Strengthening Operational Weather, Water, and Climate Services

ROAD MAP FOR ST. LUCIA

Developed in collaboration between the Government of Saint Lucia and the World Bank. May, 2017

WATER PARTNERSHIP PROGRAM

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Acronyms

AEE	Annual Average Emergency Expenses
APL	Annual Potential Preventable Loss
AVIF	Annual Value of Improved Hydromet Information and Forecasts
AWS	Automatic Weather Station
CAP	Common Alert Protocol
C-B	Cost-Benefit
CIMH	Caribbean Institute of Meteorology and Hydrology
CONOPS	Concept of Operations
DBMS	Database Management System
DVRP	Disaster Vulnerability Reduction Project
DSM	Digital Signage Manager
EAC	Expected Annual Cost
ECCU	Eastern Caribbean Currency Union
EHD	Environmental Health Department
EU	European Union
FAO	Food and Agricultural Organization
FEWS	Flood Early Warning System
FFGS	Flash Flood Guidance System
GDP	Gross Domestic Product
GFDRR	Global Facility for Disaster Reduction and Recovery
GFS	Global Forecast System
GFFG	Global Flash Flood Guidance System
GIS	Government Information Service
GOES	Geostationary Operational Environmental Satellite System
GOSL	Government of St. Lucia
GTS	Global Telecommunication System
IPCC	Intergovernmental Panel on Climate Change
IT	Information Technology
LUCELEC	St. Lucia Electricity Services Limited
NASA	National Aeronautics and Space Administration
NEMO	National Emergency Management Organization
NHS	National Hydrological Services
NMHS	National Meteorological and Hydrological Services
NOAA	National Oceanic and Atmospheric Agency
NPV	Net Present Value
NWSC	National Water and Sewerage Commission
O&M	Operations and Maintenance
OECS	Organization of Eastern Caribbean States
QPF	Quantitative Precipitation Forecast
SDED	Sustainable Development Department
SLASPA	St. Lucia Air and Sea Ports Authority
SLMS	St. Lucia Meteorological Services
SPI	Standard Precipitation Index
USAID	U.S. Agency for International Development
USGS	U.S. Geological Survey

WAFS	World Area Forecasting System
WASCO	Water and Sewerage Company Incorporated of St. Lucia
WMO	World Meteorological Organization
WPP	Water Partnership Program
WRF	Weather and Research Forecast
WRMA	Water Resources Management Agency
WRMU	Water Resources Management Unit

Executive Summary

St. Lucia's geographical location in the Eastern Caribbean leaves it exposed to many hydrometeorological (hydromet) hazards. Like many other countries in the region, St. Lucia has experienced frequent damage to agriculture and infrastructure, economic losses, and loss of life due to flash floods, droughts, and deteriorating water quality. Exacerbating natural hazards are the effects of anthropogenic global climate change that have manifested in St. Lucia through negative impacts on surface water supply, groundwater, and quality of water. In addition to threats caused by climate change, St. Lucia faces challenges meeting increased demands for water caused by increasing population and economic development as well as degradation of the upper watersheds, increased exploitation of streams and wetlands, and an inefficient and aging water distribution system (National Water Policy of St. Lucia 2004). The St. Lucia National Water Policy of 2004 suggests that the demand for water may be reaching the limited supply availability, meaning that future increases in water demand present an increased threat of water shortages. When these threats are considered together, it is clear that the stress on existing water supplies as well as the magnitude and frequency of flooding will only increase. While these challenges are well known to citizens of St. Lucia, technical officers and decision makers in the Government of St. Lucia (GOSL) lack the data to define and monitor the supply and quality of surface and groundwater resources.

This Road Map has been prepared to provide a strategic vision to the GOSL for guiding the strengthening of economically necessary meteorological and hydrological services. Strengthening of hydromet services is essential to build national disaster risk resilience, emit early warnings, and provide the technical foundation needed to plan and build water resources management for the future. In the context of St. Lucia, the National Hydrological Services Agency (known as the Water Resources Management Agency [WRMA]) and the St. Lucia Meteorological Services (SLMS) are together the critical providers of weather and climate data. Major recommendations in this Road Map concern the need to strengthen the capacity of these agencies to build resiliency for inevitable climate shocks to the economy and to provide a technical foundation for assessing and planning water resources development in the future.

To determine the gaps in providing essential weather, water, and climate services to St. Lucia, an assessment of the users of hydroclimate data, forecasts, and information was conducted through in-person interviews and written surveys. In addition to the user assessment, an evaluation of the technical capabilities and capacity of both WRMA and SLMS was conducted to determine gaps defined as barriers in delivering needed products and services to a diverse user community. To address disaster risk response and mitigation capacity, the assessment investigated the various components of the end-to-end system. The first assessed components were the data networks, communications, processing, availability of a database, and data quality assurance processes. These were followed by an assessment of communication of data to the forecasting and hydromet provider facilities. Then each hydrological and meteorological facility was assessed for modeling capacity, database, and data processing, followed by methods of dissemination of data, forecasts, warnings, and information to the users. Personnel capacity was also assessed including forecaster education, training and knowledge for forecasting, and warning competency.

Based on the surveys, interviews, and assessments, a number of recommendations were developed in the following three categories of the Road Map: (a) institutional strengthening, (b) observation infrastructure and forecasting, and (c) delivery of data, products, and services.

Road Map

(a) Institutional strengthening

For SLMS, it is important that a legal mandate is established, outlining its responsibilities and authority to legally forecast and warn the country. For the benefit of both WRMA and SLMS, a user group needs to be established that is representative of a significant cross-section of users and provides a two-way dialogue between data providers and receivers. This group needs to provide the requirements needed for products and services to meet user needs. This mechanism also is a forum for both providers to educate users on various products, services, and information needed to properly understand and interpret the content of products and capabilities.

(b) Observation infrastructure and forecasting

The emphasis of the recommendations in this component is toward improving significant data quantity and quality. Early warning system networks need to be repaired immediately. The current rain gage, stream gage, and weather station networks need to be optimized to better describe and reflect the variation of environmental conditions across the island. A comprehensive hydrological and meteorological database needs to be established with a database management system (DBMS) that processes all data, quality controls data, and parses data to different functions from a website pipeline to users and models to be used in studies and analysis.

A national rain grid based on a satellite rainfall estimate grid with observed precipitation used to improve calibration and elimination of bias and the addition of using neighboring radar data or purchase of a radar for the island will provide all users the spatially distributed rainfall data needed for decision making. A stream discharge measurement program needs to be established by WRMA for existing and planned stream gages so that discharges can be measured and water balance analysis conducted. In addition, a water quality program needs to be established that starts with a water quality monitoring program. Finally, a groundwater monitoring network needs to be established, along with studies conducted to understand the quantity of groundwater and quality of stored water available for use, as a supplement to limited surface water supplies.

Acquisition of a hydrological simulation model needs to be investigated for operational and planning applications. The flash flood guidance system of the World Meteorological Organization (WMO) should be considered as a tool for flash flood warnings, needed by vulnerable communities residing on flood-vulnerable flash streams. The existing early warning system's hydrological modeling concept should be evaluated for performance and accuracy needed for short-fused flash flood warnings.

(c) Delivery of data, products, and services

Perhaps the most important weak link in providing hydromet data and products such as forecasts and services is the lack of adequate websites for both WRMA and SLMS. Both websites require major overhaul with both real-time data and forecasts and historical data made available electronically to users.

Investment Scenarios

Given the reality and uncertainty of budgets in the government, recommended actions and costs are presented in three scenarios to demonstrate the range of choices available and resultant costs and benefits that are estimated from economic modeling. Scenario 1 is a minimal set of actions and tasks that need to be taken to provide essential services and information to most users. It represents the biggest and quickest return for cost to be spent by the GOSL. Scenario 2 represents a more comprehensive set of recommended steps and expenditures that will likely reach a large percentage of users in the country (larger than Scenario 1) but will not attempt to meet future needs of users. Scenario 3 represents modernized hydromet services for both SLMS and WRMA that will achieve best practices and is in step with progressive developing countries.

Economic Analysis

An economic analysis was carried out for these three scenarios which is based on benchmarking methodology, using (a) available national official macroeconomic and sector-specific statistics, (b) key parameters such as weather dependence of the economy, (c) the vulnerability of the country's territory to weather hazards, (d) the quality of hydromet service provision, and (e) an estimate of the annual potential preventable losses due to hydromet service improvement. This valuation considers the three implementation scenarios that differ in its objectives and thus considers different actions and investments. The net present value (NPV) for the three scenarios are US$6.61 million, US$7.23 million, and US$9.08 million. Scenario 1 has a cost-benefit (C-B) ratio of 1:4.2 while Scenarios 2 and 3 have C-B ratios of 1:2.3 and 1:2.2, respectively. Given that Scenario 1 is an integral part of Scenarios 2 and 3, one could think of sequentially executing these once Scenario 1 has been implemented. If this were the case, the C-B ratio of Scenarios 2 and 3 would increase to 1:3.34 and 1:2.88, respectively. Sequentially implementing Scenario 1, then Scenario 2, and finally Scenario 3 increases Scenario 3's C-B ratio to 1:4.38. Thus, sequentially implementing Scenario 2 after Scenario 1, and Scenario 3 after Scenario 2 is an economically more effective strategy of obtaining the expected results of these scenarios. The economic assessment of the three scenarios is robust with respect to the expected annual costs from weather, annual potential preventable loss, and discount rate. These results justify obtaining the financial support to improve existing hydromet activities as well as to modernize the system so as to implement state-of-the-art data, forecasting, and warning services.

However, these benefits will not materialize if the actual decrease in operations and maintenance (O&M) budgets of hydromet services providers continues over time and if there is no commitment to allocate the required O&M budgets. O&M budgets for hydromet data producers reduced 75 percent between 2014 and 2015, falling from US$60,000 per year to US$15,000 per year, and this has not recuperated. O&M budgets for the proposed scenarios are 8.5, 32.5, and 34.5 times actual O&M allocated budget. If the required budget is not satisfied as of year 7, the NPVs of the investment in all scenarios will significantly decrease and the C-B ratio will fall below 1:1.

Conclusions

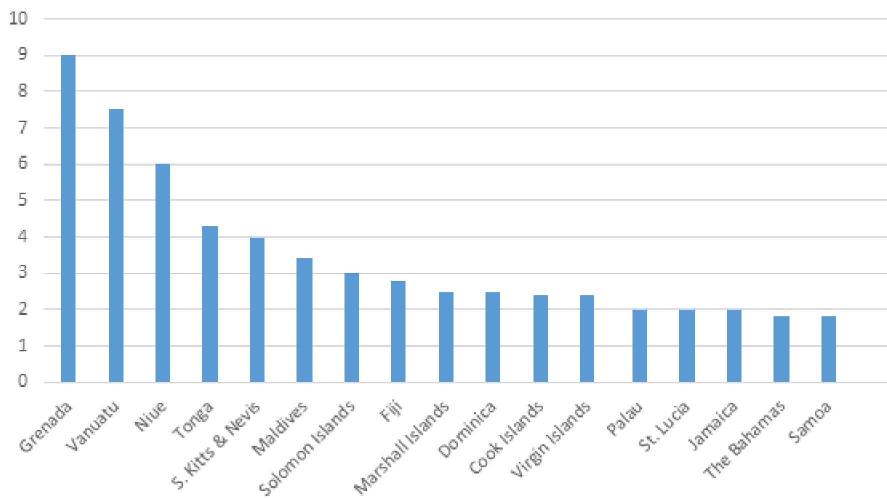
The scenario analysis along with the economic analysis provides the GOSL with options of estimated benefits versus costs on proceeding to strengthen hydromet services in the country. It seems quite straightforward that at a minimum investment will result in repairing of the existing early warning system hardware outages and restoring of a basic warning capability so that should heavy rainfall and flooding threaten these critically flood-vulnerable communities in the river basins, the warnings will provide the lead time needed to save lives and property. Together with this action, repair of all meteorological and hydrological gages and communications must be undertaken so that at least existing data can be collected and utilized by users for both disaster risk reduction and water resources management. This is the key recommendation in Scenario 1 along with training both meteorologists and hydrologists to build existing competency. Another important minimum investment that will provide needed benefits to the country is to design and build new websites that can provide needed data, forecasts, and warnings to users. The minimal actions in Scenario 1 provide a 4 to 1 return on investment for the country, which is compelling. What is not included in this analysis is the morbidity and mortality benefits that will be realized when warnings are issued to give residents time to escape harm and property losses. Early warning systems cannot stop floods, but they can significantly mitigate human loss and suffering.

The GOSL should also consider Scenarios 2 and 3. Although the C-B ratio is not as high as Scenario 1, these options could provide slow, growing benefits beyond the economic analysis studied if the various user sectors build capacity and learn (for example) how to utilize the value of additional high-resolution meteorological and hydrological data. The economic analysis indicates that Scenarios 2 and 3 should be implemented sequentially, once Scenario 1 has been executed, since this strategy presents a more favorable C-B ratio. Regardless of the scenario that is utilized, the GOSL must invest in O&M of its data networks in the future to prevent system degradation and failure that may in the future prevent lifesaving warnings and information from reaching the population at risk.

1. Introduction to Weather, Water, and Climate Hazards and Water Supply Context

The Caribbean is one of the most disaster-prone regions in the world. Rasmussen (2006) concludes that the six Eastern Caribbean Currency Union (ECCU)[1] countries rank in the top 10 most disaster-prone countries in the world when considering disasters per land area or population. Of the ECCU countries, St. Lucia presents one of the highest hurricane probabilities (17.2 percent). Average annual economic losses associated with extreme hydrometeorological (hydromet) events in small island states range from 1.8 percent to 9 percent of gross domestic product (GDP) (Figure 1).

Figure 1: Average Annual Disaster Losses in Small Island States as Percentage of GDP



Source: Vivo 2015.

St. Lucia is a small, tropical island (land area of 616 km^2) with a humid climate accompanied by northeast trade winds that generate microclimate effects on the island. Mean annual rainfall varies from about 1,300 mm along the heavy populated coastline to 3,800 mm in the volcanic mountainous rain forests. Frequently, rainfall is highly variable with the passage of rainfall events such as tropical systems, troughs, and old frontal systems due to elevation and orientation of the island. St. Lucia has a dry season that runs from December through May and a wet season from June through November caused primarily by various types of tropical systems.

There are 37 watersheds in St. Lucia (Figure 2). Rainfall is the source of freshwater, with almost two-thirds falling between August and November. During periods of the dry season of February to April, streamflow availability can be problematic. Major water quality and supply source-related concerns include agricultural intensification, lack of regulated land use, and point source contamination from untreated effluent. Water contamination risks are increasing due to activities related to hotels, distilleries, poultry farms, and cruise ships. Contamination due to gray water and sewage is especially an issue in the southern regions. Overall, water quality is a greater problem during the dry season. During the rainy season, dilution of chemicals from high volumes of water reduces chemical pollution but increases sediment yields clogging intakes and raising turbidity, which overwhelms treatment plants forcing them to temporarily cease operations.

[1] The ECCU is composed of Antigua and Barbuda, Dominica, Grenada, St. Kitts and Nevis, St. Lucia, and St. Vincent and the Grenadines.

In the northern region, the John Compton Dam provides adequate water supply for 60 percent of the population including the resorts. However, in the southern region water supply is critical, and more variable due to isolated intakes. Water supply intakes are located in the upper portions of watershed catchments where there is little human population to contaminate rivers so problems do not usually occur. When problems do occur, isolation and the lack of automation create maintenance challenges. There currently exists no connection between the northern and southern water supply areas, which makes it impossible to supply areas dependent on intakes from the John Compton Dam.

Proposed hotel developments in the southern region of St. Lucia will cause additional stress on the water supply and contribute to contamination issues unless proper measures are taken. Already, growing water demands are outstripping availability of supplies and water interruptions occur frequently, particularly during droughts, and there is an increased awareness and urgency to find a reliable water supply beyond surface streamflows. Little is known about the quantity and quality of groundwater in the island. Discussions are under way to investigate the feasibility of developing desalinization as an alternative water supply, but the costs may be high for this option.

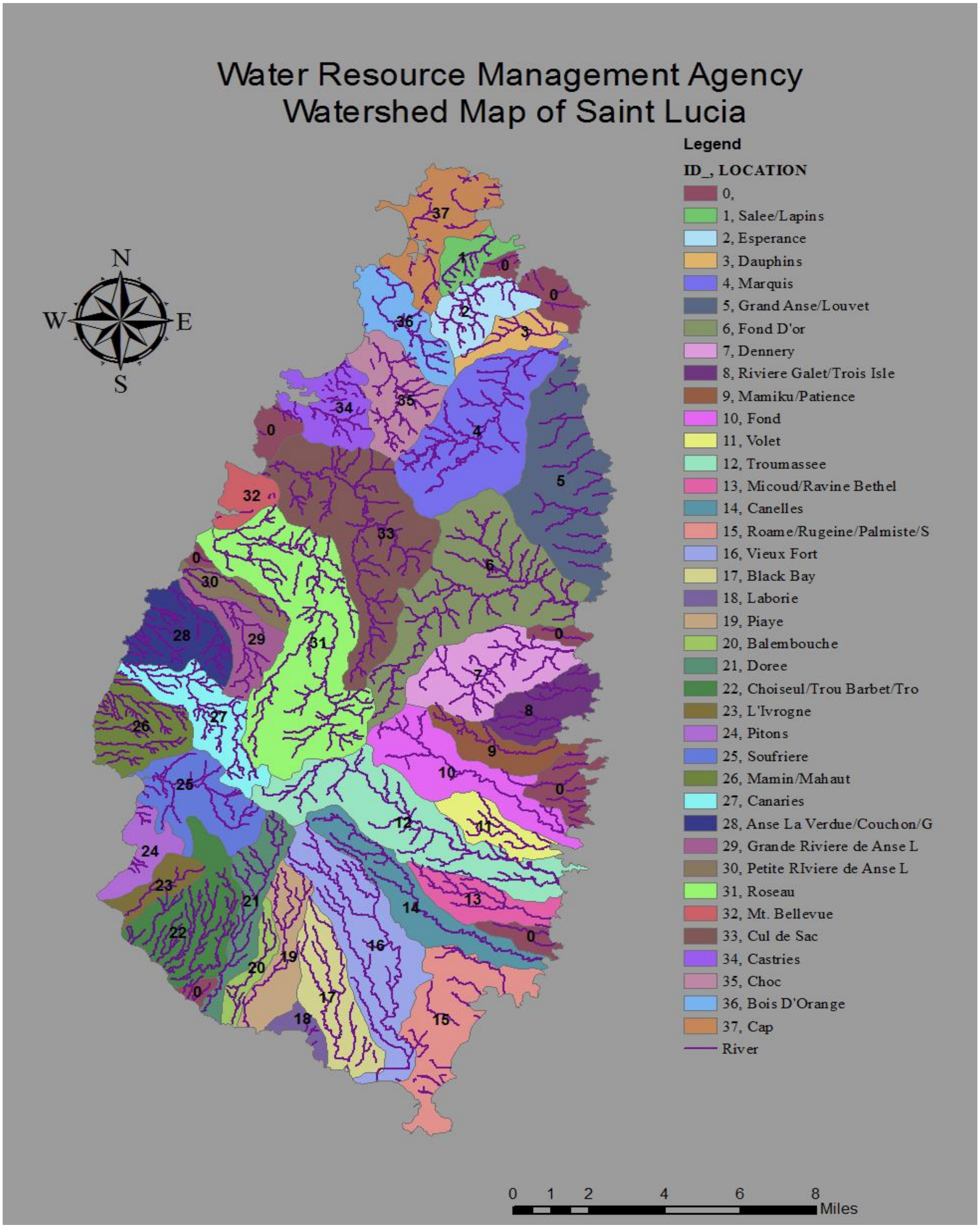
The island is located in the hurricane belt and frequently experiences hurricanes and tropical storms between June and November. On average, St. Lucia experiences a hurricane once every 13 years. Hurricane Tomas in 2010 had an estimated US$336 million in damages equivalent to 43.4 percent of the island's GDP. Furthermore, St. Lucia experiences trough events, which are multi-level disturbances (low-pressure areas) in the atmosphere that they can generate large amounts of rainfall in a region, especially if they become stationary.

The principal impact St. Lucia experiences from extreme weather, water, and climate hazards results from flash flooding and debris flows. For example, Tropical Storm Debbie in 1994 caused major flooding in low-lying areas, triggering landslides and debris flows, resulting in forest destruction that damaged 60 percent of the banana crops causing estimated losses of US$60 million. Although the majority of flooding is linked to tropical rainfall, the 2013 Christmas Trough had significant economic consequences, leading to extensive flash flooding and landslides that resulted in damages and losses of US$99 million. In November 1999, Hurricane Lenny produced significant beach erosion and US$1 million in damages from a storm surge. Occasionally wind damage is experienced from tropical systems but the majority of economic and human impact is caused by flooding. Flooding also triggers erosion and excessive sedimentation of the country's rivers. Many if not most of the river beds are filled with sediment that increases the risk of flooding from not so extreme rainfall and results in significant expenditures in river dredging activities.

The western coast of St. Lucia is prone to flooding caused by storm surges. In November 1999, Hurricane Jennie produced significant beach erosion and US$1 million in damages from a storm surge. Droughts and prolonged dry spells pose another significant risk for many sectors of the economy. The drought of 2015 prevented new agricultural users from accessing water.

The intensity and frequency of climate extreme events are increasing the risk for hydromet disasters primarily due to increased flooding and drought events. According to the Intergovernmental Panel on Climate Change (IPCC) the decadal models predict an average of 20 percent less rainfall in the future for the island. The 2007 IPCC Report and Water Resources Management Agency (WRMA) Strategic Plan: 2012–2017 states that because of its location, small land mass, and large coastal exposure, St. Lucia can expect changes in surface water and groundwater supply, water quality, increased flood and drought events, changes in water chemistry and water temperature, increases in erosion and sedimentation, increases in sea level, and decreased freshwater supply due to saltwater intrusion. Some of the expected changes, such as increases in sedimentation, have already been observed.

Figure 2: Watersheds in St. Lucia



Source: Provided by WRMA.

1.1 Background

St. Lucia has recently experienced the effects of climate extremes within one year. There was a drought between February and April 2010 due to a strong 'El Niño' event, and within the same year on October 31 over 600 mm of precipitation fell over the island in 24 hours as a result of the passage of Hurricane Tomas. Within this period the rivers of St. Lucia experienced both extreme low flows and overflow in floods throughout the island. Residents transitioned from severe water shortages to excess of water and were affected by flood-induced erosion and sedimentation, resulting in major economic damage. The Disaster Vulnerability Reduction Project (DVRP) was launched in 2014, with the support from the World Bank to build resilience of the country to weather, water, and climate hazards. Component 2 of the DVRP is technical assistance for improved assessment and application of disaster and climate risk information in decision making, which includes design and deployment of meteorological, hydrological, and sea level rise monitoring networks to provide high-resolution hydrological data.

In addition to the DVRP, the Water Partnership Program (WPP) of the World Bank's Water Global Practice and the Global Facility for Disaster Reduction and Recovery (GFDRR) are conducting a global assessment of hydrological services in which St. Lucia is included. The purpose of this assessment is to obtain comprehensive views on the capacity of the National Hydrological Services (NHS) or National Meteorological and Hydrological Services (NMHS) to respond to the demands of users and enhance hydromet data and service provision. The focus is on water monitoring and information services provided by the relevant national government agencies or organizations. All necessary links to groundwater, weather and climate, and water quality monitoring are taken into account throughout these selected countries.

1.2 Objectives

The objective of this assessment of St. Lucia's hydrological services is to prepare a Road Map to strengthen the country's hydromet services based on the needs of the user community that will sustain the country into the future. Specifically, the aim of this Road Map is to provide the decision makers of the Government of St. Lucia (GOSL) with a technical strategic framework to strengthen hydromet services to meet user needs and to be able to consider selected scenarios of costs and benefits as options in moving forward to modernize services based on funding availability versus benefits provided. Following this demand-driven approach to strengthen the capacity of the WRMA, the St. Lucia Meteorological Services (SLMS), and other data producers, it is expected that they will improve their ability to (a) produce, manage, translate, and communicate hydromet information to the users; (b) assist the users in accessing, interpreting, and utilizing this information; (c) improve the dissemination and response to warnings for public safety and economic security; and (d) inform planning and decision making to develop cost-effective investments in climate-resilient development of the country.

This Road Map will thus serve the GOSL as a strategy document helping harmonize activities and investments around hydrometeorology. Initial implementation of the recommendations is expected to be accomplished through the implementation of the DVRP.

1.3 Approach to Develop the Road Map

There are two basic steps involved in the production of a demand-driven Road Map or Strategic Plan for Strengthening the Hydromet Services and meeting these objectives. The first step is to conduct a survey of the user needs and the second step is to assess the capacity of the NMHS and other data provider organizations to respond to meet these needs. The assessment consists of (a) establishing end users' needs and gaps for hydromet and climate products and services; (b) conducting an institutional survey of legal, financial, policy, and human resources; and (c) assessing hydromet infrastructure, product generation, services provided, and dissemination to users. This strategy is complemented with an economic analysis to assess the economic feasibility of the investment.

The approach used in developing this Road Map for St. Lucia followed the abovementioned procedure successfully applied in similar projects. The initial step was to determine through a desk study and three missions, the first one was to assess who the users of hydromet information were and what their current access to and use of weather, water, and climate information was. The second mission was used to collect data to construct an economic assessment of recommendations, and the third was used to discuss and validate the conclusions and recommendations.

Furthermore, during the first mission, the additional information needed by users to improve decision making and utilization of data, forecasts, and other information was identified. In addition, the first mission was used as a brief assessment of the technical capacity of both SLMS and WRMA for the purpose of developing recommendations for the strengthening of their capacity to meet the demands of the many users on the island.

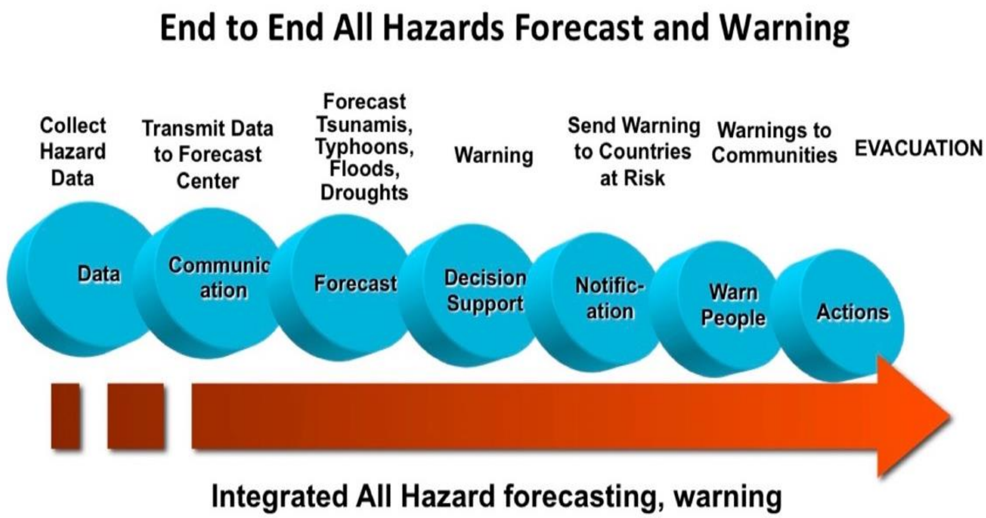
The assessment was conducted in the following manner:

- Review of reports, data, and documents that described the socioeconomic context of disaster risk
- Assessment of hydrological and meteorological data, information, forecasts, products, and services received by users was conducted by individual meetings during the first mission and by survey forms distributed to selected users who provided critical information needed for the user assessment
- Assessment of the institutional capacity of the principal hydromet providers WRMA and SLMS, as well as other providers such as the Water and Sewerage Company Incorporated of St. Lucia (WASCO)
- Assessment of the Infrastructure capabilities of the principal and secondary hydromet providers including data, communications, models, forecaster capacity, and data dissemination
- Assessment of principal and secondary providers' capabilities for delivering data, forecasts, products, and services to the various user sectors
- Assessment of regional (Caribbean Institute of Meteorology and Hydrology [CIMH]) and national organizations to exchange hydrological, weather, and climate data and information and coordination of institutions to improve water resources management, disaster risk reduction, and management and integration of water resources for the many sectors such as agriculture, water supply, and tourism

The technical assessment for all real-time services such as data dissemination, forecasts, and warnings is based on the end-to-end forecasting systems approach described in the following paragraphs.

The end-to-end system comprises a data component (collection of various types of data), a communications link (communicating data from its source to the forecast center), a forecasting center component consisting of a database, diagnostic analysis techniques, hydromet models, and professional forecaster staffing at the center, a dissemination component to deliver data, products, and information, and finally user decision making and actions. Figure 3 is a schematic representation of the end-to-end system.

Figure 3: End-to-End Hydromet Forecasting System



In a demand-driven approach, after assessing the needs of the different users including the population and different economic sectors, institutions have to be strengthened and modernized accordingly so that they are able to meet those needs. In this regard, the GFDRR of the World Bank has established three pillars for modernization of hydromet services consisting of (a) institutional strengthening; (b) modernization of observation infrastructure, data analysis, and forecasting; and (c) enhancement of service provision.

Institutional strengthening involves improving the NMHS's legal and regulatory frameworks, enhancing institutional performance as the main provider of weather, water, and climate information for its country, and building capacity of personnel and management to ensure best practices and sustainability of networks. Strengthening observation infrastructure consists of modernizing and upgrading observation networks, communications, and systems, improving both meteorological and hydrological forecast systems, and refurbishing NMHS facilities. Strengthening service delivery involves enhancing public weather, water, and climate services and developing new and improved information and products for mainly communities as well as many different users.

1.4 Organization of the Road Map

This report consists of six chapters.

- Chapter 1 provides an introduction to the rationale for the Road Map, the objectives, and the approach used for its development.

- Chapter 2 describes the needs of the users of hydrological, weather, and climate information based on the user assessment approach.

- Chapter 3 provides an assessment of both the hydrological and meteorological providers. Assessments are organized by (a) institutional and organizational functional analysis; (b) infrastructure analysis consisting of data collection, communication of information, database, modeling and forecasting; and (c) provision of data, products, and services.

- Chapter 4 presents the Road Map, consisting of recommendations and key actions to improve hydromet data, forecasts, and services to users. Recommendations are categorized into scenarios reflecting minimal, modest, and ideal (attaining state-of-the-art best practices) in improvement actions and associated costs.

- Chapter 5 is a summary of an economic analysis for the benefits to be attained based on proposed actions of the three scenarios presented in chapter 4. The detailed economic analysis is available in annex 1.

- Chapter 6 reflects next steps necessary to build on this Road Map and to engage in project activities, which will result in improved delivery of data, products, and services to users.

2. User Needs for Hydromet and Climate Data and Services

2.1 Assessment of User Needs

To understand the users' needs of hydrological and meteorological services, interviews were conducted with key persons, and surveys were distributed among key users during the October 2016 mission. In St. Lucia, there is a large cross-section of users who can be categorized into governmental, private sector, and academic. The principal users surveyed were government users consisting of persons in agriculture and food production, media, forest management, disaster risk management, land use and planning, water resources management (including water supply and sanitation), water quality, transportation, health, and regional and international cooperation. In the private sector, those surveyed were from the energy and tourism sectors.

