River	9%	8%	4%
10- Pencar-Buff Bay River	11%	11%	5%
11 – Spanish River	15%	14%	7%
12 – Swift River	11%	10%	4%
13 – Rio Grande	10%	9%	6%
14 – Drivers River	24%	23%	13%

Adapted from Table 3-14 . Section 3

These forecasts are part of a declining trend in the Q90 flows although through 2030 these declines are very modest in relation to 2005. The climate change features of significance include climatic variability some features of which have been projected to be as follows by 2050:

- Length of rainy season down by 7-8%
- Length of dry season up by 6-8%
- Increased frequency of intense rains – projected to increase 20%
- More intense hurricanes, likely increasing disaster losses.

For the crops mainly consuming irrigation water, (sugar, banana and pasture) variability in duration of the rainy or drought seasons in the projected order of magnitude, is considered by RADA specialists spoken to, to be within limits that can be adapted for, either by the application of increased irrigation (assuming water is available), the reintroduction of water harvesting, use of alternative water sources such as treated sewage effluent or through drought resistant crop modification. Because of the large and open land areas involved, adaptation strategies in relation to disasters will rely mainly on better watershed management, and flood control through improved drainage systems including river training. Also more rapid response systems in which recovery assistance and its distribution could be effected particularly where smaller and more vulnerable farm units are impacted.

Most critically will be the implication on all crops but particularly bananas of more intense hurricanes. The passage of Hurricane Dean (category 5) in August 2007 destroyed 2,359 ha of bananas halting all production for the remainder of 2007 and inflicting an estimated loss of $525M on the sector (ESSJ 2007 PIOJ .

The climatic changes described above will also affect other irrigated and non irrigated crops. These would collectively be important to the remaining contribution of agriculture. In this regard a comment on how climate change impacts crop production is appropriate. The direct effect of climate change has to do with temperature and moisture levels.

Tropical agriculture is resistant to reasonable vagaries in both of these variables. As mentioned above our main export crops, sugar and bananas, are said to be able to handle the climatic variability mentioned above. One adaptation strategy will be to carefully research the hardiness of other export crops (coffee for example) and in particular our non traditional export crops to determine their resilience to such changes and whether climatic changes will induce increased or reduced yields, which can best be determined by research including climate, economic and yield modelling.

The impact of shortfalls in irrigation water over time and based on projections to 2080, will also pose a significant threat to agriculture and should challenge the implementation of adaptation strategies, some of which are mentioned below.

The indirect effect of climate change on crop production efficiency has to do with CO_2 levels. CO_2 enrichment increases photosynthetic rates and water use efficiency. This can be accepted as also applying to a wide range of local crops. There will therefore be some compensating tendencies to water loss by this biological process itself, and this needs to be better understood by research.

Some adaptation strategies directed at crop production efficiency must include:

- investigation of important pests and plant diseases including weeds and their responses to climatic changes, as these have an important bearing on crop productivity.
- investigation of genetic diversity within crop types that might be better suited and called upon to compensate for climatic variability.
- Engagement of main stakeholders in areas such as plant breeding, agrochemicals and fertilizers, irrigation and agricultural equipment on the implications of climate change and responses by these crop based industries.

The impact of sea level rise and potential for saline intrusion into the aquifers is of importance to agricultural areas. Where appropriate adaptation strategies could reduce / redistribute abstractions in these areas while encouraging the recharge of these aquifers, as well as encouraging the use of alternative surface water sources, with reservoir storage, if available, for example St. Catherine.

Findings indicate whereas irrigation water is indispensable to increasing agricultural production, the overall loss of water resources arising from climate change up to 2030 and closer to 2050, should not significantly impact crop production dependent on irrigation.

A major threat to crop production and the wider agricultural sector arising from climate change relates to projected increasingly intense and hostile weather conditions. The loss to agriculture caused by the passage of Hurricane Dean in 2007 has been estimated at $9 billion (ESSJ 2007 PIOJ). This estimate reflects both the loss to employment, foreign exchange earnings, produce and facilities.

Adaptation strategies, elsewhere mentioned, that address the environmental challenges such as watershed management, flood control, and food security are the main defences that can be mounted against such catastrophic loss.

6.2.2 Residential Water Demand

Residences accounted for 21% of total water consumption in 2005, the next largest category after irrigated agriculture.

No convenient link between the consumption of residential water and the GDP can be made. The household sector's contribution to GDP captures monetary household services but not the value added by residential water consumption to these services. Nevertheless, some measure of the importance of residential water as a resource can be inferred by its share in total water demand.

The allocation of total water consumption among sectors is reflected in the table below.

Table 6-6: Total Water Consumption by Consumers 2005 and 2025 ($10^6 m^3/yr$)

	RESIDENTIAL	COMMERCIAL	TOURISM	AGRICULTURE	INDUSTRY	ENV	TOTAL
2005	219.1	54.8	3.6	439	86	510	1,312
%	16.7	4.2	0.3	33.4	6.6	38.9	100
2025	271.4	67.8	5.9	654	128.8	510	1,637.9
%	16.6	4.1	0.36	39.9	7.9	31.1	100
% Change	24	24	63	49	50	0	25
Average annual % Increase over period	1.2	1.2	3.2	2.5	2.5	1.6	

Source: Brace Centre for Water Resources Management (2005).

Residential water consumption accounted for a total of 17% of water demand in 2005 and is projected to account for a similar percentage in 2025. Over the 20 year period 2005 to 2025 it will grow on average by 1.2 % per annum.

If residential consumption cannot be quantitatively linked to the economy, it can be qualitatively linked into the equally critical issues of development and societal wellbeing. Access of a population to potable water is an important poverty index. Two sets of available data are indicative.

Table 6-7: Total Domestic Water Consumption 2003 to 2007

YEAR	UNITS	2003	2004	2005	2006	2007
Non-Revenue Water (NRW)		197.1	185.6	202.1	199.1	199.1
Revenue Water Consumed	10^6m^3	96.3	94.7	94.4	95.3	94.5
Total Water Consumption	10^6m^3	**293.4**	**280.3**	**296.5**	**294.4**	**293.6**
NRW as a percent of total Consumption		67	66	68	68	68
Revenue	$b	5,8	7.3	8.4	9.2	9.6

Source: Planning Institute of Jamaica (2008)

Non-Revenue water, which is estimated by the National Water Commission as being close to 70% arises from several features of the water distribution function.