A regional organization, the CIMH was also surveyed and interviews were conducted with key personnel located in Barbados. There are also other users of hydrological and meteorological information and forecasts who were not surveyed due to time and resource constraints, such as those of the academic sector, insurance industry, private marine interests and cruise lines, and individual end users such as the public, those in individual farmer districts, and NGOs and those actively working with businesses and residents to build resiliency and respond to disasters such as the Red Cross.

Surveys were disseminated to determine user gaps and needs. The following were investigated: data linkages between users and agencies, the utility of available data, particularly for decision making, the types of derived information and forecasts, and what further needs are important for users to improve productivity. Attention was also given to needs relating to reducing impacts from extreme weather, water, and climate events (see an example of the survey forms in annex 3). By filling these user gaps, both the MET and WRMA, as well as the other data and service providers could strengthen delivery of forecasts and services necessary to meet national, regional, and local needs.

2.2 Description of Users and their Needs for Data and Services

The principal stakeholders and users identified for the surveys and mission user assessment meetings were WASCO; the National Emergency Management Organization (NEMO); the Ministry of Agriculture, Food Production, Fisheries, and Rural Development; the Ministry of Tourism, Heritage, and Creative Industries; the Ministry of Public Service, Information, and Broadcasting (Media); the Ministry of Infrastructure, Port Services, and Transport; the Ministry of Health, Wellness and Human Services, and Gender Relations; and the Ministry of Physical Development, Housing, Urban Renewal (Physical Planning Division), and CIMH. These users were identified through recommendations of the providers, from understanding the general weather, water, and climate user community needs from past country projects and experiences and from identification of key users from existing reports. Non-organizational end users were not surveyed directly but rather through their government agency counterparts. In the following paragraphs, the principal users of hydrological, weather, and climate information who were interviewed and surveyed are described. User missions and current and future needs are described.

2.2.1 Water and Sewerage Company Incorporated of St. Lucia

WASCO is a state-owned water and sewerage company for St. Lucia. It is part of the water sector and provides potable water supply and sewage disposal for the population. It currently depends on WRMA for water quantity information on the island such as river stages at selected sites. WASCO also utilizes weather and climate forecasts provided by SLMS in its water supply decision making. Hydromet information is presently used in water supply planning for developing additional sources of water supply, for developing and improving of wastewater disposal capacity at new potential disposal sites, for assessing chemical samples for raw water treatment given the sediment content of inflows to treatment plants, and for responding and mitigating potential hydrological extremes such as expected flooding or extended drought response planning. WASCO is currently limited to using the existing surface water supply, even if it is dwindling during extended dry seasons or droughts. Weather, water, and climate forecasts are used predominantly during the wet season to alert WASCO of the likelihood of heavy rain and potential flood events. WASCO then launches standard operating procedures to lessen the impacts of a storm to reduce the expected impact of the flood or drought event. For example, available precipitation data and number of wet days received from SLMS are used to mitigate the effects of an expected drought. The Standard Precipitation Index (SPI), an approach to measure meteorological drought, is utilized to reflect agricultural and hydrological droughts/impacts. Expected or forecast rainfall deficits over a prescribed duration are used to mitigate the effects of dry spells or droughts. WASCO monitors the supply to its many users through its metering.

There is an unknown water supply potential from groundwater that WRMA is planning to explore and which could serve as an alternative water source during drought periods. Only a few wells are being operated by agriculture and some resorts, so little information is available concerning water quantity and quality. Past studies reveal that there are potential groundwater quality issues in certain locations of the island. For WASCO to be able to guarantee continued water supply, even during droughts, an assessment of the quantity and quality of groundwater as an alternative source of water for the island is required, especially as the risk of droughts increases. Based on the distribution of mandates and roles in St. Lucia, this exploration of groundwater availability and quality falls into the range of responsibilities of WRMA that will need planning additional drilling of wells, monitoring, and analyses.

WASCO does not have a linked water distribution system for the island. It has a linked system to the north where the John Compton Dam supplies 60 percent of the island population with water. In the central and southern parts of the island, distributions systems are independent and the supply of residences and businesses, especially during the dry season, is more fragile with some locations occasionally running dry.

WASCO utilizes limited sampling of selected water quality parameters at its water supply intakes, effluent discharge locations from treatment plants, and outlets where raw sewage is discharged. However, there is no routine monitoring of flow at most intakes. WRMA needs to establish streamflow monitoring at designated WASCO intakes (Figure 4) and discharge points, which means that stream gaging monitoring needs to be established in the future. The Environmental Health Department (EHD) does independent sampling of water quality. A high priority is to install real-time measuring equipment at the John Compton Dam to measure inflow, pool, and tailwater stream hydrological data.

Without accurate rainfall and flood forecasts and real-time data monitoring, heavy rainfall and subsequent runoff and surprise flooding near treatment plants lead to contamination and shutdown of plants. More lead time in forecasting of rainfall and induced flooding will give WASCO the needed time to shut plants down and avoid extended damages and resultant outages from contamination. Also, increasing sedimentation of rivers is causing problems by clogging intakes, and the monitoring of sedimentation is therefore needed for better planning of future water supply management.

Better access and availability of tools are needed for planning future water supply development and the water permitting process needs to become more precise in determining water availability as uncertainty exists as to how much available water really exists.

2.2.2 National Emergency Management Organization

The responsibility and mission of NEMO is to develop, test, and implement adequate measures to protect the population of St. Lucia from the physical, social, environmental, and economic effects of both natural and man-made disasters. Its responsibility is to ensure the efficient functioning of preparedness, prevention, mitigation, and response actions for the nation. The Emergency Powers Act of 1995 gave NEMO command of resources in the event of an emergency. The Disaster Preparedness and Response Act of 2000 consolidated and placed in action NEMO's responsibilities and sovereign powers and Cabinet conclusion 1149/96 authorized the National Emergency Response Plan.

NEMO staff consists of a Director, Deputy Director, Secretary, Inventories Officer, Administrative Assistant, Librarian, Mass Crowds Event Officer, Training Officer, Maintenance Officer, and a driver. Volunteers help support the mission needs defined earlier. There is a National Emergency Operation Center and a National Emergency Management Plan which outlines preparedness, prevention, mitigation, and response activities to an emergency situation associated with natural/man-made disaster or technological incidents on the island. It provides operational concepts relating to the various emergency situations and describes the overall responsibilities of NEMO and the role of all concerned sectors in assisting in minimizing loss of life and suffering. At the community level, most communities possess emergency response plans linked to the national plan.

NEMO receives alerts, watches, and warnings from SLMS and responds following the National Emergency Response Plan. NEMO has difficulty interpreting and using hydromet forecasts and determining the impact on the country's infrastructure from existing forecast and warning products. While NEMO does not have continuous access to forecasts and data, the forecasts NEMO receives are normally text products without spatial discretization. They provide description of general hazard intensities without much description of the specific hazard intensity and how impacts vary across the island. NEMO does not operate as a 24x7 service and therefore relies on SLMS to activate its response system. The SLMS does provide warnings for tsunamis, floods, storms, and hurricanes, which initiates disaster response; however, forecasts and warnings do not include impact needed by the disaster coordination team to implement the National Emergency Action Plan. WRMA provides limited information on floods and droughts. NEMO participates in operating four flood early warning systems (FEWS) in partnership with WRMA and SLMS (the section 3.1 on WRMA). The Castries River EWS at Marchand is operational and running while the Bois D'Orange EWS has two stream gages and two rain gages, and all four gages are dysfunctional. At the third EWS on the Anse La Raye River, the three automated weather stations are working but the rain gage is not, and there is no stream gage established yet at this site. The technical description and assessment of the operation of FEWS can be found under the assessment of hydrological services (WRMA) section (pages 31–32).

A fourth EWS system, Dennery, is now operational and providing real-time data and warnings based on rain gage thresholds. The Dennery Community Alerts Program sends out text messages in the Common Alert Protocol (CAP) format to flood-prone residents with cell phones. CAP is an internationally adopted standard for sending warning text messages to cell phones. This system serves as a demonstration of the new approach that will be applied to all EWS that utilize SMS notifications.

A flood hazard and landslide susceptibility analysis has been conducted for St. Lucia under the Caribbean Risk Information Program.

2.2.3 Department of Tourism

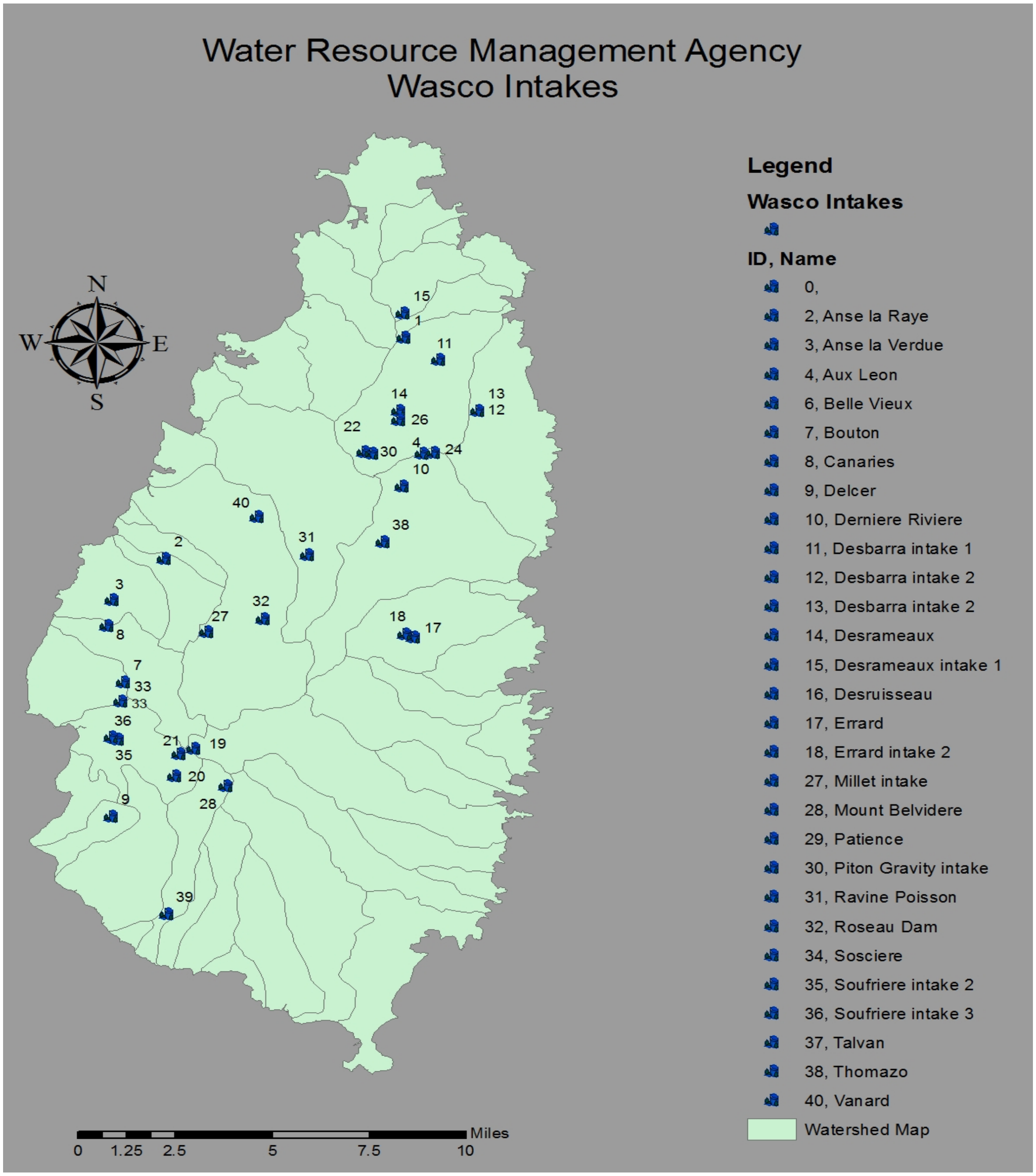
The Department of Tourism (DOT) has the responsibility to encourage the delivery of quality, authentic and distinctive destination experiences and creative products and services, with a clear focus on the needs of residents, visitors, and the environment, which will contribute to year-on-year growth. DOT receives routine weather information continuously over the radio and hurricane or severe weather warnings directly from both SLMS and NEMO. DOT notifies hotels, transport companies, and so on of warnings by email and telephone calls when severe or tropical weather threatens the island. In cases of drought, however, they only receive information from the media. According to DOT representatives, storm information is usually timely and helpful in the case of tropical storms or hurricane threats, but dissemination needs to be by making available forecast storm projections either disseminated to DOT directly or updated on a website. Specific information contained in forecasts of droughts is needed and will allow tourist industry businesses such as hotels, restaurants, cruise lines, and so on to store emergency water reserves and prepare for storm impact. The forecasts and warnings received from Meteorological Services, NEMO, and the University of West Indies are vague and do not provide information as to the impact and damages that may be caused.

DOT expressed the need for more visual or graphical presentations of forecast information, such as maps, so that it can prepare constituents in the affected geographical area. Instead of waiting for advisories, watches, and warnings by emails or having to call forecast providers every time a storm threatens, DOT would like to be able to access a website that always contains updated storm information such as forecasts, storm path forecasts, and impact information presented visually. Also, DOT would like to receive information by cell phones or emails during storms.

DOT does currently not receive drought forecasts and water supply information. Drought severity and impact forecasts are needed for the tourism service industry consisting of hotels and storeowners to plan and arrange auxiliary water supplies. Information and water quality forecasts that follow heavy rainfall are needed to assist tourism constituents in taking actions to minimize the effects of high levels of pollutant contamination. In addition, DOT would like to gain access to past historical hydro-climatic data for floods and extreme events and impacts on coastal communities and tourism zones.

DOT assists the tourist trade industry in preparing for potential natural hazard disasters by working with NEMO to facilitate disaster management plans including coordination with NEMO for workshops. NEMO trains hotels and tourism users on writing response plans with an example being the preparation of earthquake and tsunami safety rules and planning. Similar safety rules and planning for flooding and hurricanes will be required.

Figure 4: Location of WASCO Intakes



2.2.4 Environmental Health Department (Ministry of Health and Wellness)

Within the Ministry of Health, the EHD is tasked with the regulation of water quality as part of its mission to improve the quality of public health through the delivery of environmental health services and promotion of sustainable environmental health strategies. The EHD requires hydromet data and forecasts to monitor environmental risk factors for disease proliferation and transmission. Currently the EHD receives products and information on the weather, including the amount of rainfall, stream data from various river basins, and possible risks and hazards confronting the water supplies. This information is used by the department to develop its annual water quality work plan. Forecasts and information are generally received through the media, and from NEMO, for severe weather and storm warnings. Currently, forecast and hydromet information is too general to be of use and needs to be more specific to meet the needs of the EHD. Flood forecasts are needed that determine when and where flooding will begin, peak, and end. Flash flooding forecasts are also needed.

Rainfall data and forecasts are important because of potential threats to water supply from contamination. Electronic access to updated data and forecasts is needed and this access to real-time products and information should be provided through the Internet. During the rainy season, mosquito vector-borne diseases are a threat and potential breeding sites are monitored. Temperature and precipitation forecasts are well correlated to disease outbreaks. Currently the EHD does not have access to a climate database, which is needed. Detailed information regarding the level of rainfall, drought, temperature, and frequency is required.

The EHD needs to assess vulnerabilities of communities so that they can respond more effectively to a health challenge and for that purpose more water quality data are needed. Also the EHD would like to receive water quality model simulations for selected hot spots (contaminated water on the island) to better assess future health risks to the population at risk.

The EHD is also responsible for permitting coastal discharges and the Coastal Zone Management Unit in the Ministry of Physical Development and the Environment is responsible for responding to impacts of discharges.

2.2.5 The Media - Government Information Service

St. Lucia is undergoing a process to open data for the country. A government mandate to make data available, open, and free is currently under way as a ‘soft launch’. A recently opened data portal (Data.govt.lc) has been created and historical weather data at both airports on St. Lucia are available. Government Information Service (GIS) is a member of the Disaster Management Committee and works side by side with SLMS. Hydromet forecasts and warnings are transmitted on Twitter, Facebook, and WhatsApp as well as Radio, TV, and newspapers.

GIS tries to convey the latest accurate and credible weather, water, and climate information to the public. During the occurrence of extreme weather events such as hurricanes or severe flooding, the media and NEMO are continuously faced with occurrence of false rumors and misinformation that cause confusion and sometimes panic to the public. This is an extreme challenge by the media to quickly separate facts from misinformation during severe weather outbreaks.

The goal of GIS is to be a credible source of information. An individual previously employed by GIS is assisting SLMS in developing a new website. GIS is encouraging and facilitating more professional meteorologists to present TV weather forecasts and is expanding visualization and personalization of weather event forecasts, warnings, and information.

Currently public weather forecasts are provided for up to the next five days by SLMS and sent to the media for distribution to the public. Integrating information is a challenge for the media and needs to improve. The media has a challenge interpreting forecasts and warnings so that the public understands what the hazard threat is and what they should do. Terminology is technical and not known and frequently confusing. For example, terminologies such as tropical wave, depression, and trough are not understood. Better education and awareness are needed.

2.2.6 Energy: St. Lucia Electricity Services Limited

St. Lucia Electricity Services Limited (LUCELEC) is a quasi-public-private company. LUCELEC uses 99.9 percent fossil fuel to produce power for the island. There is one principal generating plant producing 87 MW with a peak demand of 20 MW that uses oil for fuel. There are two backup generators that have 4 MW of power production. LUCELEC is experimenting with solar power through prototype solar panels producing 75 KW, and they are planning to build a solar farm in 2018. There is a wind farm on the eastern coast of the island planned to produce 12 MW from wind in the next 2–5 years. LUCELEC will require rainfall rate forecasts as heavy rainfall rate can cause exhaust blockage in the smoke stacks. A growing need for rainfall, wind, temperature, and cloud cover hourly data and forecasts is emerging as increasingly passive energy is brought on line.

To receive rainfall data, LUCELEC needs to formally submit a request and does so periodically. LUCELEC expressed interest in receiving these data regularly. It is important for LUCELEC to receive rainfall data showing variability across the island, but data networks do not provide sufficient resolution of temperature and precipitation variability. Hydromet networks are sparse and many of the gages are inoperable. LUCELEC also needs lightning data and has purchased a lightning detection system that will be installed soon. These data will be made available to both WRMA and SLMS, if requested formally. Hurricanes and earthquakes are the principal threats. Generally, hurricanes with a severity of Category 3 or 4 causes potential damages such as damages to electrical infrastructure and downed wires. During Hurricane Tomas (Category 1 hurricane) in 2010, considerable damage (US$500 million) was caused and it took two weeks to recover. An island-wide power outage occurred including complete temporary disruption of communications and internet service.

Lightning, earthquakes, storm winds, and flooding are hazard threats to energy distribution to power customers. With the power station located just 1 km from the coast, there is a significant threat from flooding due to tsunamis or storm surges. LUCELEC is sponsoring a climate change study now emphasizing the increased risk of mudslides since mudslides disrupt communications and power for local communities. Although storms and floods pose a risk of disruption of power and communications, the occurrence of droughts is not a threat to energy production.

2.2.7 St. Lucia Air and Sea Ports Authority

The mission of the St. Lucia Air and Sea Ports Authority (SLASPA) is to maximize air- and seaborne traffic and related services through safe and efficient operations performed by a highly motivated workforce contributing to the sustainable, social, and economic development of St. Lucia. SLASPA was established by an Act of Parliament in 1983 and is responsible for the management of the island's two principal seaports, Castries and Vieux Fort; the George FL Charles and Hewanorra International Airports; and the smaller points of entry, which includes Soufriere, Marigot, and Rodney Bay Marinas. SLASPA was created out of the merger of the St. Lucia Ports Authority with the Airports Division of the Ministry of Communications and Works. In the past, civil aviation and meteorological forecasting were in the same organization. Today the MET provides aviation forecasts for air traffic.

The airport is vulnerable to flooding. In December 2013, the Christmas trough produced rainfall that flooded the airport and the roads between the airport and Castries stranding many travelers. In 2010, although both airports were open, Hurricane Tomas flooded the transportation routes to the airports from Castries. A study is now being conducted under the World's Bank DVRP to recommend steps that SLASPA can take to reduce the probability of this occurring in the future. Building climate extreme resilience is a priority of SLASPA.

Marine forecasts are important to the St. Lucia seaport. Wind and wave data and forecasts are important to cruise lines, cargo ships, and marine interests in general. In the future, it is anticipated that more detailed marine forecasts will be needed to support a growing yacht industry.

Chief pilots need temperature, wind direction, and velocity forecasts as well as tide gage and coastal tides and surges. Lightning voltage detection and forecasts are also another need of SLASPA. SLASPA is on the NEMO-led Disaster Management Committee.

2.2.8 Ministry of Education, Innovation, Gender Affairs, and Sustainable Development (Government) - Sustainable Development Department

The ministry's vision is to achieve sustainable development on a platform of integrated and effective environmental management in order that sociocultural, economic, and environmental goals are realized and collectively contribute to a continuous improvement in the quality of life of all St. Lucians. The mission of the Sustainable Development Department (SDED) is, "To lead the process of achieving sustainable development by facilitating an integrated and participatory approach to governance; promoting environmental management and innovative technologies; building capacity to adapt and mitigate the impacts of climate change and reduce risks; and demonstrating the value of building a green economy."

The responsibilities of the department are focused toward realizing eight long-term, strategic outcomes. Strategic outcomes include (a) providing an integrated and evidenced-based approach to governance in the area of sustainable development, (b) improving management of the natural environment, with a focus on adapting to, and mitigating the impacts of, climate change, (c) reducing and mitigating negative impacts of human activity on the natural environment and human health, (d) demonstrating the value of the green economy and other concepts related to sustainable development, with an emphasis on livelihoods and the quality of life of citizens, (e) attaining significant progress toward the provision of reliable and affordable energy, potable water, and wastewater technologies for sustainable development, (f) enhancing application of science, technology, and innovation in support of national socioeconomic development and environmental management across sectors, (g) enhancing and improving knowledge, attitudes, and behaviors among all sectors, and lastly (h) producing a rationalized structure for efficient and optimal delivery of government services in pursuit of sustainable development objectives.

For policy formulation through multilateral agreements, especially in the area of climate change, the SDED needs hydromet data, especially rainfall, air temperature, humidity, wind speed, evapotranspiration, and streamflow data. Electronic access to hydromet data (located at both SLMS and WRMA) websites is needed. In addition, geospatially referenced data are preferred.

The SDED is not a provider or routine user. It is an occasional user of hydromet data. Specifically, data used lead to climate change adaptation policy recommendations leading to climate-related financing. The SDED also works with the University of the West Indies that runs decadal climate prediction models. It also coordinates with the CIMH Climate Change Coordination Committee to provide data gaps and challenges. This process generates project proposals and scenarios.

Every four years the department coordinates the preparation of its national communications to the United Nations Framework Convention on Climate Change (UNFCC) when the SDED usually requests raw hydromet data but welcomes additional data products such as flood data (maximum heights and volumes), hourly rainfall graphics depicting long-term changes (precipitation and air temperature) and projections, and oceanographic data, including tidal data, sea level, ocean temperature, and so on (currently no agency is mandated to provide oceanographic data). Products such as graphics depicting long-term changes in precipitation and air temperature could be used in the division's public outreach program; however, such products are currently unavailable.

In the future, the SDED intends to develop an increased capacity in climate change modeling and scenario development. At this point, it uses consultancy services to provide these needed products. It is anticipated that much more internal technical capacity will need to be developed to establish more detailed climate change adaptation planning for the country's future.

Given the limited capacity at the national level, efforts should be made at the regional level (Organization of Eastern Caribbean States [OECS]) to consolidate resources and provide comprehensive hydromet and oceanographic services and products to the member states. Such an initiative was started under an OECS climate change project funded by the U.S. Agency for International Development (USAID) and needs to be continued through the establishment of appropriate institutional arrangements. Contributing initiatives are also being conducted under the OECS's Oceans Governance Unit.

2.2.9 Ministry of Physical Development, Housing, and Urban Renewal, Transport, and Aviation - Physical Planning Division

The mission of the Ministry of Physical Development, Housing, and Urban Renewal, Transport, and Aviation is to foster sustainable improvement in the quality of life of all St. Lucians, through effective integrated planning, coordination, implementation, and monitoring of physical/spatial, technological, economic, environmental, and social development activities. The Physical Planning Division is responsible for data dissemination, the production of geospatial data, and distribution. Since recently the agency has been distributing new tide gage data from an installed tide gage by the U.K. National Oceanography Center (NOC) to the Meteorological Services. A platform data bank has been established for agencies to use along with viewing tools such as layers of geospatial data. This agency is becoming the framework for opening and standardizing data for open use in the country. Flood hazard and landslide susceptibility analyses have been carried out as part of the Caribbean Risk Information Program in close collaboration with the Physical Planning Division, the Ministry of Infrastructure, Ports, Energy and Labor as well as other ministries (please see www.charim.net for the hazard maps and other products of the program). WRMA conducts analysis for physical planning relating to land use concerns. The World Bank's DVRP will provide a LiDAR survey of the country and will access topographic and bathymetric data for many users including engineers, geologists, foresters, climate change experts, and hotels.

2.2.10 Fire Department

The Fire Department needs available water resources information on the country at any given time, especially during droughts. Identifying freshwater supplies is critical to firefighting capability. Fire Department receives MET data only from NEMO and not directly. Since the Fire Department, with NEMO, acts as a first responder to storms for medical response, and rescue, it is important that it receives current data, forecasts, and warnings.

2.2.11 Ministry of Agriculture, Fisheries, Physical Planning, Natural Resources, and Cooperatives

The mission of the Ministry of Agriculture is to develop the agricultural sector to ensure increased production of quality food and other commodities through environmentally sustainable management practices for the benefit of the entire population. Meteorological and hydrological information is needed earlier and more frequently than currently received. Real-time hydromet information is generally used by technical staff to advise farmers on their cropping situation. Trends are analyzed to determine planting seasons. Forecasts and warnings for hurricanes and flooding are adequate. However, forecasting of droughts presents a concern for agriculture.

Precipitation, temperature, and evaporation data are received but need to be improved. Earth observation products are needed, especially satellite rainfall estimation and evapotranspiration for example. Surface water supply, discharge data, and streamflow forecasts are needed. Currently, the products and services are minimally considered in many important decisions. In the irrigated basins of the Baboneau, Roseau, Mabouya, and Cul De Sac Valley's regions, there is a need for hydromet data to support farming.

Current data and forecasts need to be formatted as tables, graphs, or maps. In addition to the need to visualize and present information more graphically, and in maps, communication is a challenge since farmers often do not understand the forecast product content. The information is easy to read for people who are technically inclined but should also be presented in ways that farmers can practically understand and use to make production and work decisions.

Agriculture does not collect its own water data and depends on WRMA. Water quality data do not exist but need to be collected and available to farmers.

The Forestry Department provides collaboration and partnership for the preservation and sustainable use of forests, nature, and the benefits they provide. There is one forestry preserve on the island. Also, there are offshore islands to the south of the main island that are protected. Forestry does not need hydromet data or forecasts. More likely there is not an understanding of how hydromet data and forecasts could be used.

2.2.12 Regional Disaster Management Support Organizations

Caribbean Disaster Emergency Management Agency

St. Lucia belongs to the Caribbean Disaster Emergency Management Agency (CDEMA) that provides support to NEMO in the form of training, developing hazard preparedness and response plans, developing legislation, and taking actions to reduce losses from major threats such as hurricanes.

CIMH

The CIMH has a mandate to assist in improving and developing the meteorological and hydrological services as well as building awareness of the benefits of meteorology and hydrology for the economic well-being of the CIMH member states. This is achieved through training, research, investigations, and the provision of related specialized services and advice. St. Lucia is a member of the CIMH. For hydrology, the CIMH provides training in hydrological services in the technicians' course and in instrumentation, operations, and maintenance (O&M). For meteorology, the World Meteorological Organization (WMO) training is provided by the CIMH for meteorological technicians and forecasters. Also, courses in agrometeorology and climate services have been offered in research and development internships. The CIMH collaborates with the University of Arizona and Germany's Max Planck Institute.

The CIMH archives St. Lucia's weather, water, and climate data. Archived data are quality controlled and used for training, verification, and research. The CIMH produces a regional monthly agrometeorological precipitation and weather outlook. The CIMH runs a 4 km regional meteorological prediction model for the Caribbean region. It is currently demonstrating a regional climate forecasting center capability.

The CIMH assists countries with installation of hydromet equipment. Recently, the CIMH assisted St. Lucia WRMA/MET in installing an automated rain gage and stream gage at Dennery and a soil moisture probe at Union.

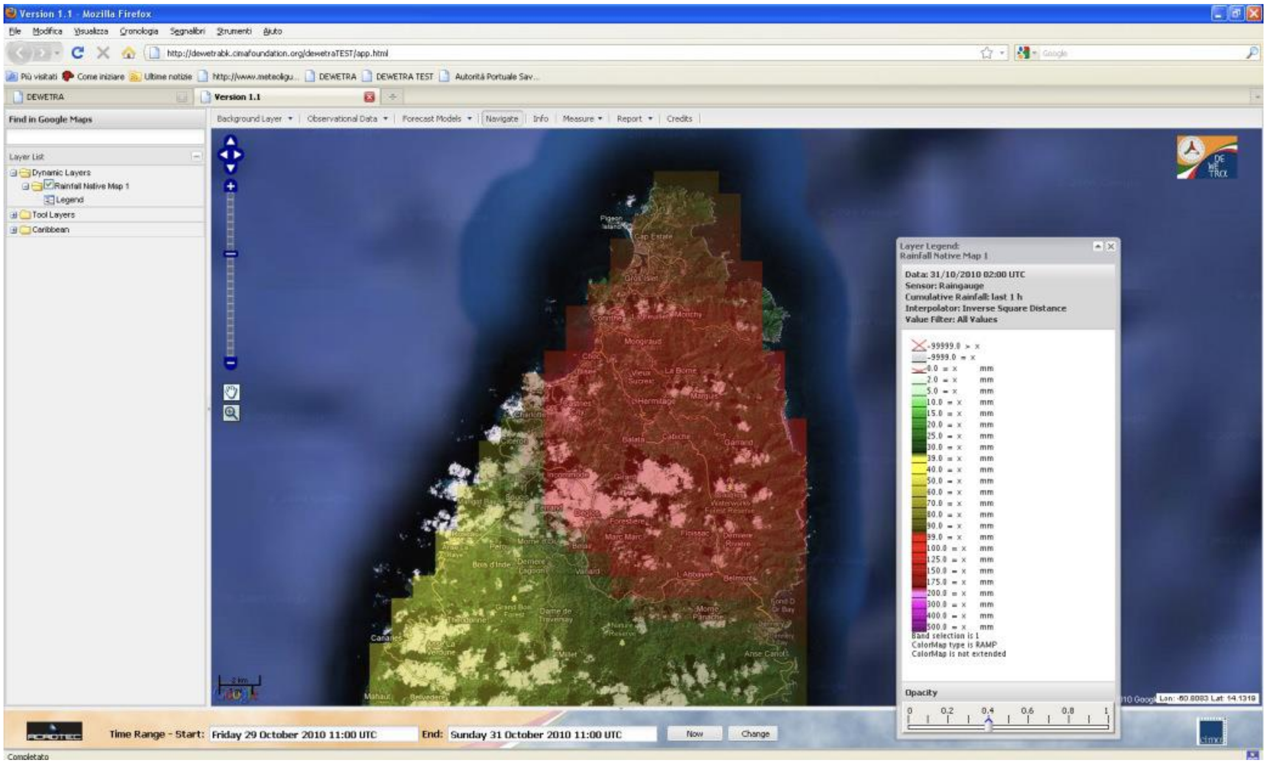
St. Lucia is now part of a United Nations Development Programme (UNDP) project, with assistance by the CIMH, to implement the Common Alerting Protocol CAP SMS warning system.

DEWETRA

The CIMH operates DEWETRA, which is a real-time data and information system established to address hydromet risk forecasting, environmental data monitoring, and disaster risk reduction, to integrate observational data in the Caribbean region. The system is operational in Italy in the Prime Minister's Office National Department for Civil Protection, *Centro Funzionale Centrale*, and was developed by the CIMA research corporation. The DEWETRA hardware/software is based on a multitiered open source software technology that links data to decision support systems. Using a multi-layered graphical user interface, the user has access through the Internet to remote web services. DEWETRA provides disaster managers with real-time weather observations, radar, and satellite products. The system installed focuses on wildfire, landslide, and floods.

The CIMH runs the Weather and Research Forecast (WRF) model with domains at 18 and 4 km. During a Hurricane Tomas scenario demonstration, data from two automated weather stations were integrated with satellite data in DEWETRA to visualize the potential impact of the storm-produced rainfall in the two watersheds in St. Lucia (Figure 5). There are five automatic weather stations (AWS) operating in DEWETRA in support of EWS, but only three are functional.

Figure 5: DEWTRA Screen Slide Showing Satellite Data Used to Visualize Impact of Hurricane Tomas



2.3 Summary of User Needs

Assessments of the principal user community have revealed that only basic forecasting services and products were being received by users. Users have made it obvious that more data in the form of observations and derived information are needed. In particular, users need more rainfall and weather observation data throughout the island, especially in the eastern region. Data sampling needs to be increased temporally from daily to hourly and, in some instances, less than hourly. Earth observation products, especially satellite rainfall and evapotranspiration estimations, will also help, especially the agriculture sector. Stream gage data are limited, which negatively affects the operation of the three EWS. Users have remarked many times that the current rainfall network does not reflect the large variation of rainfall experienced across the varied island topography. There are large spatial variations of precipitation and wind magnitude that are not captured due to the sparse density of the current network. Access to data for users is complicated by having to request precipitation data from two national organizations if they want to get the total rainfall network observations on any given day.

The need for better communication between users and providers is also evident. Users do not know what types of data, forecasts, or warning products are available. For example, many users do not know what rainfall data are available since rain gage data are collected by two national agencies separately and not integrated. Many users of forecasts and warnings indicated they need assistance in interpreting forecast terminology. Some of the existing automated (telemetry) rain gages are in a state of disrepair necessitating servicing and parts. Many, if not most, users would like to have an electronic access (website) to obtain and download real-time data, forecasts, and warnings as well as historical data such as climate information.

Water quality is beginning to deteriorate as population and water usage increase, yet no water quality data are available to users. The EHD and WRMA collect water quality data through sampling; however, an increase in the frequency of sampling as well as a greater array of sample variables is needed. Areas in need of sampling include streams, outlets for water supply, potential polluting sites such as dense agricultural regions, septic fields, and potential polluting locations such as hotels and poultry farms. Additionally, coastal locations need to be better monitored for environmental quality, as needed by the Environmental Health and Tourism Departments. High erosion rates on the island result in heavy sedimentation of the rivers, which causes stream bed elevations to increase, which, in turn, increases flood hazard. To understand and manage the sedimentation processes, users will need sediment samples to be taken in selected in-stream locations to quantify the sediment load of rivers.

Droughts have a significant impact on the island's economy and services when they occur. Although past attempts have been made, there is currently no established drought assessment and prediction program for St. Lucia and such a program will need to be established. Although there is some rainfall data from which deficits and anomalies can be calculated for the two airports, additional analysis showing trends of temperatures and precipitation is needed. Access to the historical precipitation and stream gage database does not exist along with access to drought forecast products. Given that the risk for dry spells and droughts is increasing, policy makers and planners are concerned that supplies of water could diminish significantly, resulting in a drought catastrophe. Currently, serious consideration is being given to desalinization as a backup source of water but that option is expensive. Groundwater could also serve as a more economical backup or secondary source of water for everything from agriculture to municipal water supply. However, little is known about the quantity or quality of exploitable groundwater.

Table 1 summarizes currently met and unfulfilled needs for hydromet data, forecasts, and warning information for users who were surveyed and interviewed. As indicated earlier, the assessment focused at public sector users while the needs of private sector, academia, civil society, and municipalities were not fully assessed. The various sectors and organizations are listed along with current products and services now provided and a summary of unmet needs that should be addressed by upgrading WRMA and Meteorological Services capabilities.

Table 1 Summary of Users Fulfilled and Unfulfilled Hydromet Information Needs

Stakeholder/User	Unfulfilled Hydromet Information Needs
NEMO	• Relies on SLMS for storm watches and warnings and based on warnings activates a national response plan • Relies on SLMS for tsunami alerts and relies on the Caribbean network of sensors and National Oceanic and Atmospheric Agency (NOAA) Tsunami Warning Center Watch Alerts. • Cooperates with SLMS and WRMA and communities to establish and operate 3 FEWS and is establishing fourth system at Dennery—SLMS notifies NEMO when Floods threaten based on rainfall thresholds • Needs to receive warnings for surges in West Coast of the Island • Needs assistance in interpreting technical descriptions in forecast and warning products • Needs more assistance in translating forecasts to impacts on infrastructure and population • Needs high-frequency radios and satellite phones for emergencies/disasters • SLMS sends data upon request, however NEMO would like this process to be automatized.

	• Forecasts are generally for the whole island but disasters usually are restricted to parts of the island—needs better warnings specific to areas within the island
SLASPA	• Needs flood forecasts for roads leading to the main airport • Huge demand for wave and wind conditions by marine interests. SLMS currently provides but SLASPA needs more information • Needs better resolution of bathymetry of coastline for ships and for tracking sedimentation, which is a growing problem. • Would like to receive lightning data • Would like to have more tidal gage data
Energy - LUCELEC	• Prime power plant vulnerable to tsunami or large surge— only 1 km from ocean—need climate change modeling analysis conducted. • Tropical storms and hurricanes greater than Category 3 represent a large threat to outages on the island so forecasts and warnings are critical • Needs lightning information • Needs more accurate and more detailed resolution of temperature, rainfall, wind, and how it varies across island. • Has to request rainfall data but needs them sent routinely. Needs more rainfall data to define how rainfall varies across the island (map). • Needs 24-hour high-resolution rainfall forecasts for parts of the island (map) • Critical wind forecasts on the eastern half of the island—wind farms • Will need in future hourly temperature, cloud cover, and wind speeds to support passive power growth • Drought does not affect power operations
Media - GIS	▪ Opening a data portal for the government—For meteorology soft launch for access to historical weather and climate information at both airports for demonstration • Weather data important for journalism • During hydromet disasters, rumors are a problem and they are rampart on social networks such as WhatsApp, Facebook, and Twitter. Needs ability to use these networks to better describe weather event and impact • More visualization of products needed • GIS assisting SLMS in developing a website—current website is old and cannot post data • Needs to recruit professional meteorologists to conduct TV weather forecasts • Currently 5 days of forecasts provided in 7 days; monthly and seasonal forecasts are needed • Get warnings and official forecasts from NEMO • Needs education on terminology used in forecasts, for example trough depression, • Needs assistance in interpreting technical information in forecasts and warnings • Needs forecast wording to reflect diversity of population in age (getting older), language (Creole) • More workshops and training needed by SLMS to understand technical jargon and to interpret forecasts and probabilities
Tourism - DOT	▪ Storm forecasts received from NEMO and then tourism calls hotels, transport association, and so on ▪ Weather information can be confusing. Needs technical assistance in interpreting message intended ▪ Needs awareness workshops

	▪ Need assistance in interpreting forecasts and warnings for social networks top reach people ▪ Does not get drought information that it needs. ▪ Needs weather, storm, hazard impact information, e.g. on how flood or drought will impact the island's infrastructure ▪ Needs to track water availability during drought. Trucks needed to back up water for business and resorts
Health - Department of Health	• Relies on media for climate and weather information. Gets severe weather information from NEMO • Gets rainfall data on request but needs more data quicker! Website access would be nice • Needs more rainfall and drought data. None available for eastern St. Lucia • Needs more detailed (spatially) rainfall forecasts and higher resolution as rainfall gives it indicators for contamination of water supply • Needs to know flood forecast peaks when flooding will start and end • Needs flash flood forecasts • In the south, rainfall and floods overtake treatment plants leading to contamination • During flood and hurricane disasters Cholera a threat. Temperature and rainfall forecasts across the island needed to predict disease outbreaks—good correlation • Needs access to climate database. None exists • Sedimentation problem, especially in the north of the dam. Needs sediment data. South more fragmented. • Needs other water quality data and existence of water quality database from WRMA • Would be interested in obtaining access to water quality simulation models from WRMA
Ministry of Physical Development, Housing, and Urban Renewal, Transport, and Aviation - Physical Planning Division	• Not a direct user but interested in production and distribution of Hydromet information • Interested in building database and GIS capacity but through SLMS and WRMA. Output is maps and geospatial layers • Provides geospatial data and tools, for example for floods • Responsible for developing land use policy and development control so always collects and updates data • WRMA does analysis for physical planning
WASCO - Water and Sanitation Company	• Precipitation data are used from both WRMA and SLMS as well as 24-hour rainfall forecasts from SLMS to determine whether heavy rainfall and potential flooding may occur and thus WASCO will take mitigating actions. More rainfall data and rainfall forecasts are needed beyond 24 hours • Water distribution losses of 50% occur through leaky pipes. There is an immediate need to conduct water balance studies conducted by watershed and nationally • More streamflow data are required from WRMA. In fact, streamflow data (and gages) for each of its inlets (see map) and at the dam are required. This not only means more stream gages installed but also rating (measuring discharge) at each of the stream gages so discharge can be estimated at each river stage observation • SPI durations are used to mitigate the effects of dry spells and droughts • There is a requirement for WRMA to develop watershed models that can be tools used in watershed planning

	• The SLMS information is readily available through direct contact and through access to media and Twitter. It could/should be improved to compile information on a geographic information system with set protocols and metadata • Data from SLMS and WRMA should be continuous and baseline information available to provide trend analysis • Short and long range drought forecasts needed • A vulnerability threat analysis should be determined to show where flooding, landslides, and so on will likely occur on the island to build resiliency • Limited water quality information exists. More quality data needed ASAP.
Ministry of Education, Innovation, Gender Affairs, and Sustainable Development - SDED	• Routine use of hydromet data and information are not needed • Raw hydromet data are needed periodically—specifically precipitation, temperature, wind speed, evapotranspiration, and Stream flow • Data resolution is too coarse; higher resolution is needed • Flood data are needed (maximum heights and volumes) • Hourly precipitation data are needed and not readily available • More graphics showing long-term changes in precipitation and temperature, and projections are needed • Oceanographic data including tidal data, sea level, ocean temperature, and so on are needed; however, currently no agency has this responsibility • Electronic access directly to the hydromet database should be available • Products such as graphics showing long-term changes in precipitation and temperature and projections are needed • Would prefer to have direct access to hydromet database (on Internet) • Geospatially referenced data are preferred
CIMH	• Provides regional training and research to St. Lucia • Archives St. Lucia hydromet data and then quality controls data and uses for training and some research • St. Lucia primarily benefits from the CIMH in terms of training and technical support for O&M of some equipment • WRF model run for Caribbean and available to SLMS as well as regional radar datasets that St. Lucia can access
Fire Department	• Needs available water sources from WRMA, especially during dry spells and droughts • Does not receive any SLMS information. Gets warnings from NEMO • Needs to know when storm conditions will break so as a first responder it can get out for relief, rescues, medical response, and so on
Office of Agricultural Services Extension and Engineering of Agriculture, Food Production, Fisheries, Cooperative, and Rural Development	• Main interest for agriculture is weather, water, and climate information during droughts • Forecasts and warnings for hurricanes and flooding are adequate • However, needs 109-day weather forecasts and weekly, monthly, and seasonal outlooks for water availability, temperature, and precipitation • Interested in precipitation, temperature, relative humidity, wind, and soil moisture data • Encounters a huge erosion problem on the island and resultant sedimentation of streams • Does not look at chemical testing • Agriculture does not produce its own data; it depends on WRMA • Rainfall data available is adequate • Earth observation products, especially satellite rainfall and evapotranspiration

Forestry Department	• Does not need hydromet data • One forestry reserve (park) has wildlife and trails • There are farmer cooperatives that coordinate with the Food and Agriculture Organization (FAO), European Union (EU), USAID, and OECS. • Helps understand how meteorological data and forecasts could be used

3. Assessment of Hydrological and Meteorological Services

The Assessment of Hydrological and Meteorological Services was conducted by reviewing previous reports, assessments, and evaluations as well as through meetings held with key representatives from WRMA and SLMS. Both agencies provided information through extensive surveys that contributed to a more detailed understanding of the hydrological and meteorological data collected and provided to users. These two organizations are the principal government providers of meteorological and hydrological information for the nation. There are other national, private, and regional organizations that provide hydromet information but only at a very small scale. The assessments are provided here as separate sections for hydrology (WRMA) and meteorology for Meteorological Services. Within each discipline, the assessments are categorized by (a) the institutional and organizational survey of legal, financial, policy, and human resources and (b) Infrastructure consisting of data collection, communication of information, database, modeling, forecaster competency, and capacity and dissemination of products and services.

Overall, data producers in St. Lucia have limited ability to deliver needed products and services to the user community. Their capacity is limited by lack of available data, forecasting tools, data exchange and dissemination mechanisms, up-to-date forecasting models, and the education and training skills of the forecasters. They have also faced difficulties in catching up with advancing technology for observations, forecast, and communication systems.

3.1 Water Resources Management Agency

WRMA is located in the Ministry of Agriculture, Fisheries, Physical Planning, Natural Resources, and Cooperatives. This section describes the agency, its mission objectives, structure, human resources, and budget.

3.1.1 Institutional and Organizational Functional Analysis

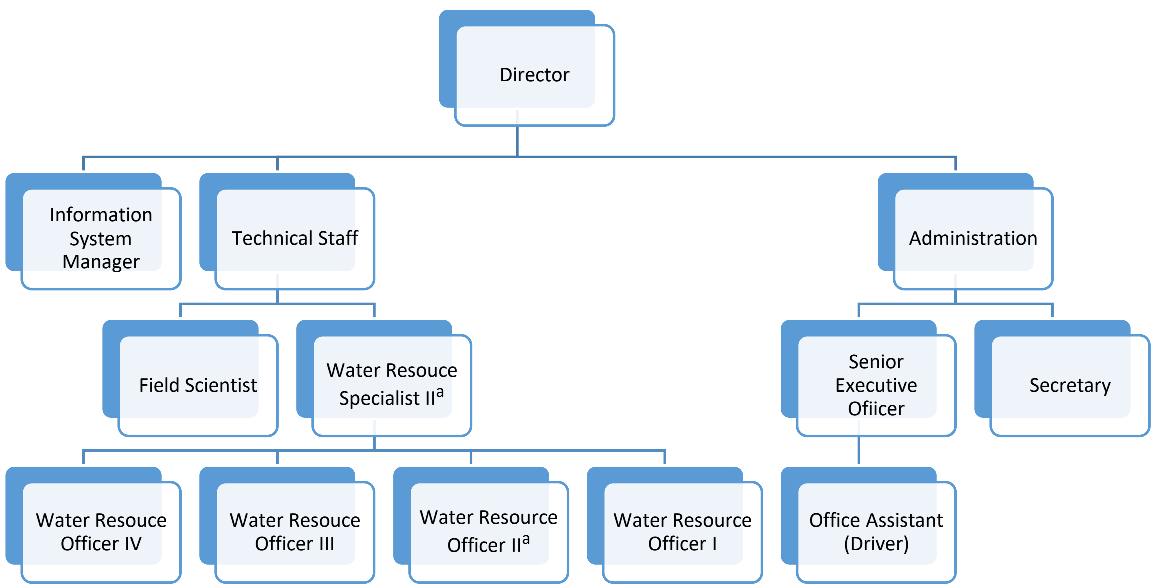
Mission objectives. WRMA is committed to advancing principles of integrated water resources management. It is also the NHS for the country. WRMA is responsible for collecting hydrological data including soil data, surface runoff, stream water elevations and discharge, groundwater elevations and flows, groundwater recharge, soil erosion and sedimentation, water quality, and all aspects of the hydrological cycle. Although WRMA does not have the flood warning responsibility for the country, it is responsible for providing hydrological expertise, information, knowledge, and development of flood forecasts in support for establishing FEWS.

Legal mandate and framework. The GOSL with financial assistance from the Caribbean Development Bank, the World Bank, and WASCO undertook from 1999 to 2009 a Water Sector Reform Project. This act established the regulatory framework needed to manage water. The Water and Sewerage Act was then enacted in 1999 establishing the National Water and Sewerage Commission (NWSC) to regulate the granting of licenses, the development and control of water supply and sewerage facilities, and related matters. In 2001 the Water Resources Management Unit (WRMU) was established within the Ministry of Agriculture, Forestry, and Fisheries under an EU-funded Water Resources Management Project (WRMP). The objective of this project was to create the capacity to effectively manage water resources for agriculture. The WRMU in collaboration with the NWSC and with the support of other agencies such as the Caribbean Council of Science and Technology (CCST), the Organization of American States (OAS), and the Caribbean Environmental Health Institute (CEHI) was responsible for the 2003 development of the island’s first National Water Policy. By 2005 the island had enacted revised legislation, the Water and

Sewerage Act No. 14 of 2005. Act 13 of 2008 was strengthened in 2009 and established a WRMA. Section 4 of the act details a number of responsibilities for WRMA including approving licenses and permits for water use; establishing and maintaining a database; promoting sustainability of water resources; advising on conservation practices, public awareness, water resources assessments and planning, watershed management plans, and allocation schemes; advising the government on enactments that relate to conservation; providing technical advice to the commission; and advising the Minister on licenses, water, waste control, and emergencies.

Structure. The staff of WRMA consists of 12 positions (Figure 6). The Director of WRMA oversees an Information System Manager, a technical staff of four Water Resources Officers, a Field Scientist Field Scientist, and a Water Resources Specialist. The supporting administration staff includes a Senior Executive Officer, a Secretary, and an Office Assistant (driver). The Water Resources Specialist and one Water Resource Officer positions were vacant at the time of the first World Bank mission for this project.

Figure 6: Organizational Chart of WRMA



Note: a. Vacant positions at the time of the first mission.

Human resources. Three out of eight members of the professional staff in WRMA have at least a bachelor's degree. The highest qualification in hydrology is a postgraduate certificate while some officers are trained in hydrology at the certificate level. One professional has a bachelor's degree in telecommunications engineering and two individuals have master's degrees. There are three nontechnical positions shown in Figure 6 that provide project management and administrative support functions.

The WRMA staff are competent but there are staff positions vacant. The existing small core professional staff need training, and there is no comprehensive training for water resources management at the national level. Regional training is available periodically by regional Caribbean organizations such as OECS Environmental and Sustainable Development University (EDSU), the Caribbean Natural Resources Institute (CANARI), and the Caribbean Public Health Agency (CARPHA) that have provided training workshops in the past. Training needs are in hydrological and hydraulic modeling, remote sensing, and geographic information systems.

Financial resources. The budget for WRMA for the past three years has been growing, but the budget for operation and expenses has been decreasing. As shown in Table 2, the budget increased from US$571,000 in 2014 to US$618,000 in 2015, and saw a slow increase to US$635,000 in the 2016 budget. O&M budget has decreased from US$24,359 in 2014 to US$20,000 in 2015 to US$12,000 in 2016.

Table 2: Recurrent Expenditure Program (US$)

Item/Year	2014	2015	2016
Personal emoluments	420,411.00	496,587.00	507,972.00
Wages	0.00	0.00	7,255.00
Travel and subsistence	60,715.00	75,632.00	76,878.00
Office and general	3,517.00	5,000.00	12,000.00
Supplies and materials	687.00	1,500.00	6,000.00
Communication	7,492.00	9,995.00	9,871.00
O&M	24,359.00	20,000.00	12,000.00
Insurance	0.00	9,813.00	3,200.00
Total	**517,181.00**	**618,527.00**	**635,176.00**

3.1.2 Observation Infrastructure and Forecasting

The end-to-end hydrological forecasting and warning system is composed of an observation system, a communication system, and a forecasting system. This section describes the status of the various subcomponents of the end-to-end system.

Hydrological Data

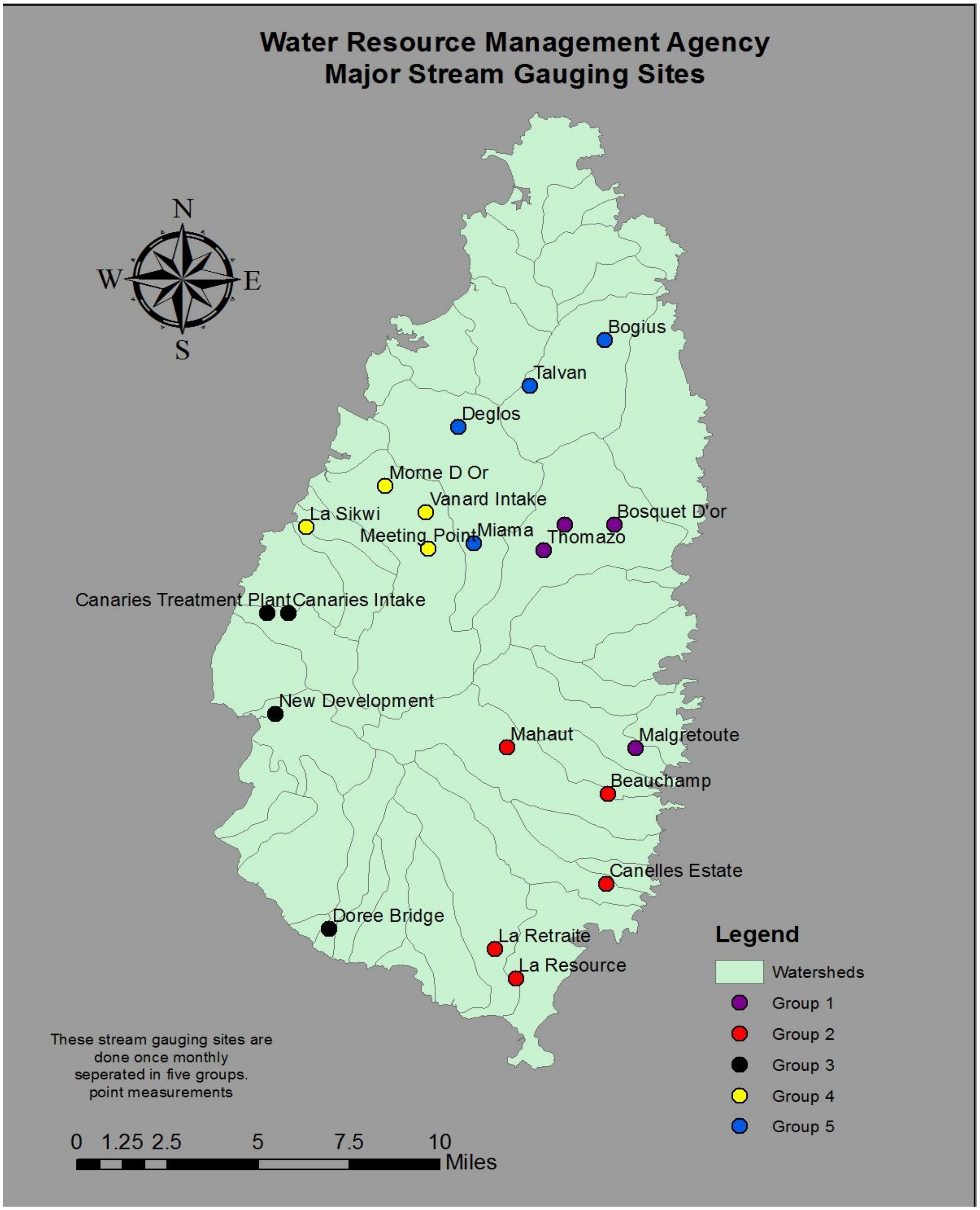
To manage the water resources of St. Lucia, it is necessary to collect data and information to determine the quality and quantity of water in the country.

Surface Water Data Network

According to WMRA inventory, there are 21 sites where streamflow point measurements are taken. There are five radar water-level sensor stream gages, but two are not operational. There are three submersible water-level pressure transducer gages and all of them are currently not working due to excessive flood damage or vandalism. In addition, there were three staff gages. Figure 7 shows the current stream gage network of the country. The color coding by groups refers to the week these gages are read and data tabulated or downloaded from the data loggers. In annex 2 is a table showing the combined hydromet network of both WRMA and the Meteorological Service.

None of the 21 sites where stream gauging is carried out are currently rated, and as a result it is not possible to calculate discharge from the stream staff reading (height) data. For all practical purposes, and especially in a situation where sedimentation is becoming a major problem to the rivers, it is important to calculate stage-discharge relationships on a routine basis for the stream gage network and to begin sediment sampling and monitoring. In the northern region, the John Compton Dam needs to be equipped with a pool gage and an inflow and tail water stream gages so that the water stored in the dam can be determined and eventually forecast to better manage the drinking water supply.

Figure 7: St. Lucia WRMA Stream Measuring Sites



Source: WRMA.

Groundwater (Quantity and Quality) Data Network:

Groundwater investigations in the 1960s revealed that a good supply of water may be available with an acceptable water quality. Water quality issues of hardness, salinity, and iron content have resulted in little exploitation of the groundwater reserve. The complex volcanic geology apparently makes access to groundwater difficult in some portions of the island (WRMU 2001). It also appears from the lack of ponds and surface water detention that very little recharge occurs to the aquifer currently. There is no groundwater monitoring currently while some wells are in use by agriculture.

Precipitation Network

There are 29 rain gages in the rain gage network of which 16 are automated. Only 12 of the 29 gages are functioning properly. Two rain gages are automated tipping bucket gages, located at Bouton and the John Compton Dam. These two stations transmit observations automatically to WRMA for collection and processing. In two locations, WRMA rain gages are located very close (within a few meters) to MET rain gages or weather stations. Two weather stations are located at and servicing the Hewanorra International Airport: (i) one more than 35 years old manual Monroe weather station which is functioning well and (ii) one Vasaila automated weather station which is currently inoperable and seems to require significant repairs or replacement. As a consequence, the air traffic is currently dependent on the functioning of the Monroe station which due to its age may need close monitoring and maintenance.

Water Quality Surface Water and Coastal Monitoring

Water quality is becoming an emerging problem for St. Lucia as more 'hot spots' are developing. There is very limited water quality sampling occurring now in the country, and there currently is no real-time water quality monitoring program being undertaken by WRMA. The EHD has access to regional water quality laboratories and conducts both routine and circumstance dependent tests (mainly bacteria). Contamination threats from agriculture, waste disposal, recreational, pesticide, and pig pens demand on-site testing. Weekly water quality tests are conducted by WASCO at designated water supply inlets that the EHD also monitors.

WRMA does some water quality testing but its testing facility is limited. For example, there is a need to test for heavy metals, but WRMA does not have the equipment or facility to conduct such needed tests. WRMA is now developing a water quality program for the country that will include a water quality monitoring program from St. Lucia's water bodies (coastal and surface water) and aquifers.

Database and Processing

Currently there is no practical hydrological database being maintained. WRMA's database is manually oriented and available as a time series on the Internet but its use is limited. Various separate spreadsheets and databases connected with FEWS are collected, processed, and maintained, but these data consist mainly of both rain gage and stream gage observations. A database called Webmap is being used by WRMA but use is limited and an upgrade is probably required so that users may use the system as intended. There is a multiuser demand for a national hydrological database that contains data from the existing observational network. A database is needed that includes surface river stage, flow, groundwater observations, well data, and water quality data, for both surface water and aquifers. In addition to the need for a central data storage facility, there is a need for tools to conduct data analysis and quality control of the data collected.

There currently are no hydrological modeling systems being run operationally in St. Lucia. However, there are operational FEWS for the Castries River at Marchand, Bois D'Orange river, the Anse La Reye River, and Canaries. These systems use rainfall thresholds and real-time rainfall data collected in the basin to trigger warnings. The thresholds are calculated by running a hydrological model. A new FEWS is being established at Dennery.

Nationally, there is no centralized hydrological forecasting system to provide hydrological forecasts and warnings for all of the flood-prone communities and to meet the forecasting needs of the water resources community. Instead, there are community FEWS established on an as-needed basis. The basic operating principle of the St. Lucia FEWS is shown in Figure 8. FEWS consist of automated rain gages deployed in the river basin, an automated stream gage, a micro-processor that processes rain gage data and shows alerts received from rain gages of the Meteorological Service located at Hewanorra Airport and a Control Siren Alarm system that will be activated if flooding is indicated. Each automated rain gage has programmed in its data logger a rainfall alert threshold that, if reached, is likely to cause flooding. The rain gage alert is sent through the ultrahigh frequency (UHF) radio transmission to the airport processor where a visual and audible alarm sound to signal the forecaster that a flood danger risk may be present. The alarm is only sounded if the forecaster believes by checking other rain gage data, flow data, or other information such as the neighboring island radar data to see if radar reflectivity and/or rainfall estimation validates the rain gage or rain gages' alerts. Various frequency (10-year flood, 50-year flood, and so on) critical rain gage thresholds are calculated by a hydrological model (Hydrologic Engineering Center – Hydrologic Modeling System: HEC-HMS) that are used to trigger alerts. A rating curve is required for each EWS river basin for this process to work.

The status of FEWS[2] is as follows:

(a) The Castries River FEWS at Marchand has one stream gage and one rain gage and is functioning normally.

(b) The Bois D'Orange River is configured for two stream gages that are not functioning and two rain gages that are also broken.

(c) The Anse La Reye River is configured for three AWS and one rain gage and no stream gages exist currently. Only on AWS is currently functioning

(d) The fourth FEWS at Dennery is now being established. Equipment has been installed but calibration is ongoing.

According to the March 2015 overview of the St. Lucia FEWS, existing hardware and software to collect weather data from the AWS operated by the MET office are outdated. Export of collected data can only be done by floppy diskette, which makes data extraction very cumbersome. Therefore, the system needs to be replaced with the latest generation of data management software and respective hardware. The recently completed Dennery FEWS does provide real-time data and text warnings.