- The loss of water to leaks and the failure to detect and rectify them quickly when they occur but also to repair them effectively:
- Water theft associated with many communities.
- Reliance on estimates because of lack of metering or inadequacies in the metering system.

Although some proportion of water theft is opportunistic anti social behaviour a significant element must be assumed to be based on survival strategies adopted by the poor. The percentage of non revenue water which is attributable to such survival strategies is unknown, but non revenue collection on close to 70 percent of water production suggests it could be significant.

High levels of non-revenue water consumption are very likely to be positively correlated to poverty. A 1996 Planning Institute of Jamaica estimate of poverty distribution listed 506 communities island wide as living in poverty and despite the problems of inner city communities in the KMA, poverty was shown to be most severe in the rural areas.

An even more indicative relationship between water and wellbeing is the percentage of the population estimated to have access to potable water.

Table 6-8: Percentage of Population with access to Potable Water

YEAR	2002	2003	2004	2005	2006	2007
% Access to Clean Water	78.5	n/a	79.4	77.7	74.5	74.5

Source: Planning Institute of Jamaica (2008)

Increasing the percent of population with access to potable water remains a stated priority of Government. Climate change will challenge this objective mainly in relation to the resource commitment required to improve water quality in:

1. population dense areas whose aquifers are threatened by saline intrusion,
2. diminished supply in populated areas where reduced stream flow threatens this source of supply.

Residential water consumption therefore is one important basis for measuring wellbeing.

In evaluating the threat to residential water consumption by climate change one starting point is to relate the demand for residential water to reliable surface and safe ground water yields from the regional sources of supply. Table 6.9 shows these yields for 5 MWUs serving the highest population centres and therefore the basins and WMUs from which the demand for residential water is highest.

Table 6-9: Residential Demand and Safe Ground Water Yield and Reliable Surface Water Flow in High Population MWUs (2005)

BASINS	**MWU**	**RESIDENTIAL DEMAND ($10^6 M^3/YR$)**	**SAFE GW YIELD AND RELIABLE SURFACE FLOW ($10^6 M^3/YR$)**
Kingston	Hope River	60.50	74.5
Rio Cobre	Rio Cobre	48.30	483.7
Rio Minho	Rio Minho	11.18	266.1
Great River	Montego River	12.45	209.8
Dry Harbour Mt	Rio Bueno White River	11.81	641.8
Total		**144.24**	**1,675.9**
All	**Jamaica**	**219.1**	**5,214.9**

Source: Brace Centre for Water Resources Management (2005)

Table 6.10 compares residential water demand with water balances in 2005 and 2025 for three WMUs which serve four parishes. These parishes contain a total of 198 communities in poverty (or 45% of all such communities identified as being in poverty).

Table 6-10: Water Demand Balances and Poverty in 4 High Water Demand Parishes .

WMUS SERVING 4 KEY PARISHES WITH A TOTAL 198 COMMUNITIES IN POVERTY (OR 45% OF COMMUNITIES IN POVERTY- BASELINE 1996)				
WMUs	**Residential Demand**		**Water Demand Balances**	
	2005	2025	2005	2025
Hope River	60.54	64.11	-13.1	-22.3
Rio Cobre	50.72	80.88	178.5	53.3
Rio Minho	11.33	14.36	90.3	63.1

Data Sources: Planning Institute of Jamaica (2008); Brace Centre for Water Resources Management (2005)

The impact of climate change up to 2025 on downstream water balances in three highly stressed MWUs can be seen. Residential demand in the communities served by the Hope River WMU in 2025 if other sections of water demand are curtailed. However modest positive water balances will exist for Rio Cobre and Rio Minho.

Important to the health of the population and its economic productivity, is that both wellbeing and poverty reduction require an adequate supply of clean water. In any future competition for water resources, while water for life may be available, clean water from treated sources is likely to be a expensive challenge.. The implications of this are very serious for water resource management and the need exists during the current period for appropriate adaptation strategies to be forged and implemented. .

The Situational Analysis Vision 2030 JNDP (Draft)

- The availability and quality of freshwater has social implications as freshwater is necessary for good health and poverty alleviation.
- Recent studies suggest that exposure to organic and inorganic chemicals in drinking water may significantly contribute to chronic disease.
- Environmental degradation only deepens poverty, so environmental conservation and poverty alleviation are parallel objectives.
- Jamaica has made significant progress in providing water services.
- The percentage of households with piped water has risen from 61% in 1990 to 67% in 1997. Over the same period the percent of households relying on water from rivers, springs and ponds has fallen from 5.7% to 3.8% while the use of pit latrines and other types of sanitation has declined commensurately
- Unfortunately the poorest 20% of the population has not shared in these improvements
- Many people in rural areas still do not have access to safe drinking water, or must make excessive efforts to fetch water.
- One third of the poorest households rely on standpipes for their water and 30% obtain their water from untreated sources such as rivers.
- Only 21% of the poorest households have flush toilets.
- Rapid urbanization in the developing world (will lead) to higher per capita water demands of the more affluent urban dwellers (and) will divert water from agricultural use. Water shortage also increases social equity.

6.2.3 Food Security

The issue of food security can be an expected fall-out of the above climate change scenario on water resources. Based on data derived by the Caribbean Food and Nutrition Institute in 1994, and reported on by the Ministry of Agriculture[10] , 10 percent of the population or just over three quarter of a million Jamaicans can be regarded as food insecure. This estimate of under nourishment may be declining in relative terms if certain trends are accepted, for example, the reported reduction in the levels of poverty. An increase in the mean per capita consumption and some reduction in malnutrition in children under 5 years (PIOJ, 2007) but in absolute terms the number may in fact be increasing and a need exists to update this research.

Depth of hunger, a measure of food insecurity, is characterized as moderate in Jamaica mainly because of an assumption that most of the undernourished population access enough of the starch staple foods but

[10] An Assessment of Food Security In Jamaica . The Ministry of Agriculture. 2001

lack a variety of other foods essential to a nutritious diet. As a little reflection will show adequate water resources underpin the current mitigation strategies proposed to address food security. These strategies include:

- The reduction in the level of poverty to reduce under nourishment.
- A priority focus on increasing agricultural output and productivity so as to reduce prices and reduce the net of food insecure persons.
- Macro-economic policies should support the production of food for export but also domestic production.
- The need to improve coordination of planning and policies for activities that impact the food sector.