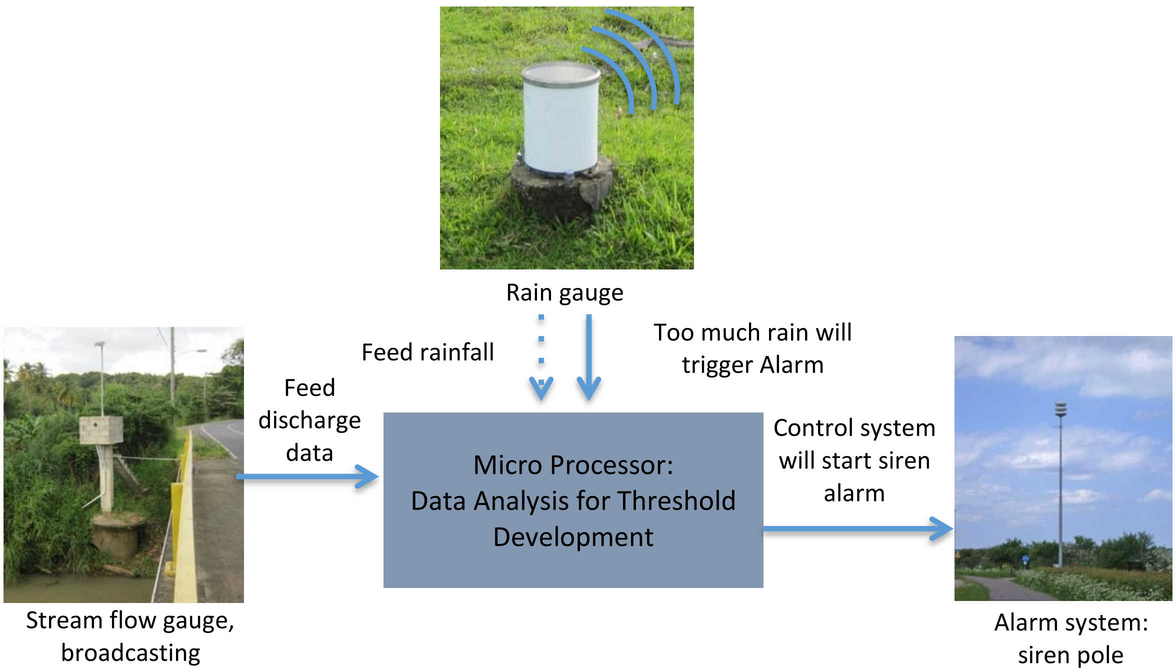
Systems such as these EWS have been used for many years in many locations throughout the world including the United States. Maintaining these systems is always a challenge and difficult to sustain. Experience has shown that very few are functioning today. Performance success for these systems depends on continued maintenance of rain gages and stream gages as well as running models daily to recompute rainfall thresholds (rainfall thresholds will vary quite a bit with soil moisture in the basin). Additionally, rated and operational stream gages reporting to a fully operational computer and an alarm system along with trained system operators are necessary.

[2] Based on WRMA spreadsheet listing hydrological gage status for the country

At a minimum the operational functionality of the Bois D'Orange and Anse La Raye systems needs to be repaired because they are not now capable of providing adequate flood warning.

In addition to the three FEWs, the Government of Brazil and the FAO have established a drought information system on the Dauphins River at Monchy. This system consists of a stream gage with a data logger, a rain gage, and a soil moisture probe. This system is fully operational.

Figure 8: St. Lucia FEWS Concept of Operations



3.1.3 Delivery of Data, Products, and Services

Delivery of products and services can be categorized into water resources management and disaster risk reduction. WRMA is responsible for collecting water resources data for the country and according to the WRMA strategic plan, 'the basic core mission of establishing and maintaining a water database is threatened' due to a lack of resources to maintain the existing network and because of the limited capacity of the staff to perform this function. Delivery of data and information to users is very restricted. In countries such as the United States, a dedicated staff position is established at all weather and river forecast offices to provide essential user awareness, outreach, and liaison services. This is in addition to established user group meetings held quarterly. These specialized positions recognize the strong need of educating users with forecast terminology and information interpretation as well as learning user requirements that the NMHS must meet. The WRMA office should consider establishing a customer liaison or a Public Awareness and Outreach Specialist to understand data and product needs of users and to provide outreach and education to the user community. This responsibility could be added to an existing position description of a WRMA professional but will recognize the need for user interaction in delivering effective services.

The WRMA website provides very limited data access for users. Data collected in real time (precipitation and river gage) is primarily used for supporting FEWS and/or used by WASCO for water supply decision making. Many other users such as the Ministry of Agriculture, LUCELEC, SLASPA, and the EHD also need the data. Data collected are also used in assessing water resources availability in the country and calculating water balance and soil erosion and used for planning for water resources development in the future.

To fulfill its mission of establishing a Water Master Plan, developing an allocation scheme of issuing abstraction permits based on available water supply and creation of river basin water management plans, WRMA will need to determine a national water balance for the country and each of its major watersheds. This information will fulfill a significant emerging priority to one of its major users, WASCO, as currently abstraction permits are not based on known supply and actual abstracted amounts are not monitored.

3.2 St. Lucia Meteorological Services

SLMS is a division of the Ministry of Infrastructure, Ports, Energy, and Labor and is responsible for weather forecasting and climate services.

3.2.1 Institutional and Organizational Functional Analysis

Mission objectives. SLMS is responsible for providing weather data, forecasts, and warnings to the public and NEMO. Warnings include forecasts and warnings for severe weather, tropical systems, and hurricanes, floods, and tsunamis.

The Meteorological Services provides meteorological data and information in a usable form to the public and essential services to agriculture and businesses as required by regulations, agreements, protocols set by local, regional, and international regulatory bodies.

Legal mandate and framework. Currently there is no legislative or legal mandate; however, a policy note is under development.

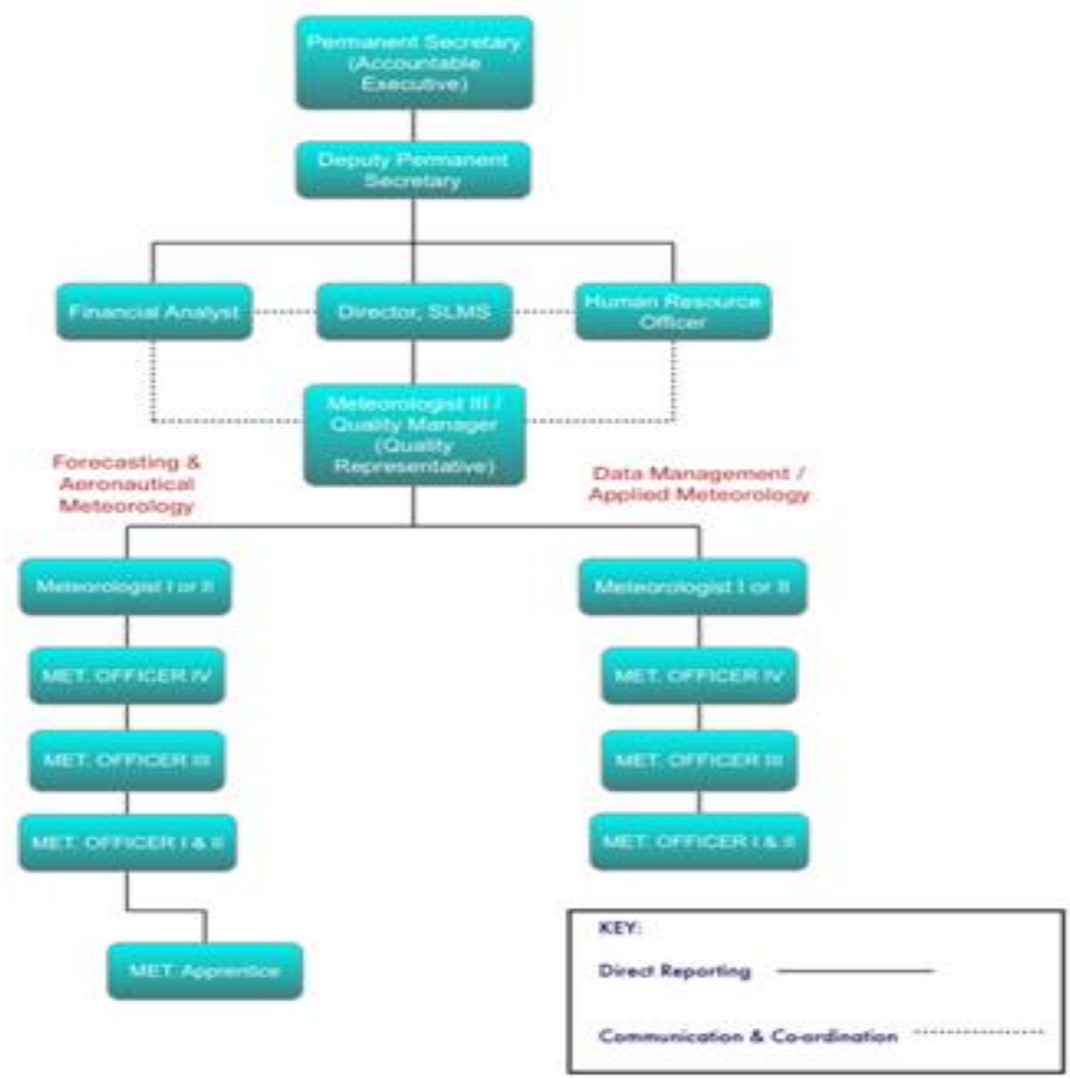
Structure. The Director of Meteorological Services (DMS) is also the permanent representative of St. Lucia with the WMO. The organigram for SLMS consists of two principal branches or groups (see Figure 9). The forecasting and aeronautical meteorology group is responsible for daily weather forecasts, warnings, and aviation forecasts. The data management and applied meteorology group is responsible for all meteorological support activities consisting of operational maintenance, climate services, development of products, and archiving.

Human resources. SLMS has eight forecaster positions and three Meteorologists. The positions consist of a Director, a Meteorologist who functions as a Quality Manager and is responsible for quality assurance. The second Meteorologist heads the Weather Forecasting and Aeronautical Meteorology branch. All forecasters must undergo WMO senior-level meteorological courses and are certified by WMO as aeronautical meteorological forecasters. The current Director, one Meteorologist, and one forecaster are temporary workers who were retained after retirement because of a lack of trained personnel on staff. There is also no Information technology (IT) position available in MET, only with the ministry. It is important for this office to have a dedicated IT position to support data and dissemination communications, which are critical functions to the forecast and warning process.

Building a competent professional meteorological workforce has been a challenge. Recruiting and retaining meteorologists has been difficult due to a perceived lack of career advancement and professional development opportunities. Training is even more difficult because of funding limitations (please refer to the paragraph on 'financial resources' below). When training is possible, SLMS uses the WMO's regional training centers such as the CIMH that provides WMO certified training. The center is badly in need of additional training for its meteorologists.

Forecasters are scheduled on one of three 8-hour shifts. On each shift there is at least one forecaster and one observer.

Figure 9: Meteorological Services Organigram



Financial resources. The overall budget for the SLMS office has risen slightly in 2016 - the actual budget history and projected budget are shown in Table 3. The line items of salaries, travel, office expenses, communications, hiring equipment, and transport (travel) have remained constant in the past three years and are projected to continue unchanged. O&M fell sharply in 2014 from US$39,000 to US$3,000 presently. This is clearly an unstainable condition for an operational agency.

Table 3: Budget for MET from 2014 to 2019

PROGRAMME:	02 : METEOROLOGICAL SERVICES						
PROGRAMME OBJECTIVE:	To provide meteorological data and information in a usable form to the public and specialized users in aviation, essential services, agriculture and businesses as required by regulations, agreements, protocols, etc. set by local, regional and international regulatory bodies.						
PROGRAMME EXPENDITURE							
SOC No.	Item	2014/15 Actual	2015/16 Budget Estimates	2015/16 Revised Estimates	2016/17 Budget Estimates	2017/18 Forward Estimates	2018/19 Forward Estimates
RECURRENT							
101	Personal Emoluments	$1,294,871	$1,441,766	$1,441,766	$1,442,229	$1,442,229	$1,442,229
105	Travel and Subsistence	$29,501	$44,246	$44,246	$53,111	$53,111	$53,111
108	Training	$28,445	$16,200	$16,200	$31,200	$16,200	$16,200
109	Office and General Expenses	$3,473	$7,866	$7,866	$7,866	$7,866	$7,866
114	Tools and Instruments	$11,899	$7,500	$7,500	$7,500	$7,500	$7,500
115	Communication	$24,853	$28,500	$28,500	$28,500	$28,500	$28,500
116	Operating and Maintenance Services	$39,172	$3,000	$3,000	$3,000	$3,000	$3,000
118	Hire of equipment and transport	$151,464	$164,650	$164,650	$164,650	$164,650	$164,650
139	Miscellaneous	$0	$0	$0	$0	$0	$0
Programme - Recurrent		**$1,583,678**	**$1,713,728**	**$1,713,728**	**$1,738,056**	**$1,723,056**	**$1,723,056**

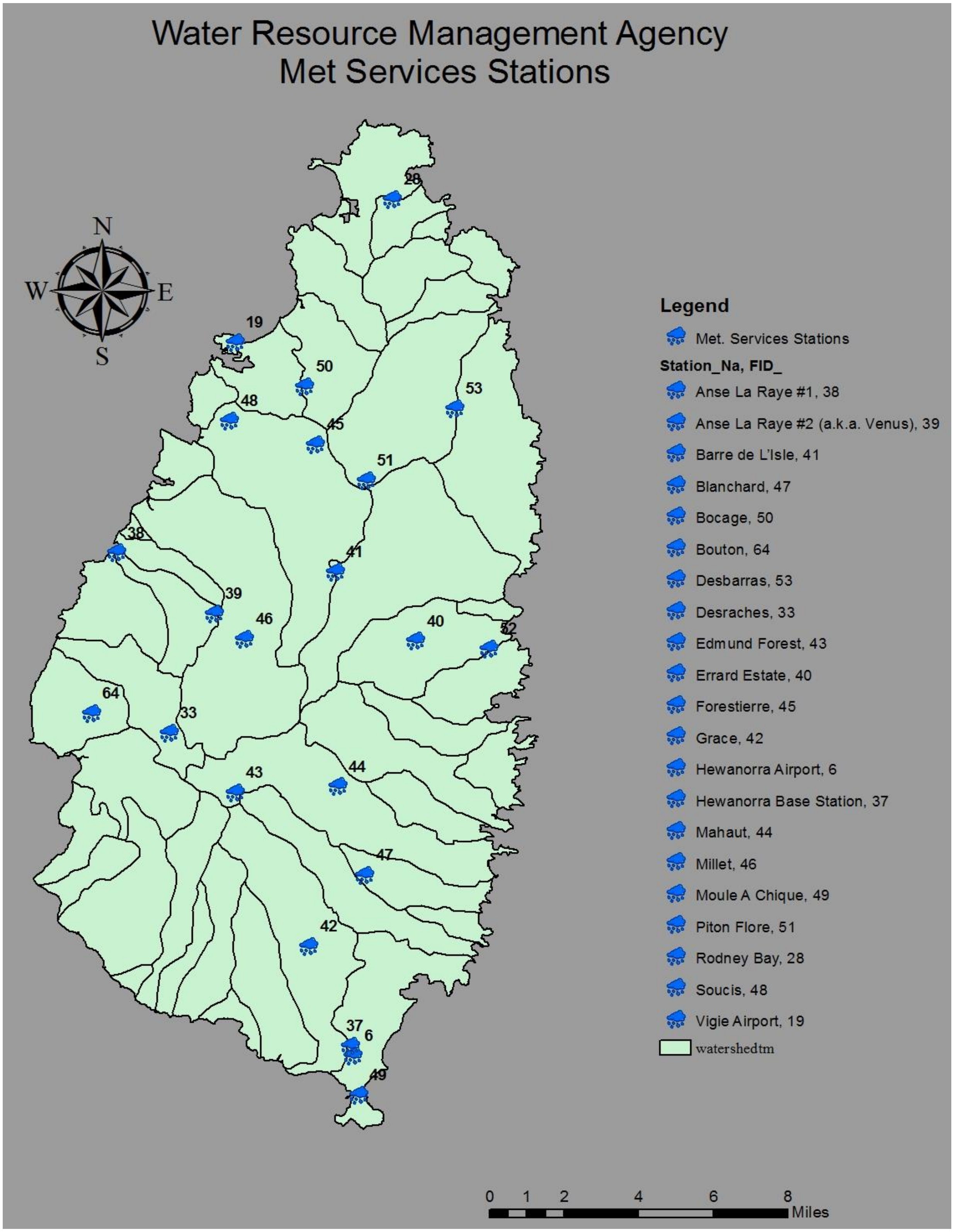
3.2.2 Observational and Forecasting Infrastructure

The infrastructure of the meteorological forecast service consists of a meteorological observational network; a real-time telemetry and communication system; a database; a procedure to analyze, diagnose, and quality control data; a collection of meteorological models; a product generator; and a data, forecast, and warning dissemination system.

Meteorological Data

The meteorological data network consists of the meteorological surface weather observation network, the climate and agrometeorological observation network, a precipitation gaging network, and remote sensing data obtained by the Internet. Annex 2 shows the combined surface weather observing network (weather stations) for both WRMA and the Meteorological Service.

Figure 10: Surface Weather Observation Network for St. Lucia



Source: WRMA.

Meteorological Observation Network

The Synoptic Surface Observation Network of St. Lucia consists of hourly observations collected at the two airports on the island. One is a manual agrometeorological station at Hewanorra Int'l Airport including one AWS reading solar radiation. The manual station is 35 years old and remains the primary source of data as the automatic station installed 2 years ago has ceased to function. The second hourly observation location is at George FL Charles Airport. There are 21 weather stations listed in the hydromet observation network spreadsheet, of which 1 was damaged by Hurricane Matthew, 2 require spare parts, and 1 has been decommissioned due to vandalism. Seventeen AWS are operational and reporting data. Some sensors in the AWS network have not been calibrated, and there are quality issues with the data. These data are downloaded monthly for archiving from data loggers.

SLMS does not receive WRMA precipitation data routinely although there is interest on SLMS. A recently signed Memorandum of Understanding between the two agencies makes provision to change this situation.

Climate Network

Both airport surface observation stations are also climate stations with 30 years of record.

Other Networks

In addition to the surface weather observation network and climate stations, SLMS operates two agrometeorological stations (at the airports) and two additional agromet stations. There is no upper air observation program for St. Lucia.

Remote Sensing Data

Satellite Data

There are two types of satellites and associated data that should be considered by St. Lucia NMHS. The first class of satellite is the Geostationary Operational Environmental Satellite System (GOES), such as NOAA's recently launched GOES R, which provides high-resolution imagery of visible cloud cover, water vapor, and infrared. These are essential products needed to diagnose, forecast, and warn users of hydromet extremes as well as for use in routine weather forecasts. The second class of satellites are polar orbiting satellites that provide very high-resolution microwave (radar) and infrared band imagery needed by forecasters for forecasting. There are also many specialized products created by European and U.S. (National Aeronautics and Space Administration [NASA] and NOAA) agencies, such as precipitation, evapotranspiration, soil moisture, vegetation cover, and water quality that can be very useful tools for both meteorologists and hydrologists. These raw data and processed data products are available to the Meteorological Service. Many of these existing products are not known and forecaster training is needed to understand the availability and access to products and how to use them.

There are currently no satellite data receivers on the Island. Satellite data by SLMS are accessed through NOAA on the Internet; however, these imagery data have a 30- to 45-minute lag time, too late to use for some warnings. Satellite data accessed consist of infrared, visible, and water vapor images that are very limited compared to the many other products available for use by forecasters as well as for WRMA hydrologists. A geostationary satellite receiver for GOES data is needed to access imagery data in real time.

Radar Data

There are no radars on St. Lucia. However, there are other Caribbean island radars operating and St. Lucia is located under the radar umbrella of their effective range. The Barbados radar covers all of St. Lucia as does the Meteo France radar from Martinique. The radar product accessible by SLMS is from the Internet and consists of images and not gridded data, possibly since it is easier to share the existing radar images than to transmit the actual gridded radar estimates. However, the images can only be used very qualitatively and if the gridded precipitation estimates could be accessed from the two radar sites, then 1 km (or less) resolution hourly rainfall estimates could be derived, which would be extremely useful in estimating rainfall variability across the island. To properly utilize the gridded estimates, a processing software system will need to be implemented to provide analysis of the radar data such as mosaicking, bias elimination, and merging with available observed precipitation data, resulting in a reestimation of the grid into a more realistic accurate representation of the rainfall pattern across the island, something most users need to obtain quality rainfall estimation.

Lightning Data

Currently there are no lightning data available on the island. LUCELEC is purchasing a lightning detecting system to which SLMS will have access once installed and operational. Utilizing lightning data will be useful in diagnosing potential severe weather and heavy rainfall events.

Meteorological Database Processing

St. Lucia recently received a Global Telecommunication System (GTS) World Area Forecasting System (WAFS). This message switching server receives all regional and some national WMO data and forecast products including global model products such as the U.S. Global Forecasting System (GFS) model products that are used by forecasters to produce forecasts for the country. Also, the three hourly weather observations for the two airports are transmitted by server to the GTS for use by the global meteorological modeling centers. The WAFS provides forecasters with meteorological products, data products, some satellite data, and some analysis and visual tools needed for forecasting.

The AWS surface meteorological data collected by the Meteorological Service are archived. They are shared with national agencies and users as protocols and agreements dictate. For example, a Memorandum of Understanding between WRMA and MET defines interagency data sharing.

Forecasting Models and System

The Meteorological Service uses the NOAA global models to forecast weather on the island along with the adjacent island radar systems and satellite data from the GTS. They use the CIMH agromet bulletins for agricultural forecasts. Twice a year, SLMS runs software to obtain climate forecasts through the Caribbean Climate Outlook Forum (CARICOF) and CIMH, which is the regional climate center for the Caribbean.

MET uses the French ARPEGE (Action de Recherche Petite Echelle Grande Echelle) model, the MM5 model, NAM, CEP, MFWAM, WINGRIDS, and the WRF regional models as guidance to produce forecasts. Model data are accessed either on the Internet or through the WAFS. They also use the European Medium Range Forecast Center 6-hour time step—10-day model runs.

Early Warning System Operations

There is a local FEWS that consists of a network of AWS and rain gages positioned at strategic points in St. Lucia continuously reporting to two base stations (located at the SLMS offices in Hewanorra and George FL Charles airports). The triggering mechanism is rainfall intensity. There are three levels of alert that are color coded; when a threshold of 25 mm/hour is reached, the alert-level changes from green to orange; at 50mm/hour, the alert level changes from orange to purple; and at 75 mm/hour, the alert level changes from purple to red. Rain gages transmit alerts to MET offices where warnings are then issued.

There is also a base station at WRMA and FEWS can be viewed through a webpage. The system works in conjunction with radar images used by the forecaster to verify that the rainfall is validated.

3.2.3 Dissemination of Data, Forecasts, and Warning Products

The Meteorological Service provides routine weather and climate products to the various users. Products consist of plain language public weather reports issued three times daily. In addition, routine marine forecasts, aviation forecasts, METAR (meteorological aviation data forecasts), and special forecasts are issued as needed such as when hazardous weather will likely affect populated areas. In addition to the daily and special products, various monthly products are produced such as regional agrometeorological bulletins and routine climate reports forwarded to a flood and drought committee. Severe weather, tropical, and flood warnings are issued when atmospheric conditions are prevalent. When hurricanes or tropical storms pose a potential threat to the country, tropical system advisories, hurricane watches, and warnings are issued. During other potential threatening meteorological conditions such as formation of severe thunderstorms, formation of troughs, or the rare occurrence of stalled fronts, severe weather advisories and warnings are issued along with advisories for small craft indicating hazardous wind and waves. SLMS does not have the diagnostic tools needed to forecast severe thunderstorms, flash floods, and tropical storms. The addition of high-resolution satellite and radar data is needed for detection and forecasting these phenomena.

Data and forecasts are principally distributed by email, fax, and telephone. Warnings are distributed directly to the Cabinet Secretary, Prime Minister, NEMO, and the media (TV, radio, and newspapers). The SLMS website needs restructuring because it only contains daily and five-day weather forecasts. It does not contain any meteorological data, rainfall information, or satellite imagery, which users are looking for. Many if not most National Meteorological Service websites contain meteorological model products, hydromet data maps, remote sensing imagery as well as international information, and various educational materials to help readers and users make sense of technical jargon. Explanation of the meaning of various products and information, as well as understanding probabilistic forecasting and how to use it, is essential to educate users on what each intended forecast product message means. The WMO has guidelines for National Meteorological Services on suggested content of websites to assist with the redesign of its site.

3.2.4 Coordination of Meteorology and Hydrology

Many users of weather, water, and climate services in St. Lucia need both hydrological and meteorological information. It has become quite evident that there are many different sources of meteorological and hydrological data throughout the user community, which, if shared, would significant improve data to all users. In addition, it is important for the close coordination of both meteorological and hydrological services for the delivery of this information to both water resources users and to users such as NEMO, WASCO, the EHD, and Ministry of Agriculture that need meteorological data and quantitative precipitation forecasts. This information is necessary as input to hydrological models for the generation of flash flood, flood, and drought forecasts and warnings to the community at risk. Establishing improved coordination between WRMA and SLMS ensures users of the availability of data needed for decision making for water resources management and in reducing losses from hydrological extremes such as floods. Improved coordination is essential and ranges from more close communication and collaboration and data exchange to actual merging of the two organizations in one unit. This need for improvement is addressed as a Road Map recommendation in the next chapter.

3.2.5 Operation and Maintenance

SLMS maintains and operates weather observing facilities at 2 airports and 21 automated weather stations. This O&M process has successfully allowed AWS data to be operational and reliable.

Near 50 percent (19) of the WRMA operational gage network (42) is nonfunctional. The O&M budget of WRMA was cut 50 percent in the past 3 years, which explains the decrease in maintenance and degradation of the operational network. Two of the three EWS are nonfunctional because of equipment disrepair.

3.3 Flood and Drought Mitigation Committee

Currently the Flood and Drought Mitigation Committee established in 2011 and modified in 2013 provides a coordination mechanism between interested agencies. SLMS chairs this committee, and organizations such as WRMA, NEMO, and 20 other sector organizations are represented. The overall goal of this committee is to mitigate damages in communities in particular for flood hazard and to reduce drought risk nationally through drought monitoring, preparedness, and early warning.

4. Road Map and Recommendations

The strategic steps needed to modernize hydromet products and services in St. Lucia are primarily dependent on the needs of the user community. The user survey conducted (both by written surveys and interviews) with clients and stakeholders has revealed that very basic levels of hydrological, weather, and climate services are now being provided and that a significant increase in services and products is needed by users to improve productivity and reduce vulnerability to the inevitability of a future of increasing climate extreme events that threatens to push the country's resiliency to its limits. In addition to the growing gap of needed data and forecast services to the country, the technical assessment of the hydromet service providers of WRMA and SLMS reveals they have fallen behind in keeping with technological and scientific progress needed to utilize best practices and standards in delivering services to a diverse set of demands by users. Weak links in the end-to-end hydromet system are noted and strengthening activities are recommended.

4.1 Institutional Strengthening

A. **Establishing a hydromet user and provider group**

Both of St. Lucia's National Hydrologic and Meteorological Services need to evolve from knowledge-based operations to demand-driven customer-driven organizations that emphasize service provision across socioeconomic sectors. This shift to user-based product and service delivery means that a mechanism needs to be adopted to facilitate communication and understanding between hydromet providers and the various user sectors. One way to accelerate this process is to establish a hydromet user group or committee. The user group needs to develop and implement a strategy for service delivery with engagement of stakeholders and users. The strategy needs to outline needs by users, priorities of needed products and information, impact to the country, and how to generate and disseminate products meeting users' needs. Since user needs change periodically, client satisfaction surveys should be made among existing and potential new key users.

The group operation will serve to communicate needs of users to the providers, but users also need to be trained on the assumptions, analysis, and interpretations of products to individual user decisions and actions. Since the user community is diverse, the sophistication of users varies from high sophistication for the energy sector to very simplistic forecast information needed for the general public. Meeting this diversity and range of needs will take time. The primary purpose of a user and provider group is to review the various requirements of users and determine the priority requirements that provide the biggest benefits given that providers have limitations and cannot meet all needs for all users. The existing Flood and Drought Mitigation Committee is a good starting point and may be the appropriate mechanism to address the need for a user/provider definition of needed products and services although the principal focus of the committee is disaster risk reduction. There are many other user needs beyond disaster risk reduction that this committee may not be willing to address, in which case a separate user group or committee would need to be established.

B. **Establishing of a legal mandate for forecasts and warnings for the country**

Currently there is no legal definition of the responsibilities of SLMS; however, clarifying this aspect needs to be a priority for the GOSL. SLMS currently is performing the responsibilities of data collection, forecasting, and delivering warnings to the public and users without legal authority.

C. **Build capacity of hydrologists and meteorologists and recruitment of professionals**

Extensive capacity building is recommended for both WRMA hydrologists and the SLMS meteorologists.

(a) WRMA has a huge challenge ahead to address potential water shortages and water quality degradation as well as increased frequency and magnitude of extreme hydromet threats such as flash flooding, flooding, and droughts that could have severe negative impacts on the economy and lives of the citizens. Training in remote sensing, hydrological modeling, database analysis techniques and tools, and geographic information systems are a few examples of training courses needed by the WRMA hydrologists and staff. To adequately determine the training courses and education needed, a training requirements analysis (study) is recommended, which will lead to development of a training plan. The training plan will identify the training needs (gaps) and priorities for training needed by the professional staff as well as specific training programs and courses needed for proficiency. It is obvious that the technical capacity of the professional workforce needs to be increased through more training and education, since it is questionable whether the current staffing levels will be able to deliver the level of effort that will be required to reduce water quality pressures, prepare water for extended water shortages, and build resilience and capability to predict and warn the population at risk for more severe flood and flash flood events.

(b) A major challenge for SLMS is to create a strong professional meteorological workforce. The advancement of the science in meteorology, technology, and development of state-of-the-art meteorological models and techniques and systems has left the staff behind. Courses in nowcasting, mesoscale modeling, remote sensing, ensemble and probabilistic modeling, GIS and geospatial systems, and IT are emerging areas where training must proceed. A similar approach recommended for WRMA is recommended for SLMS. A training requirements analysis needs to be conducted based on the existing training and educational background of the forecasters versus the recommended WMO training competencies required for various class meteorologists within the workforce. The gaps determined from this analysis will define training needs, and a training plan will outline how gaps can be filled through various existing training opportunities such as university courses, WMO training courses, CIMH training, and other training venues such as the COMET training program of the University Center for Atmospheric Research (UCAR), which is usually very low cost but high quality in meeting both hydrological and meteorological operational training requirements.

(c) The recruitment of qualified weather forecasters is a challenge for SLMS. Retirements are producing vacancies that need to be filled as existing staff are now pressured to fill the forecasting responsibilities. This is a common challenge of many developing the NMS. Recruitment barriers such as low salaries and lack of a meteorology degree program within St. Lucia dictate either a search for qualified candidates with the educational foundation coursework (physics, math, and engineering) and then establishing an in-house meteorological training program accomplished through distant learning coursework, use of CIMH training, and in-house on-the-job training.

4.2 Modernization of Observation Infrastructure and Forecasting

4.2.1 Meteorological Observation Infrastructure and Forecasting

D. **Obtain digitized radar gridded data from neighboring radars and merge data to obtain hourly gridded rainfall estimation for the island**

Currently two radars (Barbados and Martinique) overlap St. Lucia. Imagery is available to SLMS forecasters for qualitative use in forecasting precipitation; however, from the products received, it is not possible to extract rainfall intensities. It will be well worth an effort to investigate whether the digital gridded rainfall estimate data (15 minutes' duration) could be acquired from each of the radar sites in addition to the current raster imagery data received. If the rainfall gridded estimates can be acquired in real time, then a precipitation grid processor will need to be established to process routine 15-minute gridded rainfall estimates from both radars and to mosaic (combine) the data and then reestimate precipitation based on the existing observed precipitation network in St. Lucia. There are existing software packages currently in use today that provide this capability. NOAA runs a processor as part of the Community Hydrological Prediction System (CHPS) that merges satellite, radar, and observed precipitation that could be modified for the hydromet precipitation application in St. Lucia. The Hydrological Research Center that developed the flash flood guidance system (FFGS) also has a multi-precipitation processor that merges satellite, radar, and rain gage data into a grid. A second option for increasing precipitation estimates at the scale users need is to purchase an X-band Doppler dual polarization radar system. However, this option is financially costly both in the acquisition as well as its maintenance and operation and still requires a precipitation processor to integrate satellite, radar, and rain gage observations.

E. **Acquire available appropriate satellite imagery and processed satellite data products, such as satellite rainfall estimation products**

There are many different types of satellite products and information that should be investigated for access and application to meet user needs for both hydrological and meteorological data and information. The use of existing meteorological data is also needed in the database. Water resources users need precipitation data, temperature, humidity, wind velocity and direction data, evaporation data, and remotely sensed data such as satellite precipitation estimates and streamflow estimates from satellite imagery. NOAA satellite data are currently accessed by the Meteorological Service from NOAA websites. These visible, infrared, and water vapor products are used for forecast operations. These data are free but not available in real time and latencies could affect timeliness of severe weather, flash flood, and flood warnings. An example of a satellite processed product from the GOES that will be of value to WRMA and the Meteorological Services is the GOES precipitation estimate (Hydroestimator). Polar orbiting satellites (such a NOAA polar orbiting satellite) can provide important meteorological and hydrological applications such as CMORPH (precipitation), moderate-resolution imaging spectroradiometer (MODIS) that can detect fires and normalized differenced vegetation index (NDVI) used to estimate soil moisture and greenness and frequently used to measure drought severity.

This action involves investigation into the potential satellite products available to support meteorological and hydrological information to all sectors of the economy (see García et al. 2016). In addition, satellite rainfall estimation data should be utilized by SLMS and WRMA to better estimate rainfall variability throughout the island at a 1 km resolution. Contracting a satellite/precipitation analysis expert consultant or company should be pursued to implement a precipitation processing software capability for utilizing satellite rainfall data and the observed precipitation and AWS network to maximize accuracy in the real-time grid estimation. Such software is available from NOAA and in selected hydromet software systems.

If latency of real satellite products is a barrier to effective nowcasting and forecasting, SLMS should investigate acquiring a GOES satellite downlink and processing system to acquire satellite imagery instantaneously. The GEONETCAST (a global network of satellite-based data dissemination systems) should be considered. SLMS has recently installed a GTS server hardware/software system to access GTS data, send St. Lucia's synoptic data to the network, and provide forecasters with access to model products and diagnostic tools. This software has a standardized database that should be sufficient to meet meteorological forecasting requirements. A national precipitation grid will need to be established as a foundation to meeting the many needs of users throughout the country for both WRMA and SLMS customers. The national grid resolution will be driven by network densities, the satellite precipitation estimation grid for the country, and the radar grid used from Barbados and Martinique radars and will be available for use in operating the FFGS and input to hydrological models running for the various river basins. There are many applications of this grid to users from creating various scales of maps from hourly rainfall to 6-hourly to daily to weekly and monthly precipitation measures to be compared for instance with climatological maps for agriculture and energy. The precipitation grid (1 km in the United States) is used to input hydrological models for both simulations and forecast flows. This grid should be designed by a team of hydrologists (WRMA) and meteorologists (SLMS) along with the user community. A hydrological consultant company with expertise in precipitation processing of satellite, radar, and gage data should be contracted to establish this hydrological software system.

4.2.2 Hydrological Observation Infrastructure and Forecasting

F. **Strengthen and rehabilitate existing 3 FEWS and hydromet network**

Stream and precipitation gages that are in disrepair need to be fixed so that the early warning systems can function properly. Nearly 50 percent of the WRMA network equipment is dysfunctional and should be immediately repaired. The maintenance and operation budget has been reduced for WRMA, resulting in poor maintenance and eventual equipment failure. Human lives depend on the proper operation of FEWS and maintenance procedures consisting of spare parts and trained personnel as well as preventative maintenance procedures need to be in place. The stream gage network needs to be repaired—only six of the eleven stream gages are functioning normally. There should be a priority by WRMA to assess the importance of reestablishing the equipment functionality to operational status. Those stream gages connected to the current three FEWS and the planned expansion of two FEWS should be fully operational and telemetry established so that stream gage data are automatically transmitted by satellite or Digital Signage Manager (DSM) to the established receiving stations at SLMS. It is not clear what procedures are followed by WRMA and SLMS to ensure that this vital equipment is maintained and operated and diagnosed for problems to ensure operational status 24x7.

In addition, a design of a stream gage network to meet water user needs should be completed. Either WRMA, or a consultant expert (or company) on stream gage network technology, should be contracted to select and design additional stream gage sites and the hydrological network that is needed by users. This designed network should be based on user needs obtained from a user group or committee as previously recommended and should represent the priority of the need. For example, an early warning system should have the highest priority for establishing reliable transmitting stream gage data. Reevaluation for the need for operational data at the existing stream gage sites is needed as well as assessment of the functionality of the data loggers at each of these sites.

All new stream gage installations should also include recording rain gages in the contributing watersheds, and given the urgency and need for establishing water quality monitoring, additional water quality sensors should be considered for the new stream gage sites, if appropriate. The 17 WRMA precipitation gages that are nonfunctional need to be assessed to determine repairs. Real-time access to this rainfall data should also be established and telemetry added to ensure that the data are automatic and operational. Since FEWS depend on rain gage observations to trigger warnings, it is critical that these data are dependable and functioning at all times and otherwise, warnings are compromised. The rain gage data transmitted should be standardized to meet WMO standards and to harmonize with the rain gage data collected by SLMS. The WMO has standards now for AWS and soon for rain gages that will ensure compatibility of data so that they can be shared with other providers (SLMS) and users. In addition to repairing the stream and precipitation gages, four AWS also need to be repaired immediately. The surface weather observation network should be reevaluated, and given user needs, additional AWS should be expanded based on user priorities and budget restrictions. A design of an expanded network should be accomplished with the guidance of a meteorology data network expert and considering real-time data needs as well as climate and water requirements. WRMA, NEMO, and SLMS leaders should collectively coordinate with the previously recommended user group a realistic plan to operationalize the existing EWS networks including arrangements to maintain and operate the repaired system.

G. **Establish a discharge measurement program**

WRMA needs to establish an operational discharge measurement program for priority stream gage locations where determination of discharge is needed by users, which starts with the creation of rating curves for the 17 existing stream gages that are currently not rated. Most countries have discharge measurement programs and follow U.S. Geological Survey (USGS)/WMO standards for measurement. There is a fairly urgent reason to start up discharge measurements now, as many, if not most, of the streams on the island are experiencing heavy sedimentation, which reduces the carrying capacity and increases the risk of flooding. While the purchase of equipment is not expensive, a measurement program does require scheduled routine measurements and special measurements during extreme low flows as well as floods. These discharge measurements are urgently required for water supply, irrigation, and other beneficial uses as well as hydrological modeling calculations for water balance studies of the river basins.

H. **Establishing a design of an initial and optimal water quality network and establish priorities for initial sites**

WRMA is undertaking an important step in establishing a water quality program for the country. One initial step in this process is to establish a preliminary water quality monitoring network. The hydromet user group (especially EHD and WASCO) should be consulted to establish priority sites for location of water quality sensors. Agreement should be reached on parameters/variables sensed, need for real-time access to these data, and what initial sites are established. As mentioned earlier, one important factor to consider is to install water quality sensors at river flow gaging stations or vice versa, as water quality depends on concentration of the different parameters.

I. **Establishing a groundwater monitoring network design and select initial priority sites**

Groundwater could be a major secondary supply for the island, but few studies exist to assess the storage and potability of the water quality. Currently, there are a few wells in operation in St. Lucia. WRMA with technical assistance needs to design a network of well sites where groundwater monitoring equipment can be installed for monitoring and establishing the capacity and quality of groundwater for the island.

Studies need to be conducted to determine not only groundwater supply but its interaction and effect on surface streams since exploitation of groundwater could reduce the streamflow's base flow. Discussions with the USGS have revealed there have been satellite base investigations by the private sector that, although at a coarse scale, have determined groundwater reserve volumes that could be investigated. Locations of groundwater monitoring stations as well as locations of priority initial sites should be established to initialize the network.

4.2.3 Other Observations:

J. **Establish a national hydrological database that serves users' needs as well as the many hydrological applications required by WRMA**

The national hydrological database should include precipitation data, stream gage observations, any streamflow data, water quality data including sediment transport data, tide gauge, and groundwater data. Observations need to be stored in a database management system (DBMS), thus standardizing data as well as allowing processing and quality control. This database should be shared with SLMS; since the Meteorological Service also collects precipitation data, the data formats and protocols need to be shared and standardized. The database should be used to serve users by an electronic processor, principally through the website. Users also want a file sharing system for static geospatial layers such as streams, dams, lakes, bridges, roads, and so on. The Ministry of Physical Development, Housing, and Urban Renewal (Physical Planning Division) collects and distributes GIS information mainly for land use planning. It interacts with various agencies (such as WRMA) to provide layers of geospatial data and has developed an open data portal for agencies such as WRMA to access and use these tools. This agency should provide WRMA with the needed geospatial static layers, and WRMA is currently working with this agency to develop its data and spatial tools.

K. **Evaluate hydrological simulation models for usability in the St. Lucia context, select and acquire adequate models, and calibrate for use in planning and operational forecasting**

WRMA needs to increase its hydrological analysis role by implementing hydrological and hydraulic modeling for the country. Models are needed for studies, planning, and operational simulations. Currently the HEC-HMS modeling system is used for the three EWS. It provides the rainfall flood threshold criteria used to determine if a warning is needed for measured rainfall. The HEC models are standardized free models that provide hydrological analysis to support both operations and planning. Other modeling systems can and should be pursued and tested for applicability to St. Lucia. It is recommended, for example, that the WMO's Global Flash Flood Guidance System (GFFG) be implemented to provide the needed flash flood forecasting to all existing flash flood-prone river basins in the country that are a risk to communities to be flooded including replacing the existing three EWS. The GFFG is a modeling system used globally to simulate a small watershed behavior but in a predictive application. Other simulation models should be researched and considered for application in use by WRMA for planning for water resources allocation, river basin water management, and forecasting flooding and inundation of WASCO water supply infrastructure. Another important task is the evaluation of the effects of climate change both in rainfall and streamflow as well as in sea level. This will involve the sequential use of weather generators, hydrological models, and water resources models, as well as the downscaling of global climate models (GCMs) (see Ray and Brown 2015). Not only should a search for appropriate hydrological simulation and other related models be initiated, but criteria and use of model applications to St. Lucia water resource problems and uses should also be examined as to the best approach evaluated. Selection of a modeling system should include availability of training, documentation, technical support, and calibration. There are many modeling systems in use by developing country NHS that are acceptable, but each modeling system has strengths and weaknesses that need to be evaluated by WRMA.

L. **Evaluate the use of existing threshold-based FEWS modeling and determine alternate approaches for early warning capability at existing four community locations**

It is recommended that the existing hydrological model (HEC-HMS) used in FEWS be evaluated carefully and compared to alternative modeling systems and approaches. A key objective in establishing an early warning system is that it provides the lead time required to ensure evacuations and in some cases damage reduction actions are taken. An additional necessary goal is to obtain the accuracy needed to ensure credibility by the responders and population at risk. An early warning system needs to provide essential information to residents in the flood plain such as time to flood onset, elevation of the crest stage, duration of the flooding, and when the stream will fall below its banks. Threshold-based EWS cannot answer these questions and other options should be considered. Running a real-time hydrological model for the flood-prone river basins can produce a flood hydrograph that provides users with much more information than the simple rainfall threshold approach being used. Also with increasing accuracy and reliability of meteorological models and quantitative precipitation forecasts (QPF), a 24/7 flood watch-type alerting advisory could be added to FEWS operations. In addition, as referenced earlier, the WMO GFFG could be implemented in partnership with WRMA and SLMS and furthermore could provide warning capability to other flood-prone communities on the island not presently covered. No matter how WRMA and SLMS go forward, a continuous coordination between these two organizations is essential and colocated offices are recommended. In the United States, the separation and lack of coordination between the NOAA National Weather Service Weather Forecast Offices and the NWS River Forecast Centers was a barrier to integrating the services. In the 1980s during modernization of U.S. weather, water, and climate services, these offices were colocated and significant improvement to hydrological (water management and flood warning) service delivery occurred.

M. **Establish a funded operational maintenance program for gaging network**

The state of disrepair in the hydromet observation system of WRMA, which is the foundation of the operation of an FEWS, is the weak link in providing end-to-end data, forecast, and warning services to users. An equipment maintenance and operation program needs to be established. Spare parts are needed for potential equipment outages and technicians should be trained on how to repair outages. Maintenance funding cuts have resulted in the inability of WRMA and SLMS to keep FEWS and other networks operational. WMO has recommended guidelines on establishing O&M programs of the NMHS that need to be followed. Otherwise, the carefully established FEWS will break down and fail when flood disasters strike.

4.3 Delivery of Data, Products, and Services

N. **Developing a more comprehensive nationwide drought program**

Although a drought management plan exists, a more comprehensive drought program needs to be developed, which includes coordination of information and knowledge between meteorology and hydrology and establishes the drought magnitude and impact information demanded by most users of the island. Meteorological forecasts and warnings need to follow the WMO’s high-impact guidelines that include storm and flood impact information in warning products. The drought program is initiated by the hydromet providers but includes all the major user sectors in the country as user requirements are essential in defining drought forecasts and information that are linked with user decision making to mitigate effects of droughts.

O. **Training of end users in the application of hydromet products for decision making**

Capacity building is a limiting factor for end users to understand and interpret hydrological, meteorological, and climate products for decision making in the various economic sectors, and training and education will need to be implemented. It was very evident in user interviews and survey results that users do not understand how to interpret and best use weather forecasts and warnings. Training and education to the general public on watch, warnings, probability forecasts, preparation, and awareness is very important, especially for the principal hydromet threat: flooding. Training should include workshops as well as the distribution of flyers, public service videos, and publications including the provision of educational material on the website. It seems some users have accepted a reduced level of service while other users supplement SLMS forecasts by accessing other sources of weather forecasting services such as the weather channel, CNN, and Accu-weather. SLMS should establish a goal to train forecasters and users on adoption of the WMO High Impact Forecasting Program. This could be achieved by adopting the NOAA/WMO Weather Ready Nation Program, successfully implemented in the United States and now being applied to developing countries by the WMO.

P. **Increased communication and coordination is needed between WRMA and SLMS**

Another important aspect to achieve successful warning operations in drought and flash flooding and flooding systems is close coordination and interaction of hydrologists and meteorologists, especially before flooding events. Better coordination and perhaps even colocation of meteorological and hydrological offices should be considered to bring together the critical mass needed to deliver effective, accurate, and credible warning services. This consolidation will also improve day-to-day data and forecast collaboration needed in reaching services that utilize best practices of both professions. Many countries collocate or consolidate NMHS offices for this important requirement for hydromet coordination. A study of the need to integrate hydromet services for St. Lucia is recommended. Currently flash flooding forecasts are limited to the operation of the EWS that is operated by SLMS and technically supported by WRMA and NEMO. If the number of early warning systems expands or flash floods become centralized (such as through implementation of the FFGS), which will be a combined effort of SLMS and WRMA, then combining hydrology and meteorology will likely be essential.

Q. **Dissemination of hydromet data, forecasts, and warnings**

Both WRMA and SLMS should, as a priority, develop a new website that meets the needs of users. WRMA users need hydrological data and information and would like electronic access to information. A weak link in delivering end-to-end hydrological service is the lack of data access to users. The WRMA website needs to be redesigned. Both real-time data and historical hydrological data need to be available continuously for user access. This will require establishing a dynamic hydrological database that is continuously updated and posted for user access. Historical stream data should be available as well as water balance studies, water quality information, groundwater and well measurement status, soil moisture and hydrological information for agriculture, status of streams and tides in the country, forecasts of rivers and streams, especially if flooding is expected, and rainfall observations. The WRMA website needs to share data with SLMS. Rainfall data should be shared and quality controlled, and users need to be offered products such as a map displaying 24-hour accumulated rainfall. WRMA can participate in the hydromet user committee process to define priority products needed and potential new products required in the future. The SLMS website is presently inadequate and serves as a poor image for access of important weather and climate information needed by the user community. This website needs to be totally restructured. Real-time data need to be posted to the site as it is collected, forecasts need to be updated frequently, and warnings posted as established. More visualization needs to be incorporated including maps of observed rainfall totals, rainfall grid of the country by hour, and posting of satellite and accessed radar data. Most of the same data, forecasts, and information will be simultaneously distributed through other dissemination channels such as email, SMS messages for cell phones, radio transmission, and the media. Data and forecast product structure must follow standardized protocols and formats and be consistent with the website information being displayed and accessed.

4.4 Road Map Scenarios

The recommended actions and steps in this Road Map for the most part are general strategic actions the GOSL could need to take to strengthen hydromet capabilities to meet user needs. Some of these recommendations are more urgent and some will have more of a direct effect on improving services than others. However, in the case of forecasts and recognizing the end-to-end chain has many links, and fixing one weak link may not improve overall service delivery if there are other weak links restricting the needed data or forecast products or forecaster expertise needed to deliver the required products and services. In both disaster risk reduction and in day-to-day user decisions, forecasts must be accurate, timely, reliable, and understood so that maximum use can be made from the forecasts and information that are uncertain by nature. For user needs of hydrological data, some actions can be taken just to make current data available to users so that value can be obtained from other related data such as precipitation, AWS, and stream gage data. Other actions such as increasing the coverage of data throughout the country and establishing a database will take more time and benefits will be realized over a longer term. For St. Lucia, a strengthening of a number of components is needed to fill the data gaps. Given that budgets are restrictive for governments, the question frequently arises as to how to get maximum return on investment. Another observation very relevant to the process of improving hydromet services is the need for users in many of the sectors to become more informed and understanding how hydrological, weather, and climate services can improve decision making in their sectors. Many of the users interviewed did not know specifically what additional data or forecasts meant in terms of productivity or improvement of their sector's performance. Thus, if benefits are to be realized by modernization, the user community will have to increase its knowledge and ability to utilize improved data, forecasting, and information flow from the hydrological and meteorological service providers.

Because of budget constraints and the need to inform government decision makers on return on investments versus the costs of strengthening hydromet services, three scenarios of improvement paths are presented. Given that there are certain critical minimal strengthening actions needed (by both WRMA and SLMS) that will provide credible data, forecasts, and warnings to users, a minimum service level option is first presented. This is followed by a second scenario that outlines modest increases in data, communications, forecasts, modeling, and dissemination that will likely meet many of the users' defined requirements. Finally, an idealized third scenario is proposed, which will bring both WRMA and SLMS to state-of-the-art forecast and warning service capabilities that the NMHS of many developed countries have achieved.

It must be realized that this Road Map is a strategic plan and not an implementation program. Precise improvements in the various components of the end-to-end system and in obtaining benefits for users cannot be calculated until a design process is launched to determine the exact number of stream gages needed, locations of the gages, capability of the gages, which will determine the level of automation and instrumentation such as establishing a data logger or telemetry equipment. The exact strengthening actions will depend on the detailed user needs, capacities of WRMA and SLMS to deliver the needed information, and of course the costs. This Road Map cannot provide a design network or radar location or specify syllabi of training courses needed but rather provides an outline of the broad institutional, infrastructure, and service delivery improvement steps that need to be further defined in detail at a later date. In each scenario presented there are significant assumptions made on the quantity and quality of data, modeling, training, and communications, among others that will be more realistically determined in the next step, which consists of establishing a multiyear implementation program. Exact requirements need to be established and negotiated by interactions with the various users either through a user group as recommended previously or in discussions with each key user individually. The cost figures should thus be used only as general approximations of the magnitude of a particular modernization task.

Scenario 1: Investment needed to achieve critical minimal capabilities to provide hydrological, weather, and climate services (focused on building institutional capacity)

This scenario assumes that immediate benefits and results are important to many users and can be obtained by repairing the observation network being operated by WRMA and SLMS. This is especially true for FEWS, some of which have their observational equipment broken. In addition, there are institutional tasks that need to be accomplished by all three scenarios including establishing the forecast and warning legal mandate for SLMS, establishing a drought monitoring and information program, training, and establishing an SLMS strategic plan for the country. A concept of operations (CONOPS) plan needs to be developed. CONOPS defines how the new hydromet services will be provided from the science (models), technology (computers, communications, sensors, software) and capacity building of the staff, and knowledge and capabilities needed to provide data, products, and services to meet the majority of the users' needs today and as requirements evolve in the future. There already is a strategic plan for water management in St. Lucia and WRMA is currently writing a proposed water quality program that needs to be approved and funded. This scenario includes the establishment of a Water Quality Monitoring Program and funding of a prototype water quality measurement network.

A significant weak link exists in delivering products and services to users for both WRMA and the Meteorological Service. Both historical and real-time data are in demand by users but are now unavailable. Both websites are antiquated and do not have most of the information users are looking for. These sites need to be redesigned, and data, forecasts, and warnings, as appropriate, need to be available to users. This minimum scenario also acknowledges the immediate need to establish an operational discharge measurement program for existing stream gages. There will be purchase of stream gaging equipment, but the assumption is that most gages are at bridges and discharge measurements do not require boats or other special equipment and infrastructure such as towers and cableway cars, weirs, or flumes. Also, a minimum national hydromet database needs to be established. This involves the purchase of either a commercial DBMS or the use of the WMO's free system. Costs include hiring of contractors to set up (populate) the database, purchase of a computer, and a training program.

A national precipitation grid system needs to be established. This will be contracted. It requires establishing a grid resolution that will be a function of the current satellite rainfall estimator grid and the grid of the neighbor countries' radar grid resolutions. A precipitation analytical processor needs to be developed that processes radar, satellite, and precipitation observations. This grid then needs to be plotted on maps and made available on the redesigned websites of WRMA and SLMS. It is important that protocols to access these data are developed since this information is needed by all major hydromet users.

Both meteorologists at SLMS and hydrologists at WRMA are in need of training on understanding and applying best practices in water resources and hydrological, weather, and climate forecasting. Table 4 presents Scenario 1's investment and O&M estimated costs.

Table 4: Investment and O&M Costs for Scenario 1

Road Map Development Components WRMA and SLMS - 3-Year Project	Total Investment Cost (US$, thousands)	Annual O&M Costs (US$, thousands)
Institutional strengthening		
1. Establishment of a User Committee for hydrological, weather, and climate products and services and strategy for service delivery	10	n.a.
2. Create and institutionalize the data, forecasting, and warning mandate for SLMS (consultant support)	5	n.a.
3. Training of staff for institutional strengthening and to keep abreast of new technologies	50	n.a.
4. Develop a strategic plan to Improve SLMS (includes CONOPS development)	50	n.a.
5. Develop a National Drought Monitoring and Information Program	50	n.a.
Subtotal	165	n.a.
Strengthening observing, data analysis, and forecasting		
1. Repair existing Meteorological Service AWS and rain gages and equipment that are not functioning. Add a data logger and telemetry to existing stations that do not have storage and transmitting capability—include training and spares and documentation	100	15
2. Repair existing WRMA dysfunctional stream gages and rain gages and add necessary gages to establish 2 additional EWS planned—include training, manuals, and spares	125	18
3. Design initial water quality data network	10	
4. Install initial pilot water quality network (1 automatic station) and sediment sampler equipment	35	5
5. Procure equipment and initiate discharge measurement	15	
6. Establish a Hydromet Database and Management System—includes hardware and software	200	37
7. Contractor to populate and set up database (both hydrology and meteorology)—enter historical data and metadata into database and train users how to maintain and operate	100	n.a.
8. Establish a project to integrate existing radar gridded rainfall estimates for the island (hardware/software)	80	10
9. Establish a national precipitation grid project to access satellite products to acquire gridded satellite precipitation estimates and integrate with radar and observed data	250	30
10. Obtain training on hydraulic and hydrological modeling	50	
11. Begin major training program of meteorology for forecasters and develop a Training Plan	150	
Subtotal	1,115	115
Improved hydromet and climate services		
1. Reconstruct websites for WRMA and SLMS	50	6
2. Development and implementation of CONOPS for meteorological forecasting and development of operation manuals (technical assistance)	50	n.a.
3. Reconstruct a website for Hydrological Services	50	6
4. Begin a Product Improvement Program based on User Committee improvement (contractor assistance)	150	n.a.

Subtotal	300	12
Contingencies (5%)	79	6.4
Grand total	**1,659**	**133.4**

Scenario 2: Investment needed to achieve modest improvement in capabilities to provide hydrological, weather, and climate services to partially meet3 users' needs (focused on strengthening hydromet observation, data analysis, and forecasting)

In this scenario, investments exceed the minimum described in Scenario 1 and its development will accelerate the production of data, forecast, and hydromet information products that users need to more effectively make decisions. As described in Scenario 1, the first priority will be to get the existing and two additional FEWS totally operational. Existing nonfunctional gages will be repaired and a maintenance program established to ensure preventative maintenance and operational readiness of the system to produce warnings when floods threaten. Both rain gages and stream gages and AWS will include data loggers and telemetry to ensure continuous data collection and storage as well as transmission to SLMS for evaluation and warnings if necessary. As in scenario 1, there are institutional tasks that need to be accomplished such as (a) establishing the forecast and warning legal mandate for SLMS, (b) establishing a drought information program, and (c) training and establishing an SLMS strategic plan for the country. As mentioned in scenario 1, a CONOPS plan needs to be developed.

Establishing a water quality program in St. Lucia is a priority. WRMA needs to implement a water quality monitoring program. In this scenario, a water quality monitoring network design needs to be made and a continuous monitoring station network of two to three stations established, including continuous sediment sampling. There is a pressing need to purchase and equip the WRMA facility with a complete laboratory testing facility. The current lab is inadequate and cannot meet the country's testing needs. There should also be consideration for an option under this program to purchase a mobile water quality laboratory, which is considered in this scenario's costs.

Scenario 2 acknowledges that a denser network of gages is needed to better define meteorological and hydrological conditions for the country. The first step will be to determine the exact requirements for data needed by users for stream gaging, precipitation, and other weather data. A priority list will be established through meetings with users, and stream gage, precipitation, and AWS networks will be designed. Based on the establishment of priorities for data, new equipment will be purchased and installed to meet the users' needs. The hydromet network will meet WMO standards, including a standard data transmission format, and be integrated with the present data collected into a national hydrological and meteorological database that needs to be established. This combination of meteorological and hydrological data needs to be established for different users and for a variety of products and analysis needed to support the many hydrological, weather, and climate decision-making activities such as modeling, forecasting, warnings, agriculture, transportation, tourism, energy production, and water resources planning. A historical database needs to be created and linked through the Internet for user access.

Since there is a need for higher temporal and spatial rainfall data for the island, purchase of an X-band radar is recommended since the benefits of this investment reach many users. The purchase of this radar is coupled with execution of a contract to develop and/or implement a precipitation processor that utilizes radar, satellite, and rain gage data to produce a national precipitation grid. Gridded rainfall data could be available at 10-minute intervals, linked to geospatial data, and displayed as maps on the new WRMA and

[3] Estimated as 75 percent of users' needs per the survey made (see Table 1).

SLMS websites. Even if the radar is not purchased, integrating satellite rainfall estimates, surrounding available radar data (from Martinique and Barbados radars) and rain gage data to provide rainfall estimates showing variability across the island, will have extensive use by many users. The procurement of a geostationary satellite downlink system is needed to ensure real-time satellite imagery is achieved for forecasts, especially for warnings of the approach of tropical storms and fronts/troughs.

It is recommended that the FEWS approach be reevaluated through a study to be conducted to look at alternative approaches to establish flood and flash flood forecasting and warning capability. The uncertainty associated with this approach seems significant. Irrespective of the outcome of this study, an implementation of the WMO/NOAA/Hydrological Research Center's FFGS is appropriate given the quantity and quality of data available and the growing vulnerability of the population to flooding.

The need for a streamflow modeling system exists now. There are many types of modeling systems used in hydrology and a study to search and investigate the appropriate hydrological modeling system to meet users' need is recommended. It seems logical that establishing a prototype project for a river basin to learn and understand the appropriateness of a modeling system to the many operational and planning needs should be pursued.

Training for SLMS personnel is a significant gap, and training of meteorologists should be launched immediately. Various subject areas such as nowcasting, satellite meteorology, and tropical weather forecasting should be offered. SLMS should compile a priority list of courses and technical areas that forecasters need to obtain for competency in establishing best practices. Also, WRMA hydrologists and staff need to be trained in new technology and hydrological modeling.

As described in Scenario 1, a significant weak link exists in delivering products and services to users for both WRMA and SLMS. As mentioned earlier, both websites are extremely limited and old and do not have information users are looking for. These sites need to be redesigned.

This scenario also recognizes the gap and need for both WRMA and SLMS to develop new products needed by users. A mechanism needs to be established between the two providers and users to define unmet needs and to design new products that are needed by users. This process needs to begin right away through a user group-type approach, perhaps starting with the existing Flood and Drought Mitigation Committee.

Table 5 describes Scenario 2's estimated investment and operational and maintenance costs.

Table 5: Scenario 2 Estimated Investment and O&M Costs

Road Map Development Components WRMA and Meteorological Services, St. Lucia - 5-Year Project	**Total investment cost (US$, thousands)**	**Annual O&M costs (US$, thousands)**
Institutional strengthening		
1. Establishment of a User Committee for hydrological, weather, and climate products and services and strategy for service delivery	10	n.a.
2. Create and institutionalize the data, forecasting, and warning mandate for SLMS (consultant support)	5	n.a.
3. Training of staff for institutional strengthening and to keep abreast of new technologies.	50	n.a.
4. Develop a strategic plan to improve SLMS (includes CONOPS)	50	n.a.