The effect of increased climate variability with increasing floods and intense weather systems as well as potentially more frequent drought events is perhaps the single most pressing threat to agriculture posed by climate change and some of the adaptation strategies suggested elsewhere in this report are predicated on this concern for agricultural output.

6.2.4 The Hotel Sector

Indicators of tourism growth over the period 2003 to 2007 are given in Table 6.11**.**

Table 6-11: Indicators of Growth In Tourism

YEAR	2003	2004	2005	2006	2007	ANNUAL AVG % CHANGE
Visitor Arrivals (Millions)	2.48	2.51	2.61	3.01	2.88	4
Foreign Exchange Earnings $US(billions)	1.32	1.41	1.55	1.87	1.93	10
Employment (000) (accommodation sector)	30.5	31.0	31.2	33.60	N/A	3

Source: Planning Institute of Jamaica (2008)

This sector contributed about $106 billion to GDP or about 24% of total in 2005 (current prices). On average, tourism earning have increased by 10% per annum over the last 5 years. This figure as well as the sectors contribution to GDP is expected to continue growing. Governments stated target for growth in the industry is to achieve a 15% contribution to GDP over the next 10 years. Its contribution to employment is also important and has remained fairly steady at around the 30,000 mark over the last 5 years.

Although the hotel sector contributes significantly to GDP (24%) it consumes a relatively insignificant proportion of total water demand. The hotel sector consumes about 4 $x10^6$ m^3 of water per year or less than 0.3% of total water consumption. Projections for the hotel sector's demand for water are shown in Table 6.12.

Table 6-12: Hotel Sector Demand For Water

	2005	2015	2025	AVERAGE ANNUAL % CHANGE
Rooms	19,494	25,929	31,775	3%
Tourism Water Demand 106 M3/year $10^6 m^3$/yr	3.59	4.77	5.85	3%
Total Water Demand $10^6 m^3$/yr	1,312	1,512	1,637	1.2%
% of Hotel Consumption in Total Demand	0.27	0.35	0.35	(0.4%)
Total Water Surplus 106 M3/year $10^6 m^3$/yr	3,903	3,703	3,578	(0.4%)

Source: Brace Centre for Water Resources (2005)

What then are the threats to the sector posed by likely climate change scenarios? The sector represents a good example of the multiple threats that have economic consequences arising from climate change scenarios not directly caused by the availability of water. For example, if room stock sustains the 3% per annum increase target to year 2025 then implied consumption of water by the sector remain at 0.35% of total demand. If the relationship between increases in room stock and water consumption in total demand retain their same order of magnitude moving through 2050 and 2080, then it is likely that the economic threat of climate change for the sector will arise more from sea level rise and land inundation than from the availability of water because of saline intrusion of coastal aquifers or diminishing stream flows. This statement is supported by the following observations:

The hotel sector (as also the tourism industry) is almost entirely centered on the north coast of the island. Elsewhere (Section 3) the projected increases in sea level rise around the coasts of Jamaica ranges from 0.18m to 0.59m by the 2090s (IPCC, 2007a).

Although the hydrostratigraphy of the north coast is well documented and understood, the impact of projected sea level rise on saline intrusion into the predominantly limestone aquifers protected as they are by the basal and limestone aquicludes that stretch along the northern coastal zone, remains speculative. Further, in 2025 the supporting basins of Great River, Martha Brae, Dry Harbour Mountains (Blue Mountain N being intentionally excluded) are projected to have average water surpluses in excess of 300% of projected demand.
Although an expensive option, if required, water treatment combined with re-distribution strategies, will in all probability be less expensive to the economy than loss of beach resources due to sea level rise. This however remains to be confirmed by research.

Stronger hurricanes and more intense weather patterns pose a direct threat to the hotel sector. Although its high season happens to coincide with the close of the North Atlantic hurricane season, tourism is now, essentially a year round industry. Hurricane Dean (2007) inflicted damages on the industry estimated to be $43.7M. The direction and duration of that event however, favoured the North Coast. The loss to agriculture on the other hand has been estimated at $9 billion (ESSJ 2008 PIOJ).

6.2.5 The Manufacturing and Industrial Sector

Indicators of the performance of these sectors over the period 2003 to 2007 are given in Table 6.13.

Table 6-13: Indicators of Growth In the Manufacturing/Industrial Sectors J$B

YEAR		2003	2004	2005	2006	2007	ANNUAL AVG % CHANGE
Contribution to GDP	J$b	67.5	70.0	71.7	70.8	72.0	2.2
Percent of GDP	%	28.7	29.7	30.5	30.1	30.6	

Source: Planning Institute of Jamaica (2008)

These sectors contributed about $71 billion to GDP or about 28% of total in 2007 (constant prices) On average, these sectors earnings have been growing by 2.2 % per annum over the last 5 years. Their contribution to employment is also important and in 2007 stood at about 195,000, a 1.4% increase over 2006.

The manufacturing/industrial sectors in contributing 30.5% to GDP in 2005 contributed only 6% to the total demand for water. Projections for these sectors demand for water are shown in Table 6.14.

Table 6-14: Manufacturing/Industrial Sectors Demand For Water

YEARS	2005	2015	2025	AVERAGE ANNUAL % CHANGE
Sectors Water Demand $10^6 m^3/yr$	85.8	107.3	128.8	2.5%
Total Water Demand $10^6 m^3/yr$	1,312	1,512	1,637	
% of Total Demand	6.5	7.1	7.9	1.1%
Total Water Surplus $10^6 m^3/yr$	3,903	3,703	3,578	(0.4%)

Source: Brace Centre for Water Resources (2005)

Within this sectoral grouping the significant user of water is the bauxite industry which currently consumes 81% of the sector's demand. This suggests that there will be a significant correlation between the manufacturing/industrial demand for water in the future and the fortunes of this industry (Table 6.15).

Table 6-15: Trends in Local Bauxite Production and International Aluminum Consumption.

(% Change)

YEAR		2004	2005	2006	2007
Trends in Local Bauxite Production	% change	1	6	5	-2
Trends in World Aluminum Consumption	% change	10	5	8	10

Source: Planning Institute of Jamaica (2008)

World aluminium consumption has been trending upwards at a somewhat faster rate than local bauxite production. Whether this is a production cost challenge or the nature of international marketing arrangements over which, Jamaica exerts little control, a working assumption is that the industry will remain an important contributor to Jamaica's GDP into the 2050's at least.