Road Map Development Components WRMA and Meteorological Services, St. Lucia - 5-Year Project	Total investment cost (US$, thousands)	Annual O&M costs (US$, thousands)
5. Develop a National Drought Monitoring and Information Program	50	n.a.
Subtotal	165	n.a.
Strengthening observing, data analysis, and forecasting		
1. Repair existing Meteorological Service AWS and rain gages and equipment that are not functioning. Add a data logger and telemetry to existing stations that do not have storage and transmitting capability—include training and spares and documentation	100	22
2. Design a rain gage and AWS network that meets priority users' needs	10	n.a.
3. Design a stream gage network to meet priority users' needs including communications and data loggers if needed	10	n.a.
4. Repair existing WRMA dysfunctional stream gages and rain gages and add necessary gages to establish 2 additional EWS planned—include training, manuals, and spares	125	18
5. Design an initial water quality data network	10	n.a.
6. Install an initial water quality network (3 automatic stations) and sediment sampler equipment	105	15
7. Build a complete water quality test laboratory	300	10
8. Procure AWS (estimate an additional 5 AWS at US$25,000/station	125	18
9. Procure stream gage stations (including precipitation)—10 new stream gages at US$30,000/station	300	45
10. Procure additional 10 automatic rain gages at US$20,000/station—with telemetry	200	15
11. Procure equipment and initiate Discharge Measurement	30	n.a.
12. Establish a Hydromet Database and Management System—includes hardware and software	200	15
13. Contractor to populate and set up database (both hydrology and meteorology)—enter historical data and metadata into database and train users how to maintain and operate.	100	n.a.
14. Procure X-band Doppler radar with dual polarization	750	110
15. Procure a satellite downlink system for GOES	50	7
16. Establish a national precipitation grid project to access satellite products to acquire gridded satellite precipitation estimates and integrate with new X-band radar and observed data	550	82
17. Acquisition of meteorological workstation tools, visualization software, and training to produce more visual products such as maps and graphs to improve user decision support	100	10
18. Implement the GFFG	750	110
19. Acquire a prototype hydrological simulation modeling system and apply to prototype river basins and with vendor support populate a database, initialize parameters, calibrate and train WRMA hydrologists	75	11
20. Obtain initial training on hydraulic and hydrological modeling	50	n.a.
21. Start a training program of meteorology for forecasters and develop a Training Plan	100	n.a.
Subtotal	4,040	488

Road Map Development Components WRMA and Meteorological Services, St. Lucia - 5-Year Project	Total investment cost (US$, thousands)	Annual O&M costs (US$, thousands)
Improved hydromet and climate services		
1. Reconstruct the website for SLMS	50	10
2. Development and implementation of CONOPS for meteorological forecasting and development of operation manuals (technical assistance)	50	n.a.
3. Reconstruct the website for Hydrological Services	50	10
4. Implement a Drought Program (designed in step 1) including interinstitutional mechanism, drought monitoring, and forecasting system (contractor support)	25	n.a.
5. Begin a Product Improvement Program based on User Committee improvement (contractor assistance)	250	n.a.
Subtotal	425	20
Contingencies (5%)	231.5	25.4
Grand total	**4,861.5**	**533.4**

Scenario 3: Investment needed to bring NMHS providers up to state-of-the-art capabilities for providing data, forecasting, and warning services to meet users' present and future needs (focused on improving hydromet and climate services)

This scenario outlines steps that both WRMA and SLMS can take to modernize both hydrological and meteorological data to reach best practices being applied by developing countries and by implementing an end-to-end system for forecasting and warning that maximizes lead time, accuracy, and reliability of delivering services to meet most users' needs. In this scenario, as in Scenario 2, the priority will be to get the existing and two additional FEWS totally operational. Existing nonfunctional gages will be repaired and a maintenance program established to ensure preventative maintenance and operational readiness of the system to produce warnings when floods threaten. Both the rain gages and stream gages as well as AWS will include data loggers and telemetry to ensure continuous data collection and storage as well as transmission to the SLMS office for evaluation and warnings if necessary. As in previous scenarios, there are institutional tasks that need to be accomplished such as (a) establishing the forecast and warning legal mandate for SLMS, (b) establishing a drought information program, and (c) training and establishing an SLMS strategic plan for the country. These steps are needed for any significant level of upgrade. The SLMS strategic plan will serve as the vision for this scenario and as in Scenarios 1 and 2, a CONOPS will be developed.

This scenario assumes a significant increase in environmental observation systems to accommodate a design of the surface, rain gage, stream gage, water quality, and weather networks. Likewise, a groundwater program needs to be established to increase wells and monitoring of both water quality and quantity. Studies need to be conducted to assess the storage capacity, yield, and quality of groundwater at various locations throughout the country. The design of the networks should factor in present and short-term needs of users for data such as solar and wind power generation needs, agriculture, marine, tourism, disaster risk reduction (NEMO), sedimentation and erosion monitoring, community flood and flash flood warning needs, drought data and climate forecasting, groundwater monitoring needs, as well as coastal sea level, tsunami, and storm surge monitoring to maximize information needed by multiuser decision support systems.

Using the network(s) design as guidance, the environmental monitoring and sensing system upgrades will occur based on design and user needs. The number of weather stations, precipitation gages, water quality monitoring stations, stream gages, soil moisture probes, and tide gages will be determined and equipment will be procured and installed. As in Scenario 2 the hydromet network will be designed to meet WMO standards and establish a standard data transmission format. Specifications will require interoperability of components for all monitoring stations, which will, at a minimum, include a data logger and be integrated with the present data collected into a national hydrological and meteorological database.

Most data collected will be either stored at the site or sent to designated data collection sites through line-of-sight radio or cellular communications. A data processor will be developed to acquire data, quality control data, post data to the website for immediate electronic access to users, and forward date to other tasks such as modeling or analysis, diagnostic, and applications. There are commercial data processors that hydromet providers can consider. As in Scenario 2, a national hydromet database needs to be established, which will be shared by both providers. Software associated with the database (such as commercial DBMS) needs to process data including posting data to both hydrological and meteorological websites. An X-band radar will be purchased with site location analysis conducted by consultants with appropriate expertise. In addition, a geostationary satellite downlink and polar orbiting satellite downlinks will be procured and installed to ensure instant access to satellite imagery needed for forecasts and warnings. A multiple- precipitation processor will acquire radar, satellite, and in situ precipitation data and eliminate the rainfall estimation bias and integrate observations to adjust the estimated grid for accuracy. The radar-derived rainfall estimates will be posted to the website for access, but gridded data will be needed for input to the flash flood guidance modeling system as well as a distributed hydrological modeling system.

It is recommended that an FFGS be considered for forecasting flash floods at sites where flash flooding has occurred or is likely. This system is being implemented globally and is operational in Central America and under strong consideration in some Caribbean locations. The feasibility of implementing a distributed hydrological modeling system should be considered that could be linked to hydraulic models such as the HEC models applied to operational flood forecasting and used for water resources management planning to include climate change adaptation analysis. The CIMH's WRF model output of QPF will be linked to both the FFGS and hydrological modeling system and coupled with geospatial tools and GIS; rainfall forecast maps can be generated for 3–5 days for the country and posted to the Internet for user access.

A full discharge measure program will be established with a goal to define the stage-discharge relationships for all existing stream gage locations and for new stream gage sites installed later. The program will consist of training provided by organizations such as the USGS and procurement of equipment to ensure ability to react quickly and measure peak flood discharges at multiple sites when these rare events take place. Rating curves will be created for each station and posted to the improved WRMA website.

An intense training program will be launched for SLMS as a significant gap exists for forecasters. Various subject areas such as nowcasting, satellite meteorology, and tropical weather forecasting will be offered. SLMS should compile a priority list of courses and technical areas that forecasters need to obtain for competency in establishing best practices. A training plan will be established for SLMS preparing an outline of training needs and addressing training venues. WRMA hydrologists and staff will be trained in new technology and hydrological modeling.

Recognizing that a significant weak link exists in delivering products and services to users for both WRMA and SLMS, a significant effort will be required to develop dissemination mechanisms to reach the many users. As previously noted, both hydrological and meteorological websites are extremely limited. As in Scenarios 1 and 2, these sites need to be redesigned, and data, forecasts, and warnings, as appropriate, need to be posted for electronic access by users 24x7.

A concerted effort will be established to address the gap and need for both WRMA and SLMS to develop new products that are needed by users. As in scenario 2, a mechanism must be established between the two providers and users to define unmet needs and to design new products that are needed by users. This process, as already mentioned, must begin right away through a user group-type approach, perhaps starting with the existing Flood and Drought Mitigation Committee.

This scenario's activities, investments, and O&M costs are specified in Table 6.

Table 6: Summary of Scenario 3 Activities, Estimated Investments, and O&M Costs

Road Map Development Components WRMA and Meteorological Services, St. Lucia - 6-Year project	Total Investment Cost (US$, thousands)	Annual O&M Costs (US$, thousands)
Institutional strengthening		
1. Establishment of a User Committee for weather, water, and climate products and services and strategy for service delivery	10	n.a.
2. Create and institutionalize the data, forecasting, and warning mandate for SLMS (consultant support)	5	n.a.
3. Training of staff for institutional strengthening and to keep abreast of new technologies	50	n.a.
4. Develop a strategic plan to improve SLMS (includes CONOPS)	50	n.a.
5. Develop a National Drought Monitoring and Information Program	50	n.a.
Subtotal	165	n.a.
Strengthening observing, data analysis, and forecasting		
1. Repair existing Meteorological Service AWS and rain gages and equipment that are not functioning. Add a data logger and telemetry to existing stations that do not have storage and transmitting capability—include training and spares and documentation	100	10
2. Design a rain gage network that meets users' needs	10	n.a.
3. Design an AWS network that meets user's needs	10	n.a.
4. Design a stream gage network to meet users' needs including communications and data loggers if needed	10	n.a.
5. Repair existing WRMA dysfunctional stream gages and rain gages and add necessary gages to establish 2 additional EWS planned—include training, manuals, and spares	125	18
6. Design an initial water quality data network	25	n.a.
7. Install an initial water quality network (6–10 automatic stations) and sediment sampler equipment	350	50
8. Build a water quality lab and purchase a mobile water quality lab	200	20
9. Procure AWS (estimate an additional 10 AWS at US$25,000/station	250	37
10. Procure stream gage stations (including precipitation)—maximum 40 new stream gages at US$30,000/station	1200	180
11. Procure additional 20 automatic rain gages at US$20,000/station—with telemetry	400	60

Road Map Development Components WRMA and Meteorological Services, St. Lucia - 6-Year project	**Total Investment Cost (US$, thousands)**	**Annual O&M Costs (US$, thousands)**
12. Procure equipment and initiate discharge measurement	30	n.a.
13. Establish a Hydromet Database and Management System—includes hardware and software	250	15
14. Contractor to populate and set up database (both hydrology and meteorology)—enter historical data and metadata into database and train users how to maintain and operate.	150	n.a.
15. Procure X-band Doppler radar with dual polarization	750	110
16. Satellite downlink system for GOES and polar orbiting imagery acquisition	100	15
17. Establish a national precipitation grid project to access satellite products to acquire gridded satellite precipitation estimates and integrate with new X-band radar and observed data	550	82
18. Acquisition of meteorological workstation tools, software, and training to produce more visual products such as maps and graphs to improve user decision support	100	10
19. Implement GFFG	750	110
20. Acquire hydrological simulation modeling system and with vendor support populate database, initialize parameters, calibrate and train WRMA hydrologists	150	20
21. Obtain training on hydraulic and hydrological modeling	100	n.a.
22. Begin a major training program of meteorology for forecasters and develop a Training Plan	150	n.a.
23. Establish a Groundwater Program to monitor various locations of the aquifer, conduct studies to assess the storage capacity and quality of groundwater	100	10
Subtotal	5,860	747
Improved hydromet and climate services		
1. Reconstruct the website for SLMS	50	n.a.
2. Development and implementation of CONOPS for meteorological forecasting and development of operation manuals (technical assistance)	50	10
3. Reconstruct the website for Hydrological Services	50	n.a.
4. Implement a Drought Program (designed in step 1) including interinstitutional mechanism, drought monitoring, and forecasting system (contractor support)	50	10
5. Establish a comprehensive Product Improvement Program based on User Committee improvement (contractor assistance)	250	n.a.
Subtotal	450	20
Contingencies (5%)	323.75	38.35
Grand total	**6,798.75**	**805.35**

5. Economic Analysis

The evaluation of potential economic benefits of NMHS modernization is an important tool to support investment decisions. Additionally, it is a critical input for the development of recommendations and a prioritized plan of improvement of data delivery to national users.

Hydromet services involve the provision of information on the state of the atmosphere and water resources. The use of hydromet information in decision making can be used to minimize economic damages and loss of human lives, as well as to gain additional economic benefits from increased production efficiency of weather-dependent economic activities. Economic benefits of improved hydrological, weather, and climate information include the following (Pelling et al. 2002; Hallegatte and Przyluski 2010; Tanner et al. 2015):

(a) Expected avoided damages, which correspond to damages and losses that can be prevented in the event of a disaster;

(b) Increased production efficiency and economic activity owing to reduced production risk[4];

(c) Reduced morbidity and mortality;

(d) Increased water supply security; and

(e) Increased ecosystem conservation.

However, some of these benefits are very complex to analyze and require sophisticated methodologies that are data and time intensive. The scope of this evaluation is to analyze the expected avoided damage to the major economic sectors and increased production efficiency and economic activity.

In this analysis, benefits derived from avoidable costs are based on benchmark analysis, while benefit transfer is applied to the estimation of increased production efficiency. The implementation and O&M costs are those associated with the different proposed scenarios in this Road Map.

Benchmarking methodologies are most frequently employed when there are (a) significant data limitations, such as the lack of baseline economic data, particularly economic data on direct and indirect losses from extreme events; (b) lack of resources to conduct in-depth economic assessments with more sophisticated methodologies; and (c) time constraints for more comprehensive surveys and studies. A detailed description of the benchmarking approach, including its main assumptions and limitations, is given in Malik et al. 2015, Rogers et al. 2016, Tsirkunov et al. 2006, Tsirkunov et al. 2007, and Tsirkunov 2008. Benefit transfer methodologies employ benefit estimates of other studies in the setting proposed in this Road Map.

The C-B analysis identifies limitations, biases, and uncertainties on the key variables. A scenario sensitivity analysis is performed on a range of assumptions on uncertain key variables to analyze the robustness of the economic assessments. The key parameters considered in the sensitivity analysis are the expected annual avoidable cost and damages and the discount rate.

[4] Uncertainty of hydrological and weather conditions leads risk-averse firms to reduce long-term investments in productive assets, resulting in reduced production efficiency.

5.1 Methodology

As pointed out, the benefits due to damage loss reductions are based on a benchmarking analysis. Benchmarking was developed to estimate economic benefits from the use of hydromet information and services for the national economy (Tsirkunov et al. 2007). Benchmarking is a simplified method, and it does not require detailed analytical studies or time-consuming surveys (Rogers et al. 2016; Tsirkunov et al. 2006; Tsirkunov 2008). The assessment is based on (a) available national official macroeconomic and sector-specific statistics, (b) key parameters such as weather dependence of the economy, (c) the vulnerability of the country's territory to weather hazards, (d) the NMS status and the quality of hydromet services provision in a given surveyed country, and (e) an estimate of the annual potential preventable losses due to hydromet services improvement.

Table 7 summarizes the key parameters that are considered to assess economic benefits associated with each proposed investment scenario (see annex 1 for more details on the source of these parameter estimates).

Table 7: Benchmark Parameters

Parameter	Estimated Values
Expected annual costs from weather hazards (droughts, storms, hurricanes, and temperature extremes, among others)[a] (EAC)	1.7% of GDP
AEE	0.23% of GDP
Weather dependence of economy	40% of GDP[b]
Annual potential preventable loss (APL)	40% of EAC
Annual value of improved hydromet information and forecasts for the agricultural sector	0.25% of agricultural GDP

Note: a. See Table A1.26 for more detailed information on damage assessments.
b. See Table A1.23 and Table A1.24.

Several studies estimate the annual value of improved hydromet information and forecasts (AVIF) for the agricultural sector (Adams et al. 1995; Adams et al. 2003; Kite-Powell and Solow 1994; Lambert et al. 1995; O'Brien 1993; and Solow et al. 1998). Their estimates show that improved hydromet information increases agriculture's GDP by 0.14–0.43 percent. This assessment considers a value of 0.25 percent of agricultural GDP, which corresponds to the average values estimated in the literature.

At present St. Lucia's hydrological and meteorological extreme event damage reduction effectiveness is low due to

(a) Technical limitations of data availability and forecasting tools;

(b) Lack of data exchange mechanisms;

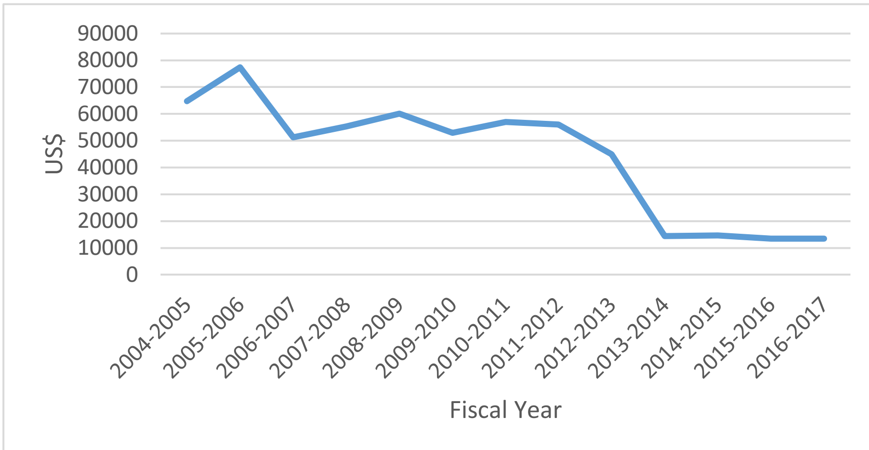
(c) Lack of up-to-date forecasting models;

(d) Insufficient education and training skills of the forecasters; and

(e) Lack of website dissemination capabilities.

St. Lucia took important measures to reduce the country's deficit during 2014 so as to increase fiscal sustainability. This explains why O&M budgets for hydromet data producers reduced 75 percent between 2014 and 2015, falling from US$60,000/year to US$15,000/year (**Figure 11**). At present, the island's fiscal situation has improved, allowing government agencies to begin to recuperate their budgets. However, this has not been the case with hydromet providers' O&M costs, and the reasons are not clear.

Figure 11: Hydromet Providers' O&M Costs



It is important to point out that all scenarios consider an important capacity and institutional strengthening program to develop the required competences. Without this, the proposed investments and actions will lead to an improved data production but with little change in decision making and, thus, very low to no impacts and economic benefits.

Scenario 1 concentrates on increasing St. Lucia's effectiveness to make use of hydromet services, in the short term. Hence, it focuses on capacity-building actions and proposes minimum equipment investments to achieve credible weather, water, and climate services.[5] Its total implementation and investment and O&M costs are US$1.7 million and US$0.133 million, respectively. The expected result is an increase in the nation's effectiveness to reduce EAC to 20 percent, of maximum potential effectiveness of 50 percent.

Scenario 2 proposes investments to bring weather, water, and climate services to meet approximately 75 percent of users' needs.[5] This scenario proposes actions for both WRMA and SLMS services to modernize St. Lucia's hydromet services so as to implement an end-to-end system for forecasting and warning that maximizes lead time, accuracy, and reliability of delivering services to meet most users' needs. The implementation of this scenario is likely to increase extreme event damage loss reduction effectiveness to 30 percent, which is considered a satisfactory effectiveness (Malik et al. 2015; Rogers et al. 2016; Tsirkunov 2008; and Tsirkunov et al. 2007). Its total implementation and investment costs are 3 times those of Scenario 1, reaching US$4.9 million; its total O&M costs are US$ 0.53 million.

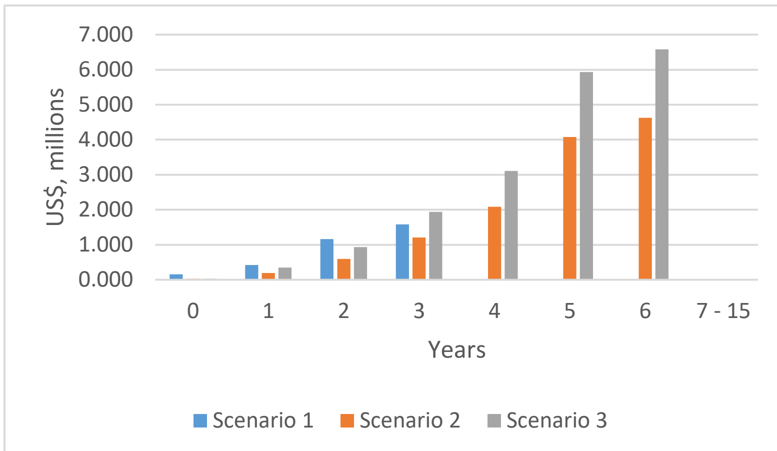
Finally, Scenario 3 recommends investments to bring NMHS providers up to state–of-the-art data, forecasting, and warning services to users and considering users' future needs[5] so as to increase St. Lucia's damage loss reduction effectiveness to 40 percent, which is considered as a good level in the literature.

[5] A more detailed description of each proposed scenario can be found in section 4.4 on page 40 of this report.

The required implementation and investment costs, to reach this objective, are US$6.8 million, which is 4 and 1.4 times the investment costs of Scenarios 1 and 2, respectively.

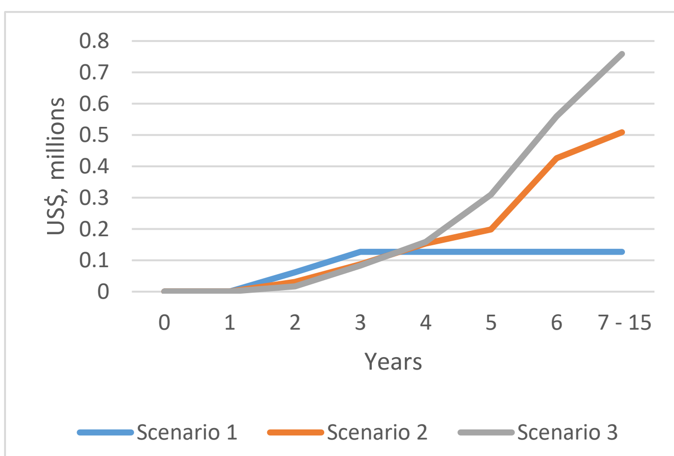
Following the implementation horizon of most hydromet improvement investments, the installation and strengthening of St. Lucia's hydromet infrastructure follow a 5–6-year horizon for Scenarios 2 and 3 (Figure 12). Since Scenario 1 proposes a set of actions to build institutional capacity and repair existing equipment, it can be implemented in a 2–3-year time frame.

Figure 12: Implementation Horizon for Each Scenario



O&M costs are considered to be 10–15 percent of capital cost of equipment, depending on the scenario. The average O&M cost of Scenario 1 is 8 percent, while for Scenarios 2 and 3 it is 11 percent and 12 percent, respectively. Since each scenario is implemented gradually, O&M costs increase progressively (Figure 13). Operations and maintenance begin during year 2 for all scenarios, since the first year is covered by the equipment's warrantee and stabilizes as of years 3 and 7 for Scenario 1 and Scenarios 2 and 3, respectively.

Figure 13: Gradual Increase in O&M Costs



Discounting future flows is required to conduct a cost-benefit (C-B) analysis when investments produce annual net benefits over time, as shown in the proposed scenarios in this Road Map. Many governments and international agencies, considering a uniform opportunity cost of capital, employ discount rates in the 7–14 percent range. This assessment considers a 10 percent discount rate and conducts a sensitivity analysis with 6 percent, 10 percent, and 14 percent discount rates.

5.2 Economic Assessment of Strengthening Operational Weather, Water, and Climate Services for St. Lucia

The economic assessment results associated with each of the proposed investment scenarios are presented in Table 8.

Table 8: Economic Assessment of the Proposed Scenarios (US$, millions)

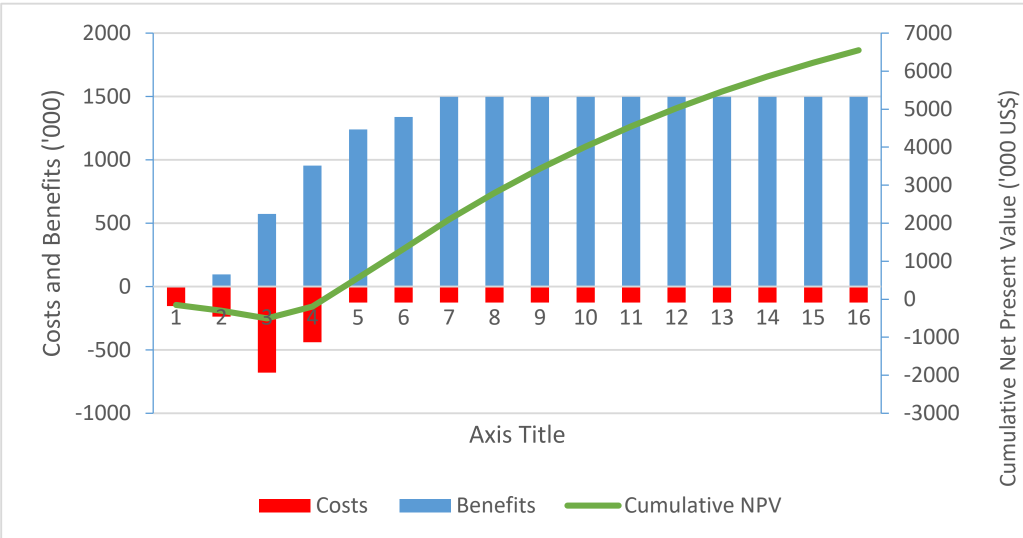
	Scenario 1	Scenario 2	Scenario 3
NPV	6.607	7.279	9.081
Present value benefits	8.668	12.799	16.930
Present value O&M costs	0.834	2.296	3.287
Present value implementation costs	1.227	3.224	4.562
C-B ratio	1:4.2	1:2.3	1:2.2

Scenario 1's annual expected benefits are US$1.5 million. Benefits when a specific extreme event occurs would be significant. For example, if Scenario 1 had been implemented before Hurricane Tomas, St. Lucia would have been able to avoid US$27 million of total damages of Hurricane Tomas.

The NPV[6] for Scenario 1 is US$6.61 million, which yields a 1:4.2 C-B ratio; each dollar invested in this scenario will help avoid approximately US$4 of economic losses on average (Figure 14). This C-B ratio is close to the average value of the estimated C-B ratios found in the literature (1:6). Hence, significant benefits can be achieved by investing on capacity-building actions and the minimum required equipment to achieve credible weather, water, and climate services. This is mainly achieved by significantly increasing St. Lucia's effectiveness to reduce damages (ε) through capacity building. Therefore, the decision to implement Scenario 1 is clearly justified from an economic point of view.

[6] NPV = Present value of net benefits − Present value of investment costs.

Figure 14: Scenario 1's Estimated Benefits, Costs, and NPV



Investment costs:
US$1.580 million

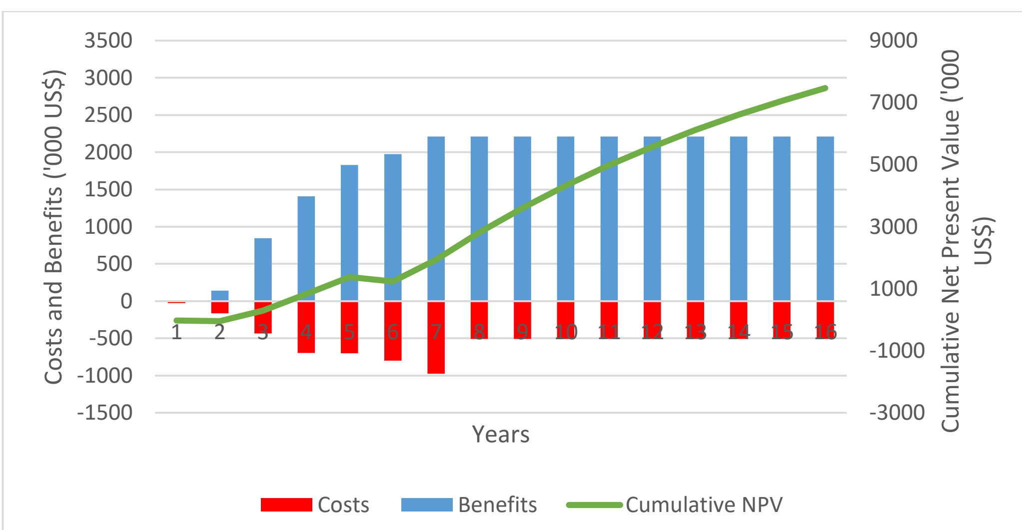
O&M costs:
US$127,000

NPV:
US$6.549 million

C-B ratio:
1:4.2

Scenario 2's expected annual benefits are US$2.2 million. These are significant should an extreme event such as Tomas occur; investing in Scenario 2 would have reduced US$40 million of Hurricane Tomas' damages. The NPV of this scenario is US$7.28 million, equivalent to a 1:2.3 C-B ratio (**Figure 15**). Consequently, each dollar invested to bring weather, water, and climate services to meet 75 percent of user needs by implementing an end-to-end system for forecasting and warning that maximizes lead time, accuracy, and reliability of delivering services generates US$2 of benefits. As with Scenario 1, the decision to implement Scenario 2 is thus justified from an economic point of view.

Figure 15: Scenario 2's Estimated Benefits, Costs, and NPV



Investment costs:
US$4.630 million

O&M costs:
US$488,000

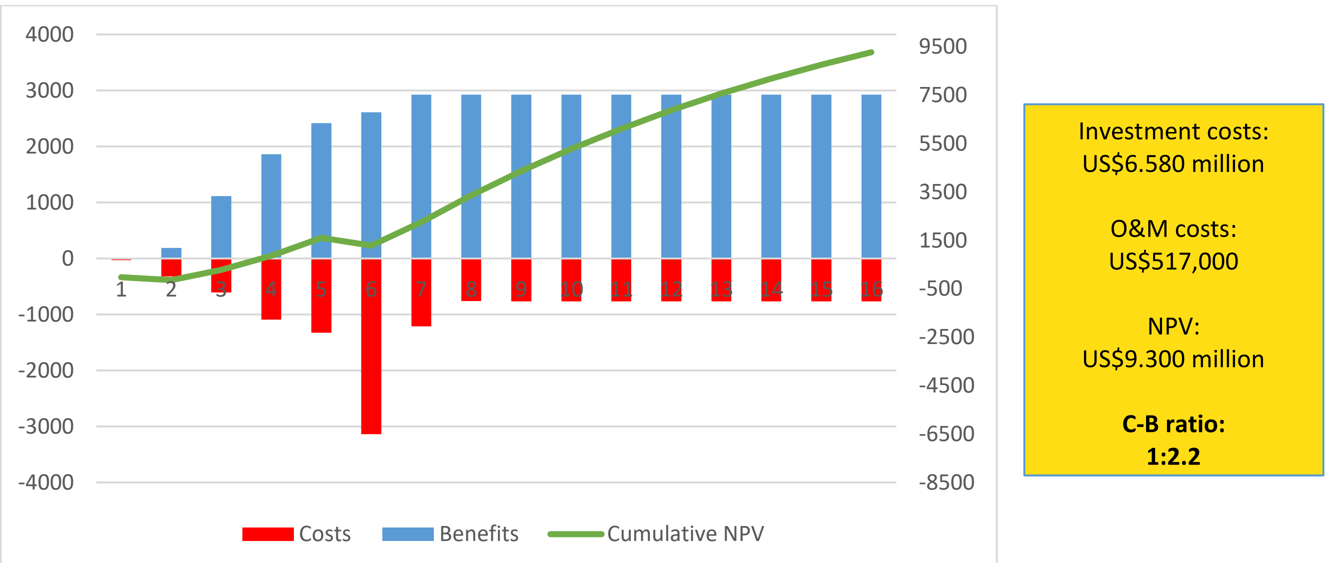
NPV:
US$7.492 million

C-B ratio:
1:2.3

It is important to note, however, that the C-B ratio of this scenario is 46 percent lower than Scenario 1. This can be explained by the fact that the present value of benefits for Scenario 2 is 47 percent higher compared to scenario 1, while O&M and implementation costs increase by 177 percent and 164 percent, respectively.

Avoided costs due to investment in Scenario 3 under a specific extreme event are significant; these benefits would have been US$54 million under an event such as Hurricane Tomas. Scenario 3 is economically justifiable given that its C-B ratio is 1:2.2. That is, investments needed to bring NMHS providers up to state-of-the-art data, forecasting, and warning services to meet users' present and future needs generate US$2 of benefits per dollar invested. As with Scenario 2, the C-B ratio of Scenario 3 is 50 percent lower than Scenario 1. This can be explained by the fact that investment and O&M costs increase significantly more than benefits.

Figure 16: Scenario 3's Estimated Benefits, Costs, and NPV



Given that Scenario 1 is an integral part of scenarios 2 and 3, one could think of sequentially implementing these scenarios, once Scenario 1 has been implemented. If Scenario 2 were implemented sequentially, once scenario 1 has been implemented, the C-B ratio would increase by 43 percent, from 1:2.3 to 1:3.3. The C-B ratio of Scenario 3, if it were sequentially implemented, would increase by 27 percent reaching 1:2.8. Therefore, a sequential implementation of Scenario 2 or 3 (S.1 → S.2 - S.1 → S.3) is a more economically rational strategy of obtaining the expected results of these two scenarios. Finally, sequentially implementing Scenario 3 once Scenarios 1 and 2 have been implemented yields a C-B ratio for Scenario 3 of 1:4.4 (S.1 → S.2 →S.3).

5.3 Sensitivity Analysis

Sensitivity analysis is applied to assess the robustness of the economic assessment with respect to the key assumptions and parameters. The parameters considered in this sensitivity analysis are EAC from weather hazards (droughts, storms, hurricanes, and temperature extremes, among others), APL, and the discount rate (see Table 9).

Table 9: Key Parameters Considered in the Sensitivity Analysis

Parameter	Estimated Values	Minimum	Maximum
Expected Annual Costs (EAC)	1.7% of GDP	1.4% of GDP	2% of GDP
APL	40% of annual loss	30% of annual loss	50% of annual loss
Discount rate (δ)	0.1	0.06	0.14

The C-B ratio estimates of Scenario 1 are robust since they range between 1:2.53 in the worst case scenario (highest discount rate and lowest damage loss reduction) to 1:7.1 in the most optimistic situation (EAC = 2 percent GDP, APL = 50 percent, and δ = 6 percent). Scenario 2 is also robust since the C-B ratio fluctuates between 1:1.48 to 1:3.36 and, thus, investment in Scenario 2 is justifiable under all possible situations. Similar conclusions are reached for Scenario 3, since the estimated C-B values range from 1:1.35 to 1:3.36 for all cases.

5.4 Economic Assessment Conclusions

The proposed hydromet investments generate significant benefits by reducing damage losses from extreme hydrological and meteorological events and increased production efficiency, particularly for agriculture, by implementing an end-to-end system for forecasting and warning that maximizes lead time, accuracy, and reliability of delivering services to meet most users' needs (Table 10).

Table 10: Cost Benefit Ratios for Each Scenario

	Scenario 1	Scenario 2	Scenario 3
NPV (US$, millions)	6.607	7.279	9.081
C-B ratio	1:4.2	1:2.3	1:2.2

These results justify obtaining financial support to improve existing hydromet activities as well as to modernize the system so as to implement state-of-the-art data, forecasting, and warning services.

Results also indicate that a sequential implementation of the scenarios may be a favored approach. This is particularly important due to the actual low effectiveness in reducing potential damages and increasing production efficiency due to

(a) Technical limitations of data availability and forecasting tools;

(b) Lack of data exchange mechanisms;

(c) Lack of up-to-date forecasting models;

(d) Insufficient education and training skills of the forecasters; and

(e) Lack of website dissemination capabilities.

It is important to note that not all economic benefits have been estimated, and thus these results represent a lower-bound estimate. Some of the nonquantified benefits are

(a) Reduced morbidity and mortality;

(b) Reduced development opportunities;

(c) Increased water supply security; and

(d) Increased ecosystem conservation.

These were not included due to data limitations and time restrictions that only allowed for assessments based on secondary data. In future assessments, it will be important to consider these.

However, these benefits will not materialize if the actual decrease in O&M budgets of hydromet services providers continues over time and if there is no commitment to allocate the required O&M budgets. O&M budgets for hydromet data producers reduced 75 percent between 2014 and 2015, falling from US 60,000/year to US$15,000/year, and this has not recuperated. O&M budgets for the proposed scenarios are 8.5, 32.5, and 34.5 times the actual O&M allocated budget. If the required budget is not satisfied as of year 7, the NPVs of the investment in all scenarios significantly decrease and the C-B ratio falls below 1:1.

Finally, expected benefits have been estimated considering historic extreme event occurrence probability. The 2014 IPCC concludes that climate change will lead to a higher magnitude and frequency of extreme events. Thus, the C-B ratios will be greater than those estimated in this assessment.

6. Conclusions and Way Forward

The user assessment and technical evaluation of the capacity of both WRMA and SLMS have revealed the need for significant steps and investments to produce data, forecasts, and information needed by the various sectors in the economy. There are certain gaps in the end-to-end forecasting system that need immediate attention. First, at a minimum investment it is critical to immediately resolve the existing early warning system hardware outages and restore a basic warning capability so that when heavy rainfall and flooding threaten these critically flood-vulnerable communities in the river basins, warnings will save lives and reduce economic losses. Also, it is obvious that the websites of WRMA and SLMS need to be redesigned so that up-to-date data, forecasts, and warnings can be made available to all users in addition to existing standardized warning dissemination channels such as email, SMS messages, and telephone calls. These are short-term fixes that need to be resolved now and will result in quick generation of benefits to users. These actions are described and recommended in Scenario 1 that emphasizes short-term fixes that are not very costly and reap almost immediate beneficial results to users, with a 4:1 C-B ratio.

Other improvements will take longer time and will provide a slow incremental improvement in the accuracy and utility of data as users increase their needs and learn how to maximize use of new information and products generated. It is important that government budget decision makers understand the resultant benefits to each of the proposed scenarios. In fact, the economic C-B analysis results show clearly that investments will result in long-term sustainable benefits by meeting forecast and data needs of the country. St. Lucia will have to strategically adapt to a changing climate regime that will involve building resilience and shifting the economy to goods and services less affected by a warming climate, which is subject to more extreme climate episodes. Building a robust hydromet provider capacity that is sustainable will ensure reduction of future losses, an economy that is more resilient to climate extreme shocks, and resultant improvement in productivity in energy, agriculture, tourism, and other important sectors as essential hydrological and meteorological information becomes available to the users.

The next steps and way forward involve prioritization of actions to be taken by the government to strengthen hydromet services. Scenario 1 represents a minimal essential strategy to repair and restore networks and early warning systems. A key to sustaining these elements is establishing a viable maintenance and operation program. Budget cuts suffered by both hydromet service providers have resulted in decay of the data and early warning system that they do not function properly. A well-funded maintenance and operation program is essential to building sustainable forecast, warning, and water management services in demand by the many sectors of the economy. According to the economic analysis, a significant return on investment of about US$4 is realized for every US$1 invested in Scenario 1. This scenario is essential to saving lives and realizing significant benefits to the economy. Scenarios 2 and 3 provide benefits to the users but at a slower and reduced rates of return. Both scenarios benefit from a 2:1 ratio of benefits to costs. All scenarios involve interaction and coordination between users and the providers.

However, these benefits will not materialize if the actual decrease in O&M budgets of hydromet services providers continues over time; SLMS has suffered a 92 percent O&M budget cut between 2014 and 2016, while WRMA's O&M budget has fallen 51 percent in the same period. If there is no commitment to allocate the required O&M budgets and maintain them over time, the NPV of the investment will significantly decrease and the C-B ratio will fall to below 1:1, which represents an unfavorable investment.

As in every country, there will never be enough resources to meet all users' needs by a government agency. Most important is that the essential and critical needs are met by the hydromet providers to minimize losses from severe weather and hydrological extremes and to have a complete understanding of the priorities of various users through establishment of active communication mechanism. Users need to understand what science, data, and technology are available and the hydromet providers must understand how to best meet the primary needs of their customers. Some of the recommended actions in all scenarios will take time such as essential training of meteorologists and hydrologists, establishing a mechanism for users and hydromet providers to define needed products and services, education of the users, especially the public, on how to understand and best use products in decision making.

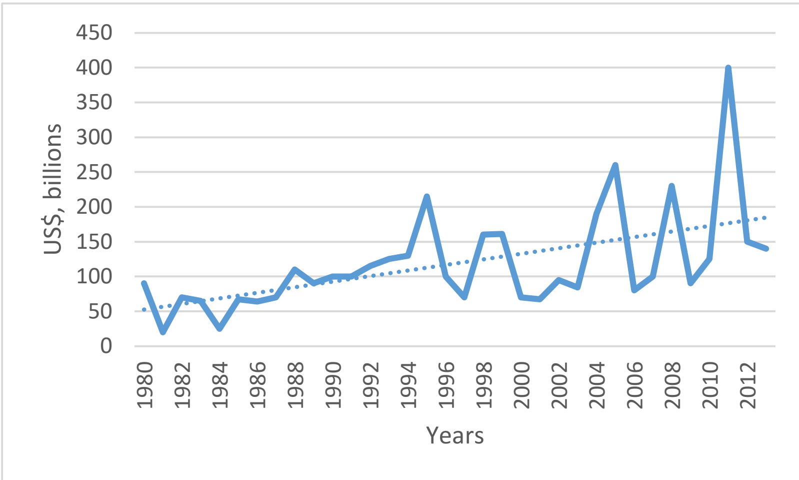
Once priority actions have been determined, an implementation plan needs to be constructed. The implementation plan includes network design, determination of the hardware and software needed to build everything from a database and DBMS to a website to computers, and hydrological modeling systems. The costing of each of the tasks involved in building a meteorological and hydrological system includes hiring consultants and experts to assist the Meteorological Service and WRMA in strengthening technical capabilities needed to produce data, forecasts, and information for users. Data networks need to be designed, and the existing flash flood EWS needs to be assessed for performance and in lieu of other choices of flash flood forecasting capability. Also, users need to be consulted (through user groups) to determine data and information needs so that priorities can be determined in expanding data collection, processing, and forecasting capabilities.

Annex 1: Economic Assessment of the Road Map to Strengthen Hydromet and Climatic Services in St. Lucia

A.1. Introduction

Weather and climate extreme events negatively affect the economy and growth of a country (Hsiang and Jina 2014). The total worldwide disaster and weather-related losses have increased since the 1980s (Tanner et al. 2015), reaching in 2015 an average of US$250 billion to US$300 billion each year (UNISDR 2015), four times the total loss in 1980 (**Error! Reference source not found.**).

Figure A1.1: Disaster and Weather-Related Losses 1980–2013



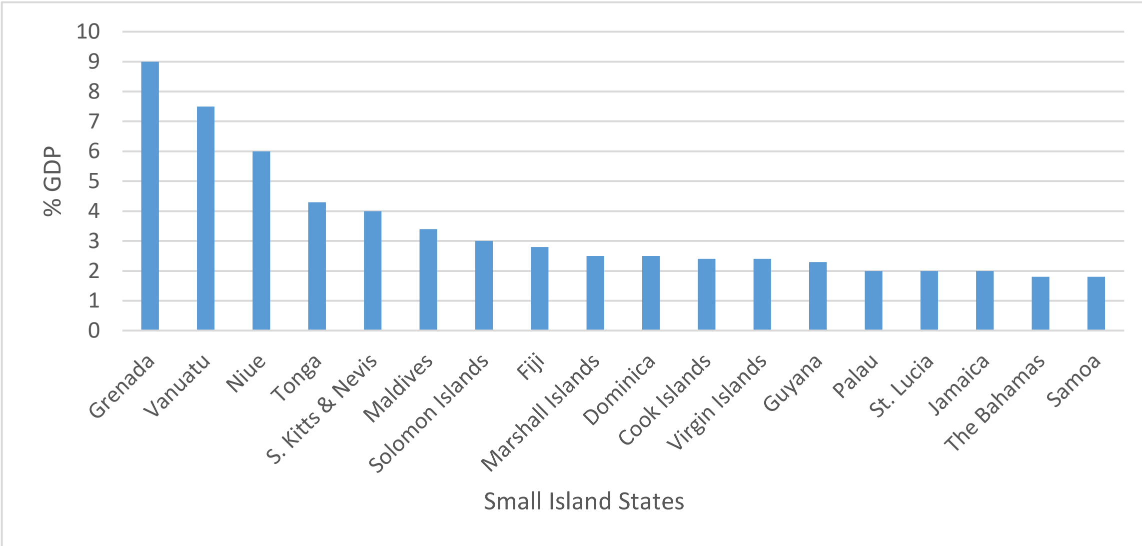
Source: Tanner et al. 2015.

The Caribbean is one of the most disaster-prone regions in the world. Rasmussen (2006) concludes that the six ECCU[7] countries rank in the top 10 most disaster-prone countries in the world when considering disasters per land area or population. Of the ECCU countries, St. Lucia presents one of the highest hurricane probabilities (17.2 percent). More importantly, Hsiang and Jina (2014) find that GDP does not recover immediately, and in some cases the recuperation of a country's GDP can take approximately 20 years.

Average annual economic losses associated with extreme hydromet events in small island states range from 1.8 percent to 9 percent of GDP (Figure A1.2). Average annual economic losses of St. Lucia are equivalent to approximately 2 percent of GDP (Harmeling and Eckstein 2012; Vivo 2015).

[7] The ECCU is composed of Antigua and Barbuda, Dominica, Grenada, St. Kitts and Nevis, St. Lucia, and St. Vincent and the Grenadines.

Figure A1.2: Average Annual Disaster Losses in Small Island States as Percentage of GDP



Source: Vivo 2015.

Hydromet services involve the provision of information on the state of the atmosphere and water resources. The information provided can be used to change decisions, thus increasing human welfare. Hence, societies benefit from hydromet services since they inform hydrology and weather-sensitive human decisions and thereby can improve the outcome of the decision. Economic benefits of improved hydrological, weather, and climate information include the following (Hallegatte and Przyluski 2010; Pelling et al. 2002; Tanner et al. 2015):

(a) Expected avoided damages, which correspond to damages and losses that can be prevented in the event of a disaster and

(b) Increased production efficiency and economic activity owing to reduced production risk.[8]

It is important to point out that in general, the benefits due to improved hydromet services are nonexclusive[9] and nonrival[10] in nature. Nonrivalry means that once a basic hydromet service is provided for one person, it is available for all to use. This implies that hydromet services become less costly on a per user basis when the service can be offered to a greater number of users. Nonexclusion, on the other hand, implies that once the service is provided, it is available to all the population. Therefore, hydrological, weather, and climate information is a public good and, as such, will not be adequately provided by private markets. Consequently, hydromet services must be supplied by the state so as to keep the population safe, reduce natural disaster losses, and enhance weather and hydrology-dependent production.

Additionally, aggregate benefits of a public good correspond to the vertical sum of individual benefit functions. This implies that social economic benefits due to improved hydromet services are given by the sum of benefits accrued by individual beneficiaries. Hence, the benefits of improved hydromet services will be larger when the number of beneficiaries increases.

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[8] Uncertainty of hydrological and weather conditions leads risk-averse firms to reduce long-term investments in productive assets, resulting in reduced production efficiency.
[9] Nonexclusion implies that individuals cannot be effectively excluded from accessing these services.
[10] Nonrivalry implies that the use of the services by users does not reduce the availability of the information for other users.

Several studies have assessed the economic benefits associated with hydromet services improvements to conduct a C-B analysis (ADB 2002; Cabot Venton and Venton 2010; Zimmermann and Stössel 2011).

A.2. Literature Review

A.2.1. Economic Benefits of Hydromet Services

Expected Avoided Damages

The occurrence of extreme hydrological (droughts and floods) and climatic (hurricanes and troughs) events causes significant damages and losses. These impacts can be reduced when society and decision makers have access to improved hydromet and climatic data and forecasts since steps can be taken to increase the protection from extreme hydrological and weather events.

The magnitude of these damages is variable, since damage costs are event specific and depend on their intensity. Additionally, these damages present themselves only when these extreme events occur. Thus, conceptually, the potential expected benefits of improved hydromet services are the expected avoided damages; formally,

(1) $$PB = (EDC^{wop} - EDC^{wp}),$$

where *PB* represents the potential expected hydromet project benefits (expected avoided damages), and EDC^{wop} and EDC^{wp} are the expected damage costs due to an extreme event without and with the project, respectively. The expected damage costs are

(2) $$EDC^{i} = \int_{0}^{\infty} DC_{x}^{i} f(x) dx \; i = wpo, wp,$$

where DC_{x}^{i} are the damage costs due to an extreme hydrological or meteorological event x that has a probability of occurrence $f(x)$[11] (Carsell et al. 2004).

Estimating the damage costs requires the distinction between direct and indirect losses. Direct losses are the immediate consequences of the extreme event, such as those resulting from building, lifeline, and infrastructure damages. Indirect losses, on the other hand, are those that follow the physical damages, for example, commuter disruptions, loss of local tax revenues, and reduced tourism, among others.

Several researchers have concluded that the effectiveness of the investment in hydromet services depends on the accuracy of the data and forecasts, the access end users have to the data and analysis, their comprehension of the information, and their ability to respond, among others (see Figure A1.3). For example, Carsell et al. (2004) point out that the effectiveness of the investment in hydromet services to reduce damages (ε) is a function of the proportion of producers and the public that (a) receives the information, (b) knows how to respond effectively, and (c) is willing and capable of responding. Sorensen and Mileti (1988) study evacuation decisions under improved warning systems and find that their effectiveness is reduced since few people evacuate instantaneously to improved information. Lindell and Prater (2003) show that the lack of emergency preparedness practices can limit the full benefits of

[11] $f(x)$ is the probability density function of the random variable x. In general, it is assumed that x is log-normally distributed; *that is,* $x \sim LN(\mu, \sigma^2)$.

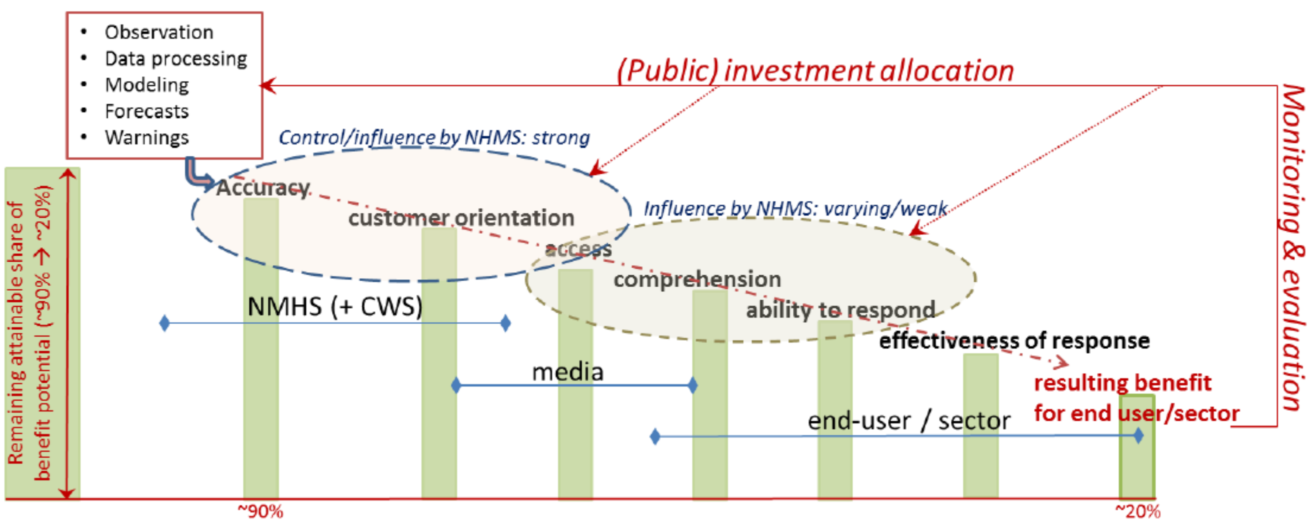
increased hydromet services. Hence, education and preparedness programs are key to achieving the desired benefits of improving hydromet services (EWC III,2006; Parker et al. 2009).

Thus, it is essential to consider the effectiveness of the investment in hydromet services to reduce damages, to not overestimate the benefits. Incorporating this into equation (1) implies that the expected benefits of an improvement in hydromet services are estimated as follows:

(3) $$B = (EDC^{wop} - EDC^{wp})\varepsilon = PB\varepsilon,$$

where $\varepsilon \in [0,1]$ is the damage reduction effectiveness of the investment project. Given that $\varepsilon \in [0,1]$, $0 \leq B \leq PB$.

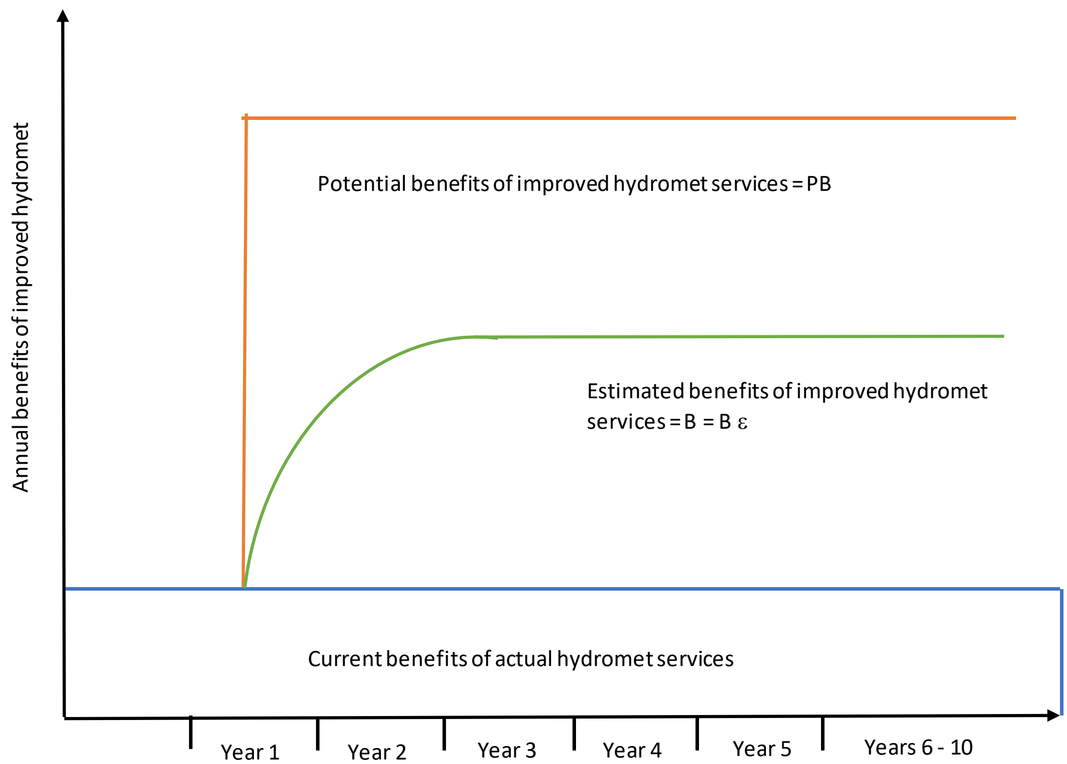
Figure A1.3: Effectiveness Determinants along the Hydromet Services Chain



Source: Perrels et al. 2013.

In general, the effectiveness of the hydromet services is expected to increase over time (Figure A1.4), as a greater fraction of the population adopts improved decision making based on the upgraded hydromet services (Tammelin 2015).

Figure A1.4: Effectiveness increase of time



Source: Tammelin 2015.

Increased Production Efficiency and Economic Activity

There is strong evidence that the probability of weather extreme events affects economic growth. The risk of extreme weather events and disasters looms as an ever-present background risk.

Uncertainty of hydrological and weather conditions leads risk-averse households and firms to reduce long-term investments in productive assets and decrease planning horizons, leading to development opportunities being lost and reduced production efficiency. Hence, hydrology and weather-dependent economic sectors, such as agriculture, require information to improve planning and decision making, which leads to increased production levels. For example, better information and forecast ability of hydrological conditions, seasonal precipitation, drought vulnerability, and mean and extreme temperatures leads to improvements in agricultural producers' decision making, such as determining the type of crop that can be profitably grown in a region. Thus, the economic value of increased production efficiency due to improved hydromet information on production risk can be estimated by the reduction in a producer´s risk premium[12] (Δ_ρ). Formally, a producer's risk premium is defined as

(4) $$U(W_o + \bar{\pi} - \rho) = EU(W_o + \tilde{\pi}),$$

[12] The risk premium is defined as the payment that leaves the agent indifferent between accepting the certain and the uncertain prospect.

where ρ denotes the agent's risk premium, $U(\cdot)$ represents the producer's von Neumann-Morgenstern utility function,[13] W_o stands for initial wealth, $\tilde{\pi}$ is the stochastic profits associated with the uncertain prospect such as hydrological and weather conditions, and $\bar{\pi} = E(\tilde{\pi}|HMS)$ are expected profits given existing hydromet services. Improved hydromet services lead to improved decision making and, thus, expected profits increase, that is,

(5) $$\Delta_{\bar{\pi}} = E(\tilde{\pi}|HMS^{wp}) - E(\tilde{\pi}|HMS^{wop}) \geq 0.$$

An agent's von Neumann-Morgenstern utility increases as expected profits increase, sin marginal utility is nonnegative. Thus, as hydromet services are improved, the producer's risk premium reduces. The reduction in risk premium Δ_ρ is such that

(6) $$U(W_o + \bar{\pi}^{wp} - \rho^{wp}) = EU(W_o + \tilde{\pi}) = U(W_o + \bar{\pi}^{wop} - \rho^{wop}).$$

The main methodologies that have been applied to value risk premium reductions are contingent valuation, production changes, economic modelling, and benefit transfers (Table A1.1). Most studies have used economic decision models to estimate the value of improved hydromet information.

A.2.2. Expected Hydromet Services Benefit Assessment Methodologies

There is no unique method for assessing the social and economic benefits generated by improved hydromet services. The chosen methodology must allow for the (a) identification of how hydromet services benefit a sector or country and (b) estimation of the benefits attributable to an improvement in these services. Different studies have thus employed different assessment frameworks.

The most commonly used benefit estimation methodologies are presented in Table A1.1.

Table A1.1: Benefit Estimation Methodologies

Valuation Methodologies			Hydromet Services Benefits	Advantages	Limitations
Non-Market Valuation	Stated Preferences	Contingent Valuation	EAD[a], IPE[b]	Survey-based approaches that explicit individual's choices in hypothetical situations. Estimates use and nonuse values	Time-intensive, expensive to implement, requires careful survey design and pretests
		Conjoint Analysis			
		Experimental Economics			
	Revealed Preferences	Averting Behavior	EAD	Uses observed market behavior to infer values	Data- and time-intensive (requires primary data), sophisticated
		Hedonic Prices			

[13] The agent´s risk attitudes (risk aversion and downside risk aversion) are represented by their von Neumann-Morgenstern utility function.

Valuation Methodologies			Hydromet Services Benefits	Advantages	Limitations
		Production Changes	IPE		econometric modelling. Only estimates use values. Requires well-functioning markets
Economic Modeling	Decision Models	Prescriptive	EAD, IPE	Decision model based on normative theory, which yields benefit estimates for a user whose decisions maximize welfare	They do not necessarily provide consistent estimates of the actual value to society given current decision practices
		Descriptive		Determines a user's decision model based on the user's actual behavior and decisions. Yields estimates of the actual value of forecasts of a user who may or may not use this information optimally.	They may underestimate the full benefits by not considering additional benefits due to improvements in the user's decision making process.
	Equilibrium Models	I-O (Input Output) analysis	EAD, IPE	Models the economy as a whole with the input-output matrix, which is the basis for GDP calculation. Considering net impact of value added from other sectors, backward and forward linkages	Requires a detailed input-output matrix disaggregated into all sectors of the economy
		CGE (Computable General Equilibrium) model		Is an algebraic representation of the abstract Arrow-Debreu general equilibrium structure, which is calibrated on economic data. CGE models are descended from the input-output models but assign a more important role to prices	Data- and time-intensive, sophisticated modelling. Results cannot be traced to any particular features of their database or input parameters, algebraic structure, or method of solution

<table>
<tr><th colspan="2">Valuation Methodologies</th><th>Hydromet Services Benefits</th><th>Advantages</th><th>Limitations</th></tr>
<tr><td rowspan="2">Avoided Costs</td><td>Benchmark</td><td>EAD</td><td>Estimates the net benefits at the national or country level based on GDP. Based on readily available, generally reliable, estimates of GDP. Is the most widely applied approach</td><td>In many countries, GDP may not be reliably reported or computed. Too aggregate to evaluate specific benefits of information that may be important to hydromet targeting or location.</td></tr>
<tr><td>Sectoral</td><td>EAD</td><td>Estimates the net benefits at the national or country level based on benefit transfer. Based on the specially designed surveys of experts from weather-dependent sectors. Estimates sector-specific benefits</td><td>Expert assessments and surveys are time and resource intensive. Quality of expert opinion and availability of outside information that can be transferred is an obstacle.</td></tr>
<tr><td colspan="2">Benefit Transfer</td><td>EAD, IPE</td><td>Estimate benefits by transferring available information from studies already completed in another location and/or context</td><td>Existence of important differences among the types of conditions studied in the primary empirical research, which must be considered. Obtaining relevant, high-quality existing studies can be difficult</td></tr>
</table>

Note: a. EAC.
b. Increased production efficiency.
Based on Letson et al. (2007), Perrels et al. (2013), Stewart (1997), Freebairn and Zillman (2002), Wu et al. (2014), Gunasekera (2003), Weiher et al. (2002), Lazo et al. (2008), and Malik et al. (2015).

A.2.3. Hydromet Services Benefit Assessments

Studies in various countries have shown that the C-B ratio improvements in hydromet services are, in general, favorable. The summary presented in Table A1.2 shows that C-B ratios range from around 1:2 to 1:10.