The bauxite industry's relationship to water resources suggests that over the 20 year period 2005 to 2025 the sector's demand for water will have grown by 50% or 2.5% annually. In 2025 the annual average demand for all industrial water will account for only 7.9% of total water demand. Assuming that structural changes in the economy support this water consumption relationship into 2030 and 2050 even approximately, Table 6.16 gives some indication of the implications of the climate change scenario for the bauxite industry. In Table 6.16, the focus is on two Basins / MWUs: The Rio Cobre and the Rio Minho for which climate change impact has been modelled through 2050. However the water balances in both Basins/WMU's for 2050 are based on assumed constant demands for bauxite water from 2025 onwards and therefore the negative balances indicated would be increased if the 2.5% growth rate in water demand by the bauxite sector is actually maintained. Currently from water consumption data, these Basins/MWU's support about 50% of water demand by the entire Bauxite Industry.

Table 6-16: Future Bauxite Water Demand in 2 Stressed WMUs

YEAR	2005	2050
Bauxite Water Demand $10^6 m^3/yr$ [11]	32	48
Rio Cobre Water Balances	178	- 40
Rio Minho Water Balances	90	20

Future water availability to bauxite in these two basins/ WMUs becomes a serious challenge in the period leading up to 2050 and could significantly impact productivity unless adaptation strategies are put in place. To a lesser extent these challenges could face the rest of the industry.

The diversion of water from nearby basins with positive balances may be the preferred cost benefit solution for the economy. Technological improvements that might reduce the use of water in bauxite production could offer some hope. Alternatively, the desalination of sea water for industrial use may by then be economically feasible for industrial use. These are all areas that the Jamaica Bauxite Industry would need to give some consideration.

The majority of the manufacturing sub sector, though much smaller consumers of water resources, are also mainly located in these basins and the options for adaptation suggested above, may equally apply to them.

6.3 Environmental Water

The contribution of environmental water to the economy is not in doubt. A value measure of this however remains highly elusive and very speculative. However if it is accepted that environmental water significantly impacts the economy it also follows that in the future under our assumed climate change scenarios, environmental water will assume even more relative importance.

[11] Based on projecting water demand for bauxite between 2005 and 2025 at an annual average of 2.5%

The Situational Analysis Vision 2030 JNDP (Draft)

- Jamaica's water resources are quite extensive and support diverse ecosystems
- However the areas of high demand are often far away from the required sources.
- Demand for water and the exploitable water resources of the island are unevenly distributed.
- The greatest demand for water occurring in the south and most of the available water being in the north.
- The water resources are adequate to supply the needs of the Island for the foreseeable future.

A useful perspective on the issue may be had by using the estimated water resources availability modelled to 2050 and 2080 in Table 3-12 (Section 3).

Table 6-17: Environmental Water Consumption As a Proxy Value for Ecosystem Threat

	ENVIRONMENTAL WATER[1] 2005 INTO 2080	**WATER BALANCE 2005**	**WATER BALANCE 2080**	**RELATIVE SHARE OF ENV WATER IN WATER BALANCE**	
				2005	**2080**
Hope River	2.3	53.6	12.8	4.3%	18%
Rio Cobre	37.8	145.9	-100.6	26%	39%
Rio Minho	5.8	91.0	-67.6	6.4%	9%

Source: 1: Brace Centre for Water Resources Management (2005)

Since environmental water (or flows) is defined as the flow of water required by rivers to maintain their functions and in-stream ecosystems, the measure of these flows must be a constant for any given system of ecosystems. We have no appropriate measure of how ecosystems will respond or regroup to climate change. It follows however that as water balances change (partly as a consequence of diminished stream flows) these minimum flows that determine the value of environmental water flows, will change.

In 2080 therefore the percentage of environmental water in declining water balances must also be an indicator of its relative diminution .and we can at least infer that serious ecosystem loss or radical modification will take place as one approaches 2080.

Jamaica's efforts towards achieving sustainable development will be supportive of maintaining biodiversity. The threat to biodiversity lies largely in the human condition, so that issues of pollution, deforestation, overgrazing, dumping are all part of the solution of maintaining or increasing the environmental water proportion in total water demand. Such a trend will indicate that biodiversity is under less threat.

While the relationship between environmental water resources and the economy may never be reliably measurable, future trends in the following indicators of sustainable development will point to which way water resources and its relationship to the economy is trending.

Table 6-18: Sustainability Indicators

INDICATORS	2003	2004	2005	2006	2007
Quality of Life					
% of households with access to piped water	n/a	79	77	74	74
% of households squatting	n/a	0.1	1.2	1.2	1.2
Poverty					
% of households below poverty line	14.8	11.9	10.6	10.3	10.3
Gini Coefficient	0.3791	0.3826	0.381	0.3826	0.3826
Environment					
Rate of Deforestation	0.1	0.1	0.1	0.1	0.1
Energy Consumption per capita (FOE)	9.3	9.2	10.6	11.2	10.3

Source: Planning Institute of Jamaica (2008)

6.4 Resource Allocation to Climate Change

Throughout this document recommendations for adaptation strategies have been made. It can be assumed that some will need little or no additional funding as for example where administrative or legislative changes are required or projects more efficiently managed, while others will require a commitment of significant allocations, in some instances over extended periods of time.

Resource allocation to the water sector comes from three main areas:

- Central Government subventions which mainly target recurrent expenses
- income generated by the respective agencies and
- technical assistance funds received from bilateral or multilateral sources.

Government's stated development priorities are not certain indicators of how resources will be allocated. They are even less reliable indicators of whether promised funds will be allocated.

Past allocations to the water sector are therefore as good an indicator as any of its short term future support to the water sector.

Table 6-19: Estimated Financial Resources Used by The Water Sector J$M. (2003-2006)

AGENCY	2003	2004	2005	2006	AVG ANNUAL RESOURCES (2003-2005)
WRA Income	61.8	90.1*/	71.9	n/a	74.6
Operating Exp	56.1	95.1	72.9	n/a	74.4
Capital Projects	1.3	0.72	1.2	n/a	1.1
NIC Income	343.9	348.4	411.9	439.3	368.0
Operating Exp	307.4	346.3	390.8	417.4	348.2

AGENCY	2003	2004	2005	2006	AVG ANNUAL RESOURCES (2003-2005)
Capital Projects	10.4	24.9	21.9	49.6	19.0
NWC Income	5,145	6,124	7,574	na	6,264
Operating Exp	5,752	6,397	7,250	na	6,466
Capital Projects	1300	2,000	1400	Na	1567
RWS	-	-	-	-	-
Central Gov's Subventions to Water Sector	331.0	314.8	471.8	702.7	455.1
% Total Central Gov Exp.	0.1	0.1	0.1	0.2	0.1

Sources: 1. Annual Reports 2004 -2007 from the respective agencies where available. 2. Planning Institute of Jamaica (2008)

Over the four year period (2003-2006) of comparable data, on average the annual resources available to the water sector amounted to $7.16 billion of which approximately 87% was accounted for by the NWC. This figure includes GOJ's subventions and technical assistance funds, but excludes data for the Rural Water Supply Ltd. Local Government water projects absorbed an additional $58m annually. Of the $7.16 billion available annually $6.88 billion was actually spent. Capital expenditures averaged $1.59 billion each year of which NWC accounted for 98%.

Government's subventions to the water sector amounted on average to $455M. These subventions have increased annually by about 31% but represent only about 0.1% of its total annual budget. This is most likely because these agencies have been mandated to earn their way through user fees etc.

Many of the programs currently undertaken by the agencies can be seen as adaptation strategies or complementary to them, as for example the KMA Water Supply Project. Further, projects undertaken in other sectors may be supportive of adaptation strategies required in the water sector. Nevertheless, climate change's main threat is arguably to the water sector and specific interventions for adaptation need to be expanded or implemented or conceptualized with increasing urgency. Even without a clearly prioritized and costed adaptation to climate change strategy, the question can still be posed as to what are the prospects of adequate additional funding being available to meet the challenge? The following observations militate against optimism. They can be stated without much elaboration.

- Central Governments subventions to the water sector remain at less than half of one percent of sectoral allocations.
- With almost 70 cents in each dollar of Government expenditure paying down national debt there seems to be little room within which to be responsive.

- Climate change is only now, beginning to find its way into the language of the budget presentations and has yet to reflect, in budgetary allotments to any ministry, that its significance is fully appreciated. Education and health and crime are where the priorities have been ordered.
- Water sector agencies can only 'pay their way' by increasing user fees or by attracting technical assistance flows. In low income economies this is a dilemma.
- International agencies place Jamaica in the mid range of the Emerging Market and Developing Countries where technical assistance flows are very competitive. Although there appears to be a shift of concern towards climate change and away from poverty alleviation much as the shift once occurred between structural adjustment and liberalization, Climate change is a world wide phenomena and Jamaica is but one of some 52 SIDs.
- Of Official Development Assistance (ODA) received by Jamaica in 2007 of $7.6 billion, water sector projects received about $1.38 billion or about 18%.

The current ODA projects in the water sector referred to above are summarized in Table 6.20.

Table 6-20: Water Sector Share in Official Development Assistance

PROJECT	**EXPENDITURE TO DEC 2007 $JM**
Broadgate Water Supply Scheme. SM.	36.3
Redwood water Supply Scheme SC	38.7
Hudderfield/Mango Valley Scheme SM	74.0
Rural Water Supply Project. Phase 11. C. M. P.	97.2
Rural Water Program. SE. C. ST S M	434.5
KMA Water Supply Project. KMA	689.7
Total	**1,370.40**

Planning Institute of Jamaica (2008)

The range of projects and their objectives are not evenly important to the water sector. Other than the large scale KMA project and the Rural Water Program, they seem relatively modest in light of the challenges of climate change now beginning to take shape.

6.5 An Outline Approach for Developing Socio Economic Scenarios for Use in Vulnerability and Adaptation Assessments

Earlier in this report, the challenge for adaptation strategies was represented as partly the difficulty of predicting the interface of the economy and climate change over long periods of time. Reference was made to the efforts of The Global Environmental Facility through its National Communications Support Unit in encouraging research towards a better understanding of this interface.

Although time, available data and most importantly the essential consultative process, has not permitted an attempt at working through the model for Jamaica, a description of the approach will perhaps point to the direction that a research project might take. For a more detailed appreciation of the methodological steps required two sources can be consulted:

Global Environmental Facility- National Communications Support Handbook: Economic Scenarios for Use in Vulnerability and Adaptation Assessments (April 2004). Malone, Elizabeth L; Joel B. Smith, Antionette L. Brnkert, Brian Hurd, Richard H. Moss, and Daniell Bouille (2004) SRES projections for Region ALM are calculated from the web site: http://sres.ciesin.org/OpenProcess/.

The Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC's) produced a Special Report on Emission Scenarios (2000) now generally abbreviated to SRES. A scenario is described as an "internally consistent set of interrelated variables to form a whole picture of what a country sector or locality might be like at some future date". Several regional scenarios were developed each with values projected for a wide range of socio economic indicators that were considered useful for use in vulnerability and adaptation assessments. Scenarios reflected one of four sets of assumptions about the world development profile over time, from A1 & A2 through B1 & B2, where A1 represents a very rapid future economic growth process highly internationalized and B2 represents a world development profile in which the emphasis is on local solutions for economic social and environmental sustainability and a more diverse technological change and intermediate levels of economic development.

Table 6.21 presents the average values relating to countries belonging to the ALM Region which comprises developing countries in Latin America Sub-Sahara Africa and North Africa assuming the B2 scenario for world development. The selection of this scenario was very judgmental but has the benefit of being the most conservative. The models acceptance assumes that Jamaica's values are more closely related to these means than would be the case for the other 3 scenarios.

Table 6-21: Socio Economic Indices Developed from SRES modeling for ALM Region.

SOCIO ECON INDICES	1990	2010	2030	2050	2080
% Increase GDP	0	136	521	1310	3300
%Increase in Population	0	55	120	180	232
%Increases in Rural Populations	0	56	54	-	-
% Decrease(-) in cropland	0	-9	-10	-16	-37
% Increase in Final Energy Use Electricity	0	85	259	574	1200
% Increase in $S0_2$ Emissions	0	35	60	115	50

Table 6.22 (unpopulated) presents the framework within which Estimated Basic Food Demand is calculated for a country. The intention is that these estimates would be derived through consensus seeking with key stakeholders and linked where helpful to the projected economic scenarios developed in Table 6.21. As

agriculture is the major consumer of water resources, this justifies the selectivity of the variables estimated for.

Table 6-22: Estimated Basic Food Demand for Applying D (percentage changes from the ALM 1990 base year).

	2010	**2030**	**2050**	**2080**
Population % Change (Table 6.21)				
Estimated Change in GDP (ditto)				
Estimated Change in Total Food Consumption.				
Estimated Total Cereal Needs				
Estimated Import and Food Aid Share				
Estimated - in-Country Production				
Average Cereal Crop Yield				
Estimated percentage increase in crop yields				

The water resource situation is the developed by the same process of consultation (Table 6.23). Data centres such as the Water Resources Authority and the National Water Commission are key stakeholders in this process.

Table 6-23: Water Resource Situation for Applying D (percentage changes from the ALM 1990 base year)

	2010	2030	2050	2080
Population Change %				
GDP Change %				
Level of Development of Domestic Water Resources				
Annual Withdrawals				
Per Capita Annual Withdrawals				
Agricultural Water Consumption %				
Industrial Water Consumption %				
Residential Water Consumption				

The relationship between Tables 6.21 which represent regional scenarios and Tables 6.22 and 6.23 which relate to the national situation is essentially one of "downscaling". A formulae has been arrived for doing this which can be stated as follows:

Baseline data *(1+D/100) where D stands for the percentage change from the 1990 regional data (Table 6.21).

This will calculate country specific projections which can then conveniently be graphed against for example income per capita.

Provision is also made for the introduction of such social indices as population density, literacy rates, Gini coefficient, unmanaged land (proxy for squatting) and pollution indicators (SO_X).

6.6 In Summary

The effective planning horizon for economic change is generally not much longer than 20 years. Therefore the interface between climate change scenarios 2030-2080 and the economy is not a comfortable one and challenges the meaningful extrapolation of the economy into those time periods.

The approach taken is to examine the current relationship between water consumption and the economy as a basis for suggesting how this relationship might change given expected climate change scenarios.

Currently this relationship is one in which 4 main economic sectors, contributing 93% of GDP consume about 7% of exploited water resources while three major consumers of water, the environment, irrigated agriculture and residential water consume about 93% of total exploited water resource but directly contribute only 7% of measurable GDP.

With respect to irrigated agriculture, which accounts for about one third of annual water use, three crops account for 90% of the land under irrigation. Also four parishes, accounting for 82% of all land under irrigation are significant producers of the three main irrigated crops: St. Thomas and St. Mary (bananas), St Catherine (sugar and pasture land) and Clarendon (cane). The projected water balances in the four basins mainly supporting these crops, reflects a sufficiency of exploitable water through year 2025 and 2030, although in two basins Rio Cobre and Rio Minho serious challenges already arise in balancing competing demands for usable water. With the exceptions noted however, whereas irrigation water is indispensible to increasing agricultural production, the overall loss of water resources arising from climate change up to 2030 and closer to 2050, should not significantly impact crop production dependent on irrigation. A more serious threat to agricultural produce is likely to arise from projected increasing climate variability (storms & droughts) Residences accounted for 21% of total water consumption in 2005, the next largest category after irrigated agriculture. No convenient link between the consumption of residential water and the GDP can be made. Over the 20 year period 2005 to 2025 it will grow on average by 1.2 % per annum. Climate change will challenge the objective of ensuring clean water supply to population dense areas whose aquifers are threatened by saline intrusion and in diminished supply in populated areas where reduced stream flow threatens this source of supply. Based on preliminary water balance modelling in three highly stressed MWUs, residential demand in 2080 will only be satisfied if other areas of water demand are re-allocated or demands are reduced.

Poverty reduction and food security are both important issues on which an adequate supply of clean water will impact.

Although the hotel sector contributes significantly to GDP (24%) it consumes a relatively insignificant proportion of total water demand, less than 0.3%. Based on projections by WRA for the hotel sectors demand for water it is possible that the economic threat of climate change for the sector will arise more from sea level rise and land inundation than from the availability of water because of saline intrusion of coastal aquifers or diminishing stream flows. Water treatment combined with re-distribution strategies, will in all probability be less expensive to the economy than loss of beach resources due to sea level rise. This however remains to be confirmed by research.

The manufacturing/industrial sectors in contributing 30.5% to GDP in 2005 contributed only 6% to the total demand for water. Within this sectoral grouping the significant user of water is the bauxite industry which currently consumes 81% of the sectors demand. Future water availability to bauxite in two basins/WMUs which support about half of bauxite production (Rio Cobre and Rio Minho) becomes a serious challenge leading up to the 2050 period and could significantly impact productivity unless adaptation strategies are put in place. To a lesser extent these challenges could face the rest of the industry. The diversion of water from nearby basins with positive balances may be the preferred cost benefit solution for the economy. Technological improvements that might reduce the use of water in bauxite production could offer some hope. Alternatively, the desalination of sea water for industrial use may by then be economically feasible for industrial use. These are all areas that the bauxite industry would need to give some consideration to.

With respect to environmental water which accounts for a significant proportion (39%) of available water resources, it can be inferred that serious ecosystem loss will occur or radical modification will be required as one move further towards 2080. Though its economic impact cannot be quantified, the ramifications of this cannot be overstated. Sustainable development initiatives need to be continued and strengthened as an urgent priority.

Adequate financial resources for adaptation strategies are likely to be challenging to secure. Currently Government allocates about 0.1% of its total budget to water resources. Water sector agencies can only 'pay their way' by increasing user fees or by attracting technical assistance flows. Both options present challenges.

This review can only confirm the need for future research. A worse case climate change scenario although by no means the most likely scenario)) has the potential for being economically socially and physically exceedingly challenging for Jamaica. In 2008, we just do not know enough to be conclusive on this or to put specific cost parameters to it Such being the case two imperatives are non debatable, firstly the need for undertaking serious ongoing research, and. secondly, the adoption of the 'no regrets' principal in planning for climate change

6.6.1 Summary of Recommended Adaptation Strategies

Irrigation water is a major annual user of extracted water. For the main crops consuming irrigation water, (cane, banana and pasture) adaptation strategies due to likely climate change impact on water supplies include the application of increased irrigation efficiency, the reintroduction of water harvesting, use of alternative water sources such as treated sewage effluent and drought resistant crop modification. Also increased weather threats will require better watershed management, improved drainage systems including river training and flood control, as well as more rapid response systems in which recovery assistance and its distribution could be effected particularly where smaller and more vulnerable farm units are impacted.

Other non irrigated crops such as coffee, cocoa and pimento are also important to the economy: Some adaptation strategies directed at crop production efficiency must include:

- investigation of important pests and plant diseases including weeds to climatic changes. Since these have an important bearing of crop productivity.
- investigation of genetic diversity within crop types that might be better suited and called upon to compensate for climatic variability.
- engagement of main stakeholders in areas such as plant breeding, agrochemicals and fertilizers, irrigation and agricultural equipment etc on the implications of climate change

Sea level rise and the resulting potential saltwater intrusion into the aquifers of important agricultural growing areas such as on the Clarendon plains is a significant threat. Further research into the development of specific adaptation measures is required, but they are likely to include the need to reduce / redistribute abstractions, investigation of the use of alternative surface water sources (including use of surface water storage), and assessment of the use of aquifer recharge to act as barrier to saline intrusion amongst others.
Climate change will challenge the objective of ensuring clean water supply mainly in relation to the resource commitment required to improve water quality in : 1) population dense areas whose aquifers are threatened by saline intrusion and 2) in diminished supply in populated areas where reduced stream flow on important sources threatens this supply.
Adequate water resources underpin the current mitigation strategies proposed to address food security. Required strategies include:

- reduction in the level of poverty to reduce under nourishment.
- priority focus on increasing agricultural output and productivity so as to reduce prices and reduce the number of food insecure persons.
- macro economic policies should support the production of food for export but also domestic production.
- need to improve coordination of planning and policies for activities that impact the food sector.

Future water availability to the bauxite industry could become a serious challenge in the 2050 and 2080 periods particularly in two important basins that support this production. Adaptation strategies to be considered would need to address the following considerations: the diversion of water from nearby basins with positive balances may be the preferred cost benefit solution for the economy. Technological improvements that might reduce the use of water in bauxite production could offer some hope. Alternatively the treatment of sea water for industrial use may by then by economically feasible. These are all areas that the bauxite industry would need to give some consideration.

With respect to environmental water which accounts for a significant proportion of potentially available water resources, it can be inferred that serious ecosystem loss will occur or radical modification will be required approaching 2080. Sustainable development initiatives need to be continued and strengthened.

Research into the likely impact of climate change on the economy should be commissioned through the PIOJ. It could be guided by the Stern Report undertaken for the UK Government in 2006.

REFERENCES

Ahmad R (2004) Natural Hazard Maps in Jamaica: Foundations for Sustainable Development. Proceedings National Scientific Conference on the Environment, Jamaica Institute of Environmental Professionals. Kingston Jamaica. pp. 6.1-6.25

Alexander, L. V., Zhang, X., Peterson, T. C., Caesar, J., Gleason, B., Klein Tank, A., et al. (2006). Global observed changes in daily climate extremes of temperature and precipitation. *Journal of Geophysical. Research, 111*(D5) 5109 DOI: 10.1029/2005JD006290.

Brace Centre for Water Resources Management (2005) Water Resources Development Master Plan. Report prepared for Water Resources Authority, Ministry of Water & Housing, Govt. of Jamaica. Second Draft, September 2005.

Chen A.A., Falloon T, Taylor, M. (2005) Monitoring Agricultural Drought in the West Indies Chapter 11 pp144 – 155. In Monitoring and Predicting Agricultural Drought: A Global Study Ed. by Vijendra K. Boken, Arthur P. Cracknell, R. L. Heathcote. World Meteorological Organization

Chen, A. A, and M. A. Taylor, 2002: Investigating the link between early season Caribbean rainfall and the El Niño+1 year. *International Journal of Climatology* , 22, 87-106.

Christensen, J.H., B. Hewitson, A. Busuioc, A. Chen, X. Gao, I. Held, R. Jones, R.K. Kolli, W.-T. Kwon, R. Laprise, V. Magaña Rueda, L. Mearns, C.G. Menéndez, J. Räisänen, A. Rinke, A. Sarr and P. Whetton, 2007: Regional Climate Projections. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Church, J. A., White, N. J., Coleman, R., Lambeck, K., Mitrovica, J. X. (2004). Estimates of the regional distribution of sea-level rise over the 1950-2000 period. *J. Climate 17***,** 2609-2625

Economic Commission for Latin America and the Caribbean (2002) Jamaica: Macro-Socio-Economic Assessment of the Damage Done by Flood Rains and Landslides May 2002. Published July 2002.

Economic Commission for Latin America and the Caribbean (ECLAC), United Nations Development Programme (UNDP) & Planning Institute of Jamaica (PIOJ) (2004) Assessment of the socioeconomic and environmental impact of Hurricane Ivan on Jamaica. Published October 2004

Evelyn, O. (2007) Using Geographic Information Systems (GIS) To Determine Optimum Forest Cover For Minimizing Runoff In A Degraded Watershed: A Case Study – The Rio Minho Watershed, Jamaica. Unpublished thesis submitted in partial fulfilment of the requirements for the degree of Master of Science in Geographic Information, City University, London, UK

Forestry Department (2002) National Forest Management and Conservation Plan. Published by the Forestry Department, Ministry of Agriculture, Government of Jamaica.

Global Environmental Facility National Communications Support Unit. UNDP New York 2004.

Goldenberg, S., C. Landsea, A. Mestas-Nuñez, W. Gray (2001) The Recent Increase in Atlantic Hurricane Activity: Causes and Implications *Science* 20 July 2001:Vol. 293. no. 5529, pp. 474 – 479. (http://www.sciencemag.org/cgi/content/full/293/5529/474)

Gray, W. M., C. W. Landsea, P. W. Milke Jr. and K. J. Berry, 1994: Predicting Atlantic Basin seasonal tropical cyclone activity by 1 June. *Weather and Forecasting*, 9, 103-115.

Haiduk, A. (2008) Pers. Comm. 15th February 2008.

IPCCb (2007) Climate Change 2007: Impacts, Adaptation and Vulnerability. (2007) Contribution of Working Group II to the Fourth Assessment . Report of the Intergovernmental Panel on Climate Change, M.L. Parry,

IPCCa, 2007: Summary for Policymakers. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Avery, M.Tignor and H.L. Miller (Eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Karanjac, J (2005) Vulnerability of Ground Water in the Karst of Jamaica . Prepared for Conference: Water Resources & Environmental Problems in Karst, Beograd & Kotor, Serbia & Montenegro, 14-19 September 2005.

Klotzbach, P., W.Gray and W. Thorson (2006) Extended range forecast of Atlantic seasonal hurricane activity, individual monthly activity and U.S. landfall strike probability for 2006. http://typhoon.atmos.colostate.edu/forecasts/2006/aug2006/ Accessed 27 April 2008.

Malone, Elizabeth L; Joel B Smith, Antoinette L. Brenkert, Brian Hurd, Richard Moss, and Daniel Bouille (2004); Socio Economic Scenarios for use in Vulnerability and Adaptation Assessments.

Medardo M. and F. McDonald (1988) Sinkhole management and flooding in Jamaica. Environmental Geology Volume 12, Number 2 pp.113-116

Meehl, G.A., T.F. Stocker, W.D. Collins, P. Friedlingstein, A.T. Gaye, J.M. Gregory, A. Kitoh, R. Knutti, J.M. Murphy, A. Noda, S.C.B. Raper,I.G. Watterson, A.J. Weaver and Z.-C. Zhao, 2007: Global Climate Projections. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S.,D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Molina, M., and F. McDonald (1988) Sinkhole management and flooding in Jamaica. Environmental Geology Volume 12, Number 2 pp113-166

Nakićenović, N., and R. Swart (eds.), 2000: *Special Report on Emissions Scenarios*. *A Special Report of Working Group III of the Intergovernmental Panel on Climate Change.* Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 599 pp.

National Water Commission (2007) Three Year Action Plan (2007 September) Executive Summary. NWC Jamaica.

Neelin, J. D., Munnich, M., Su, H., Meyerson, J. E., & Holloway, C. (2006). Tropical drying ttrends in global warming models and observations. *Proc. Nat. Acad. Sci., 103*, 6110-6115.

NIC (2004) National Irrigation Development Plan Projects. National Irrigation Commission, Kingston, Jamaica

NCRA (1997) State of the Environment Report. http://www.nrca.org/publications/SoE/soe_97/index.htm

Oouchi, K., et al., 2006: Tropical cyclone climatology in a global-warming climate as simulated in a 20km-mesh global atmospheric model: Frequency and wind intensity analyses. *J. Meteorol. Soc. Japan*, **84**, 259–276.

O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 976pp.

Peilke Jr, R. A. Landsea, C., Mayfield, M., Laver, J. & Pasch, R. (2005). Hurricanes and global warming. *Bull. Amer. Meteor. Soc., 86*, 1571-1575.

Peterson, T. C., Taylor M. A., Demeritte R., Duncombe D., Burton S., Thompson F., et al. (2002). Recent changes in climate extremes in the Caribbean region, *J. Geophys. Res., 107*(D21), 4601, doi:10.1029/2002JD002251

Philip J. Klotzbach and William M. Gray (2006). Forecast of Atlantic hurricane activity for September and October 2006 and seasonal update through August. Colorado State University. Retrieved on 15-10-2007

Planning Institute of Jamaica (1997) Economic and Social Survey of Jamaica 1996. Published October 1997.

Planning Institute of Jamaica (2005a) Assessment of the Socio-Economic and Environmental Impact of Hurricanes Dennis and Emily on Jamaica. Published August 2005.

Planning Institute of Jamaica (2005b) Assessment of the Socio-Economic and Environmental Impact of Hurricane Wilma on Jamaica. Published October 2005.

Planning Institute of Jamaica (2006) Economic and Social Survey of Jamaica 2005. Published 2006.

Planning Institute of Jamaica (2007) Economic and Social Survey of Jamaica 2006. Published October 2007.

Rahmstorf, S. (2007) A Semi-Empirical Approach to Projecting Future Sea-Level Rise. *Science* 19 January 2007:Vol. 315. no. 5810, pp. 368 - 370

Statistical Institute of Jamaica (1994) Statistical Yearbook of Jamaica, 1993.

Taylor, M. A., Centella, A., Charlery, J., Borrajero, I., Bezanilla, A., Campbell, J., Rivero, R., Stephenson, T. S., Whyte, F., Watson, R. (2007). Glimpses of the Future: A Briefing from the PRECIS Caribbean Climate Change Project*,* Caribbean Community Climate Change Centre, Belmopan, Belize. 24 pp.

Trees for Tomorrow Project (2002) Watershed Management Study of the Rio Minho and Martha Brae Watershed Management Units, Canadian International Development Agency CIDA Project No. 504/15808

Trees for Tomorrow Project (2004) Watershed Management Study of the Buff Bay / Pencar Watershed Management Units, Canadian International Development Agency CIDA Project No. 504/15808

Underground Water Authority (1990) Water Resources Development Master Plan. Published by the Government of Jamaica, March 1990.

United States Army Corps of Engineers (2001) Water Resources Assessment of Jamaica. Mobile District and Topographic Centre, February 2001.

United Nations Development Programme, Human development Report 2007/2008, Palgrave Macmillan (Publishers), New York, 2007.

Water Resources Authority (2008) Preliminary investigation of the April 2008 flooding of Ocho Rios and environs. Water Resources Authority of Jamaica, 12th May 2008.

Water Resources Authority (2008) A National Water Resources Master Plan for Jamaica – Second Draft.

Watson, R. A., M. A. Taylor, T. S. Stephenson and J. D. Campbell, 2008: Jamaica's future climate deduced from climate models. Eighth Bi-annual Conference of the Faculty of Pure and Applied Sciences, University of the West Indies, Mona, February 26-28, 2008.

Webster, P. J., Holland, G. J., Curry, J. A., Chang, H. R. 2005. Changes in tropical cyclone number, duration and intensity in a warming environment. *Science, 309*, 1844-1846

Witter, J.V Robinson D. E., Mansingh A., and Dalip K. M. . (1999) Insecticide Contamination of Jamaican Environment V. Island-Wide Rapid Survey of Residues in Surface and Ground Water. Environmental Monitoring and Assessment Vol. 56, The Netherlands: Kluwer Academic Publishers.

Websites

http://www.pioj.gov.jm/NDP_info.aspx