Table A1.2: Estimates of C-B Results Based on Avoided Costs Estimation

Country	Economic Sector	C-B Ratio	Reference
Albania	All sectors	1:4	Tsirkunov et al. 2007
Armenia	All sectors	1:2	Tsirkunov et al. (2007)
Australia	General public	1:4	Anamann and Lellyett 1996 cited by Perrels et al. 2013
Azerbaijan	All sectors	1:3–1:4	Tsirkunov 2008; Tsirkunov et al. 2007
Belarus	All sectors	1:3–1:5	Tsirkunov 2008; Tsirkunov et al. 2007
Croatia	All sectors	At least 1:3	Leviäkangas et al. 2008 cited by Perrels et al. 2013
Finland	All sectors	1:5	Leviäkangas and Hautala 2009 cited by Perrels et al. 2013
	Transport	1:10	Nurmi et al. 2012 cited by Perrels et al. 2013
Georgia	All sectors	1:2–1:3	Tsirkunov et al. 2007
Kazakhsatan	All sectors	1:5	Tsirkunov et al. 2007
Kyrgyz Republic	All sectors	1:2	Rogers et al. 2016
Russian Federation	All sectors	1:3–1:4 1:4–1:10	Bedritsky and Khandozko 2001 cited by Perrels et al. 2013 (World Bank 2005)
Serbia	All sectors	1:7	Tsirkunov et al. 2007
Switzerland	All sectors	1:5	Frei 2010 cited by Perrels et al. 2013
	Transport	1:10	Frei et al. 2012 cited by Perrels et al. 2013
Tajikistan	All sectors	1:2	Rogers et al. 2016; Tsirkunov 2008
Turkmenistan	All sectors	1:2–1:3	Rogers et al. 2016
Ukraine	All sectors	1:2	Tsirkunov 2008
United Kingdom	General public	1:7	MET Office 2007 cited by Perrels et al. 2013
	Meteorological infrastructure	1:5–1:20	Joo et al. 2011 cited by Perrels et al. 2013
United States	General public	1:6	Lazo et al. 2009 cited by Perrels et al. 2013
	Transport	1:2–1:3	Ye et al. 2009 cited by Perrels et al. 2013

A.3. Benefit Estimation Methodology

Benchmarking methodologies are the most frequently employed when there are (a) significant data limitations, such as the lack of baseline economic data, particularly economic data on direct and indirect losses from extreme events; (b) lack of resources to conduct in-depth economic assessments with more sophisticated methodologies; and (c) time constraints for more comprehensive surveys and studies. A detailed description of the benchmarking approach, including its main assumptions and limitations, is given in Malik et al. 2015, Rogers et al. 2016, Tsirkunov et al. 2006, Tsirkunov et al. 2007, and Tsirkunov 2008.

Benchmarking was developed to estimate economic benefits from the use of hydromet information and services for the national economy (Tsirkunov et al. 2007). Benchmarking is a simplified method, and it does not require detailed analytical studies or time-consuming surveys (Tsirkunov et al. 2006; Tsirkunov 2008; Rogers et al. 2016). The assessment is based on (a) available national official macroeconomic and sector-specific statistics, (b) key parameters such as weather dependence of the economy, (c) the vulnerability of the country's territory to weather hazards, (d) the NMS status and the quality of hydromet service provision in a given surveyed country, and (e) an estimate of the annual potential preventable losses due to hydromet services improvement.

Estimates of EAC due to extreme climate events for St. Lucia are presented in Table A1.3.[14]

Table A1.3: Average Mortality and EAC of Extreme Weather Events in St. Lucia

Study	Period	Average Losses			
		Death Toll	Deaths per 100,000 Inhabitants	Losses in Mill US$ PPP	Losses as % GDP
Harmeling and Eckstein 2012	1992–2011	1	0,64	26,94	1,9
Kreft et al. 2013	1994–201	1	0,82	25,02	1,7
World Bank 2016a	—	—	—	9,5	0,7

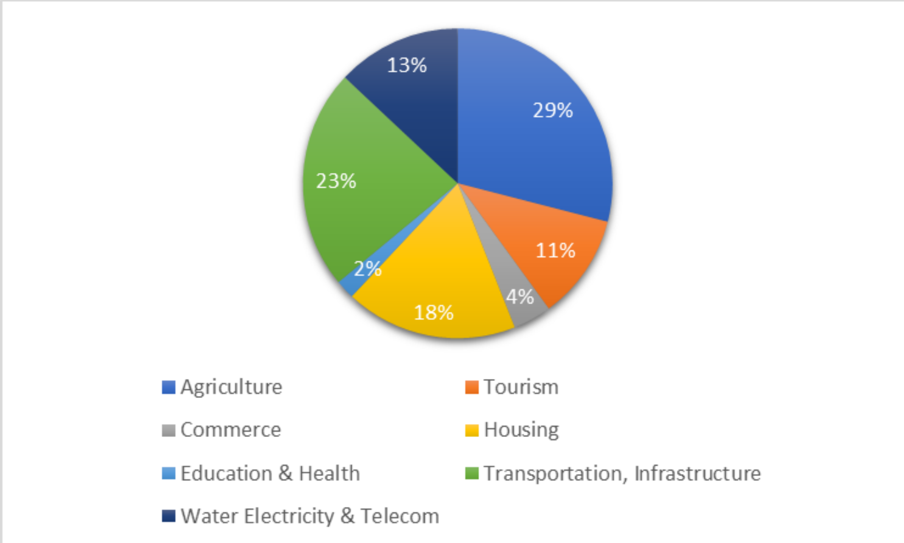
Note: Estimate based on a loss exceedance curve.

The difference in annual EAC estimates between the Global Climate Risk Index and the World Bank assessments is explained by the events that are considered. The studies conducted by Harmeling and Eckstein (2012) and Kreft et al. (2013) estimate average mortality and EAC considering all storms, floods, as well as drought, temperature extremes, and mass movements (heat and cold waves and so on) that have caused damage to St. Lucia's economy and population. On the other hand, the World Bank (2016), CCRIF (2013), and GFDRR (2010) estimate average damage loss only due to storms and hurricanes.

The Global Climate Risk Index EAC assessments consider damages caused by extreme weather events to infrastructure, residential sector, and the major weather-dependent economic sectors of St. Lucia—agriculture and tourism (Harmeling and Eckstein 2012; Kreft et al. 2013). The most vulnerable economic sector is agriculture, followed by transportation and infrastructure (see Figure A1.5). Agriculture and tourism account for 40 percent of the economic damages due to extreme weather events.

[14] Table A1.26 presents more detailed economic damage assessments associated to specific weather related events.

Figure A1.5: Sectoral Loss and Damage due to Storms and Hurricanes



Source: World Bank 2015, Harmeling and Eckstein 2012, Kreft et al. 2013, and World Bank 2016.

Given that Kreft et al. (2013) study considers all events, including droughts, and a more recent time series, this assessment considers that the average EAC from weather hazards for St. Lucia is 1.7 percent of GDP.

Additionally, St. Lucia's average annual emergency expenses (AEE) for 2005–2015 are US$2.14/year, which is equivalent to 0.23 percent of GDP.

Most benchmarking assessment studies consider that the range of annual potential preventable weather losses due to hydromet services is 20–60 percent. Of these, the majority consider an average preventable loss (APL) due to hydromet services of 40 percent (Malik et al. 2015; Rogers et al. 2016; Tsirkunov 2008; Tsirkunov et al. 2007). Based on these studies, this assessment considers an average potential preventable (APL) loss of 40 percent for St. Lucia.

Several studies estimate the AVIF for the agricultural sector (Adams et al. 1995; Adams et al. 2003; Kite-Powell and Solow 1994; Lambert et al. 1995; O'Brien 1993; Solow et al. 1998). Their estimates show that improved hydromet information increases agriculture's GDP by 0.14–0.43 percent. This assessment considers a value of 0.25 percent of agricultural GDP, which corresponds to the average values estimated in the literature.

Table A1.4 summarizes the key parameters that are considered to assess economic benefits associated with each proposed investment scenario (see section 4.4 on page 52 for more details of each scenario).

Table A1.4: Benchmark Parameters

Parameter	Estimated Values
EAC from weather hazards (droughts, storms, hurricanes, and temperature extremes, among others)[a]	1.7% of GDP
AEE	0.23% of GDP
Weather dependence of economy	40% of GDP[b]
APL	40% of annual loss (P)
Annual value of improved hydromet information and forecasts for the agricultural sector	0.25% of agricultural GDP

Note: a. See Table A1.26 for more detailed information on damage assessments.
b. See Table A1.23 and Table A1.24.

As was discussed in section 3 of this Road Map, at present St. Lucia's hydrological and meteorological extreme event damage reduction effectiveness is low due to

(a) Technical limitations of data availability and forecasting tools-

(b) Lack of data exchange mechanisms-

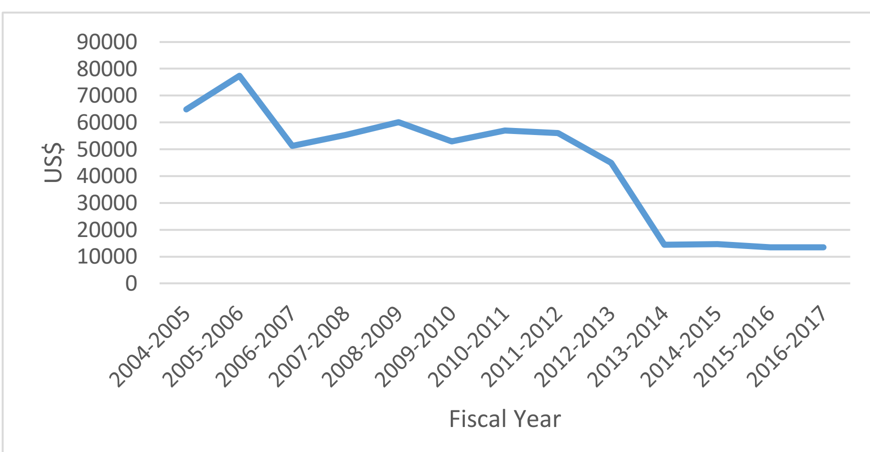
(c) Lack of up-to-date forecasting models-

(d) Insufficient education and training skills of the forecasters - and

(e) Lack of website dissemination capabilities.

St. Lucia took important measures to reduce the country's deficit during 2014 so as to increase fiscal sustainability. This explains why O&M costs budgets for hydromet data producers reduced 75 percent between 2014 and 2015, falling from US$60,000/year to US$15,000/year (). At present, the island's fiscal situation has improved, allowing government agencies to begin to recuperate their budgets. However, this has not been the case with hydromet providers' O&M costs, and the reasons are not clear.

Figure A1.6: Hydromet Provider's O&M Costs



These significant reductions in O&M budgets for hydromet data producers has led to

(a) Deterioration of observation networks and reduction in observation programs;

(b) Depreciation of equipment and outdated technology;

(c) Lack of modern monitoring equipment and forecasting methods;

(d) Insufficient scientific and research support; and

(e) Lack of trained specialists.

On the other hand, meetings and survey answers of hydromet data users evidenced that there is a gap between actual and required competences so as to obtain the expected results of improved hydromet services, such as reductions in extreme event damages, impacts of drought, and emergency expenditures, among others.

This assessment, therefore, indicates that St. Lucia has, at present, a poor effectiveness to make use of hydromet service modernization to reduce its expected annual losses due to extreme hydrological and meteorological extremes. It is assumed that only 10 percent of the APL can be achieved under actual conditions. This is consistent with the findings from the damage reduction effectiveness evaluation conducted by NEMO in 2014 (NEMO 2014).

Therefore, to increase the nation's effectiveness to make use of hydromet services, this Road Map considers three implementation scenarios (section 4.4 on page 529). Each scenario differs in its objectives and thus considers different actions and investments to (a) build institutional capacity, (b) strengthen hydromet observation, data analysis, and forecasting, and (c) improve hydromet and climate services.

It is important to point out that all scenarios consider an important capacity and institutional strengthening program so as to develop the required competences. Without this, the proposed investments and actions will lead to an improved data production with little changes in decision making and, thus, very low to no impacts and economic benefits.

Scenario 1 (minimum investment) concentrates on increasing St. Lucia's effectiveness to make use of hydromet services in the short term. Hence, it focuses on capacity-building actions and proposes minimum equipment investments to achieve credible weather, water, and climate services. Its total implementation and investment and O&M costs are US$1.66 million and US$ 0.133 million, respectively (Table A1.5 and Table A1.6). This assessment considers that the expected result is an increase in the nation's effectiveness to reduce EAC to 20 percent.

Scenario 2 (modest investment) proposes investments to bring weather, water, and climate services to meet 75 percent of users' needs.[9] This scenario proposes actions for both WRMA and SLMS to modernize St. Lucia's hydromet services so as to implement an end-to-end system for forecasting and warning that maximizes lead time, accuracy, and reliability of delivering services to meet most users' needs. It is assumed that the implementation of this scenario is likely to increase extreme event damage loss reduction effectiveness to 30 percent, which is considered a satisfactory effectiveness (Malik et al. 2015; Rogers et al. 2016; Tsirkunov 2008; Tsirkunov et al. 2007). Its total implementation and investment costs are three times those of Scenario 1, reaching US$4.86 million (Table A1.5); its, total O&M costs are US$0.53 million (Table A1.6).

Finally, Scenario 3 (total investment) recommends investments to bring NMHS providers up to state-of-the-art data, forecasting, and warning services to respond to users' present and future needs,[9] assuming an increase St. Lucia's damage loss reduction effectiveness to 40 percent, which is considered as an adequate level in the literature. The required implementation and investment costs, to reach this objective, are US$6.80 million, which is 4 and 1.4 times the investment costs of Scenarios 1 and 2, respectively.

Table A1.5: Implementation Costs for Each Scenario

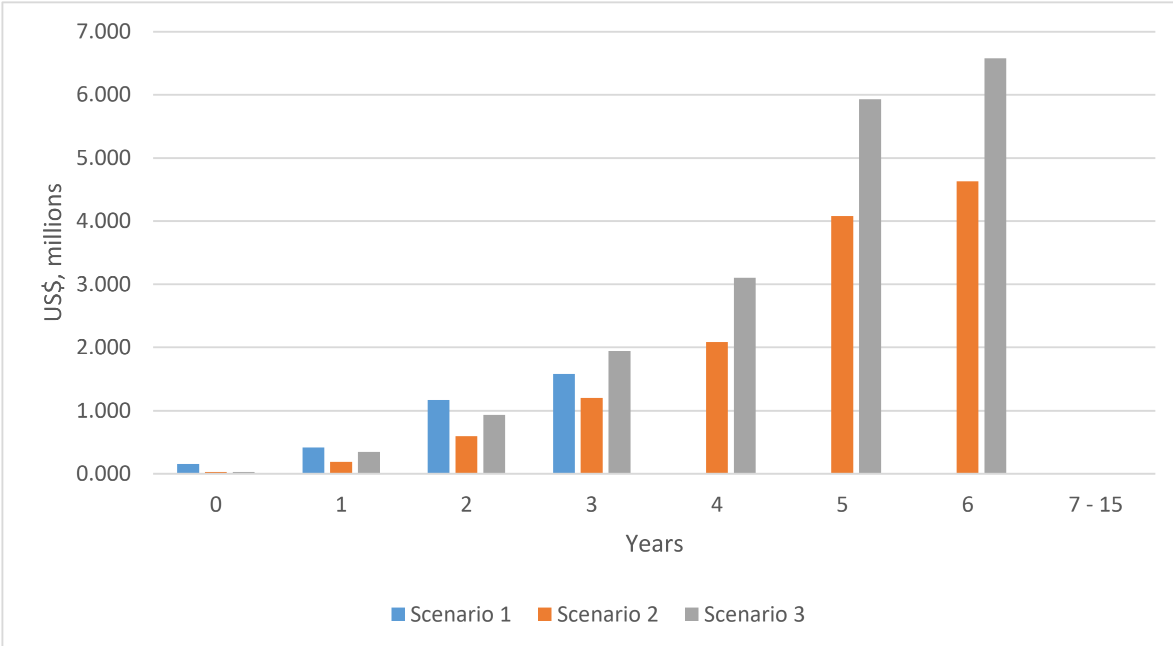
	Implementation Costs (US$, millions)		
	Scenario 1	**Scenario 2**	**Scenario 3**
Institutional strengthening	0.17	0.165	0.17
Strengthening observing, data analysis, and forecasting	1.12	4.040	5.86
Improved hydromet and climate services	0.30	0.425	0.45
Contingencies	0.08	0.232	0.32
Total implementation costs (US$, millions)	1.**66**	4.**862**	6.**80**

Table A1.6: O&M Costs for Each Scenario

	O&M Costs (US$, millions)		
	Scenario 1	**Scenario 2**	**Scenario 3**
Institutional strengthening	0.00	0.00	0.00
Strengthening observing, data analysis, and forecasting	0.12	0.49	0.75
Improved hydromet and climate services	0.01	0.02	0.02
Contingencies	0.01	0.03	0.04
Total implementation costs (US$, millions)	0.**13**	0.**53**	0.**81**

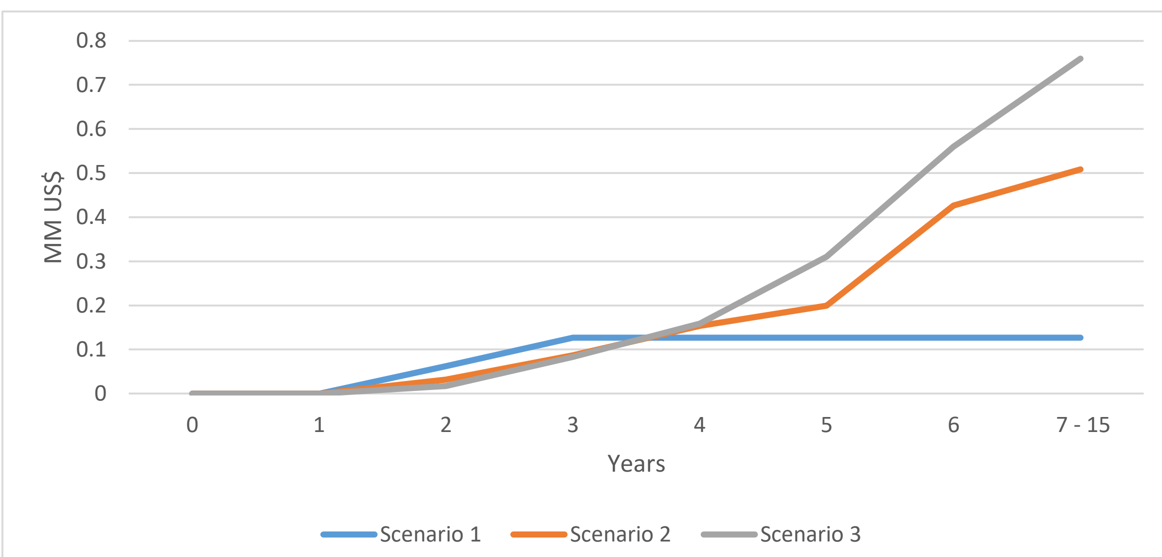
Following the implementation horizon of most hydromet improvement investments, the installation and strengthening of St. Lucia's hydromet infrastructure follows a 5–6-year horizon for Scenarios 2 and 3 (Figure A1.7). Since Scenario 1 proposes a set of actions to build institutional capacity and repair existing equipment, it can be implemented in a 2–3-year time frame.

Figure A1.7: Implementation Horizon for Each Scenario



O&M costs are considered to be 10–15 percent of capital cost of equipment, depending on the scenario. The average O&M cost of Scenario 1 is 8 percent, while for Scenarios 2 and 3 it is 11 percent and 12 percent, respectively. Since each scenario is implemented gradually, O&M costs increase progressively (Figure A1.8). Operations and maintenance begin during year 2 for all scenarios, since the first year is covered by the equipment's warrantee and stabilizes as of years 3 and 7 for Scenario 1 and Scenarios 2 and 3, respectively.

Figure A1.8: Gradual Increase in O&M Costs



Discounting future flows is required to conduct a C-B analysis when investments produce annual net benefits over time, as shown in the proposed scenarios in this Road Map. Many governments and international agencies, considering a uniform opportunity cost of capital, employ discount rates in the 7–14 percent range. This assessment considers a 10 percent discount rate and conducts a sensitivity analysis with 6 percent, 10 percent, and 14 percent discount rates.

The C-B ratio estimates are calculated considering the present value of the project's investment and O&M costs and the present value of benefits.

A.4. Economic Assessment of Strengthening Operational Hydrological, Weather, and Climate Services for St. Lucia

A.4.1. C-B Assessment

Benchmark economic assessment estimates associated with each of the proposed investment scenarios are presented in Table A1.7 to Table A1.10.

C-B Assessment Scenario 1

The annual estimated net benefits generated by (a) damage loss reduction, (b) lower average emergency expenditures, and (c) increased agricultural efficiency increase gradually over time and stabilize as of year 6 at US$1.397 million (Table A1.7), equivalent to 0.15 percent of St. Lucia's GDP.

Table A1.7: C-B Assessment of Scenario 1

Years	0	1	2	3	4	5	6–15
Annual Benefits (US$, millions)							
Average annual Cost (EAC)	0	1.000	6.000	10.000	13.000	14.700	15.700
AEE	0	0.140	0.810	1.360	1.760	1.200	2.130
APL (40% EAC and AEE)	0	0.456	2.724	4.544	5.904	6.360	7.132
Effectiveness	—	20%	20%	20%	20%	20%	20%
Total annual preventable loss	0	0.091	0.545	0.909	1.181	1.272	1.426
AVIF	0	0.004	0.027	0.045	0.058	0.066	0.070
Total annual benefits	0	0.096	0.572	0.953	1.239	1.338	1.498
O&M costs (US$, millions)							
Institutional strengthening	0	0	0	0	0	0	0
Strengthening observing, data analysis, and forecasting	0	0	0.050	0.115	0.115	0.115	0.115
Improved hydromet and climate services	0	0	0.012	0.012	0.012	0.012	0.012
Contingencies	0	0	0	0.0064	0.0064	0.0064	0.0064
Total O&M costs	0	0	0.**0620**	0.**1334**	0.**1334**	0.**1334**	0.**1334**
Implementation costs (US$, millions)							
Institutional strengthening	0.015	0.050	0.100	0	0	0	0

Years	0	1	2	3	4	5	6–15
Strengthening observing, data analysis, and forecasting	0.140	0.212	0.496	0.267	0	0	0
Improved hydromet and climate services	0	0	0.150	0.150	0	0	0
Contingencies	0	0	0	0.079	0	0	0
Total implementation costs (US$, millions)	0.155	0.262	0.746	0.**496**	0	0	0
NPV (US$, millions)	6.61						
C-B ratio	1:3.21						

The NPV[15] for this scenario is US$6.61 million, which yields a 1:4.2 C-B ratio; each dollar invested in this scenario will help avoid approximately US$4 of economic losses on average. This C-B ratio is close to the average value of the estimated C-B ratios found in the literature (1:6). Hence, significant benefits can be achieved by investing on capacity-building actions and the minimum required equipment to achieve credible weather, water, and climate services. This is mainly achieved by significantly increasing St. Lucia's effectiveness to reduce damages (ε) through capacity building. Therefore, the decision to implement Scenario 1 is clearly justified from an economic point of view.

However, this will not be the case if there is no commitment to allocate the required O&M budgets over time. For example, if the required budget is not satisfied as of year 7, the NPV of the investment will decrease by 76 percent and the C-B ratio will fall below 1:1.

C-B Assessment Scenario 2

The results of the economic assessment of implementing Scenario 2 are presented in (Table A1.8).

Table A1.8: C-B Assessment of Scenario 2

Years	0	1	2	3	4	5	6–15
Annual benefits (US$, millions)							
EAC(EAC)	0	1.000	6.000	10.000	13.000	14.700	15.700
AEE	0	0.140	0.810	1.360	1.760	1.200	2.130
APL (40% AAL and AEE)	0	0.456	2.724	4.544	5.904	6.360	7.132
Effectiveness	—	40%	40%	40%	40%	40%	40%
Total annual preventable loss		0.137	0.817	1.363	1.771	1.908	2.140
AVIF	0	0.004	0.027	0.045	0.058	0.066	0.070
Total annual benefits	0	0.141	0.844	1.408	1.829	1.974	2.210
O&M costs (US$, millions)							
Institutional strengthening	0	0	0	0	0	0	0
Strengthening observing, data analysis, and forecasting	0	0	0.027	0.072	0.133	0.179	0.489
Improved hydromet and climate services	0	0	0.005	0.015	0.020	0.020	0.020

[15] NPV = Present value of net benefits − Present value of investment costs.

Years	0	1	2	3	4	5	6–15
Contingencies	0	0	0	0	0	0	0.0254
Total O&M costs	0	0	0.032	**0.087**	0.154	0.199	0.5339
Implementation costs (US$, millions)							
Institutional strengthening	0.015	0.050	0.100	0.000	0	0	0
Strengthening observing, data analysis, and forecasting	0.010	0.116	0.204	0.533	0.628	2.000	0.550
Improved hydromet and climate services	0	0	0.100	0.075	0.250	0	0
Contingencies	0	0	0	0	0	0	0.232
Total implementation costs (US$, millions)	0.025	0.166	0.404	0.608	0.878	2.000	0.782
NPV (US$, millions)	7.279						
C-B ratio	1:2.3						

The NPV for this scenario is US$7.28 million, which yields a 1:2.3 C-B ratio. Consequently, each dollar invested to bring weather, water, and climate services to meet most users' needs by implementing an end-to-end system for forecasting and warning that maximizes lead time, accuracy, and reliability of delivering services generates US$2 of benefits. The decision to implement scenario 2 is thus justified from an economic point of view.[16]

It is important to note that the C-B ratio of this scenario is 46 percent lower than scenario 1 (**Error! Reference source not found.**). This can be explained by the fact that the present value of benefits for Scenario 2 is 48 percent higher compared to Scenario 1, while O&M and implementation costs increase by 178 percent and 165 percent, respectively.

Table A1.9: Percentage Change between Scenarios 2 and 1 (%)

NPV	12
Present value benefits	48
Present value O&M costs	178
Present value implementation costs	165
C-B ratio	-45

If Scenario 2 were implemented sequentially, once scenario 1 has been implemented, the C-B ratio would increase by 43 percent, from 1:2.3 to 1:3.34. This is a more effective strategy, from an economic point of view, of obtaining the expected results of Scenario 2.

C-B Assessment Scenario 3

The annual estimated net benefits generated by (a) damage loss reduction, (b) lower average emergency expenditures, and (c) increased agricultural efficiency increase gradually over time and stabilize as of year 6 at US$2.93 million (Table A1.10), equivalent to 0.32 percent of St. Lucia's GDP.

[16] The same caution must be taken to ensure a commitment to allocate the required O&M budget over time. In this case this is of greater importance than in Scenario 1, since O&M costs in this scenario are 3 times greater than in Scenario 1.

The NPV for this scenario is US$9.3 million, which yields a 1:2.2 C-B ratio. That is, investments needed to bring NMHS providers up to state-of-the-art data, forecasting, and warning services to meet users' present and future needs generate US$2 of benefits per dollar invested.[17]

Table A1.10: C-B Assessment of Scenario 3

Years	0	1	2	3	4	5	6–15
Annual benefits (US$, millions)							
EAC(EAC)	0	1.000	6.000	10.000	13.000	14.700	15.700
AEE	0	0.140	0.810	1.360	1.760	1.200	2.130
Annual potential preventable cost (40% AAL and AEE)	0	0.456	2.724	4.544	5.904	6.360	7.132
Effectiveness	0	40%	40%	40%	40%	40%	40%
Total annual preventable loss	0	0.182	1.090	1.818	2.362	2.544	2.853
AVIF	0	0.004	0.027	0.045	0.058	0.066	0.070
Total annual benefits	0	0.187	1.116	1.862	2.420	2.610	2.923
O&M costs (US$, millions)							
Institutional strengthening	0	0	0	0	0	0	0
Strengthening observing, data analysis, and forecasting	0	0	0.012	0.068	0.139	0.29	0.7395
Improved hydromet and climate services	0	0	0.005	0.015	0.02	0.02	0.02
Contingencies	0	0	0	0	0	0	0.038
Total O&M costs	0	0	0.0170	0.083	0.159	0.31	0.**805**
Implementation costs (US$, millions)							
Institutional strengthening	0.015	0.050	0.130	0.000	0	0	0
Strengthening observing, data analysis, and forecasting	0.010	0.270	0.358	0.933	0.965	2.675	0.650
Improved hydromet and climate services	0	0	0.1	0.075	0.2	0.15	0
Contingencies	0	0	0	0	0	0	0.324
Total implementation costs (US$, millions)	0.025	0.320	0.588	1.008	1.165	2.825	0.**974**
NPV (US$, millions)	9.081						
C-B ratio	1:2.2						

As with Scenario 2, the C-B ratio of Scenario 3 is 50 percent lower than Scenario 1. This can be explained by the fact that investment and O&M costs increase significantly more than benefits (Table A1.11).

[17] In this case it is of greater importance to ensure the required O&M than in Scenarios 1 and 2, since O&M costs in this scenario are 6 and 2 times greater than in Scenarios 1 and 2, respectively.

Table A1.11: Percentage Change between Scenarios 3 and 1 (%)

NPV	177
Present value benefits	226
Present value O&M costs	466
Present value implementation costs	342
C-B ratio	−50

Given that Scenario 1 is an integral part of Scenario 3, one could think of sequentially implementing Scenario 3 once Scenario 1 has been implemented. In this case, the C-B ratio will increase by 27 percent reaching 1:2.8. Finally, sequentially implementing Scenario 3 once Scenarios 1 and 2 have been implemented yields a C-B ratio for Scenario 3 of 1:4.4 (S.1 → S.2 →S.3). Thus, sequentially implementing Scenario 3 after Scenario 1 is an economically rational effective strategy of obtaining the expected results of this scenario. It is important to note, however, that the full benefits of Scenario 3 would materialize at a later date than if it were implemented directly.

A.4.2. Sensitivity Analysis

Sensitivity analysis is applied to assess the robustness of the economic assessment with respect to the key assumptions and parameters. The parameters considered in this sensitivity analysis are EAC from weather hazards (droughts, storms, hurricanes, and temperature extremes, among others), APL, and the discount rate (see Table A1.12).

Table A1.12: Key Parameters Considered in the Sensitivity Analysis

Parameter	Estimated Values	Minimum	Maximum
EAC	1.7% of GDP	1.4% of GDP	2% of GDP
APL	40% of annual loss	30% of annual loss	50% of annual loss
Discount rate (δ)	0.1	0.06	0.14

Sensitivity Analysis of Scenario 1

Table A1.13 to Table A1.15 summarize the results of the sensitivity analysis for Scenario 1.

With respect to the original parameter values, a reduction in the discount rate to 6 percent increases the C-B ratio by 13 percent, while it decreases by 30 percent when δ increases to 14 percent. The C-B ratio ranges between 1:3.90 and 1:5.01 (Table A1.13). On the other hand, should APL fluctuate between 30 percent and 50 percent, ceteris paribus, Scenario 1's C-B ratio varies between 1:3.36 and 1:5.46. Finally, considering an APL of 30 percent and δ of 14 percent), Scenario 1 presents a C-B ratio of 1:3.82; thus, even in a pessimist scenario, Scenario1's C-B ratio continues to be favorable.

Table A1.13: EAC 1.7% of GDP

		30%	40%	50%
Discount rate	6%	1:3.82	1:5.01	1:6.20
	10%	1:3.36	1:4.2	1:5.46
	14%	1:2.97	1:3.90	1:4.83

This sensitivity analysis is repeated for a low and high value for EAC (1.4 percent and 2 percent). The results are presented in Table A1.13 to Table A1.15. These results indicate that the economic assessment justifies investing in this scenario, since even in the most pessimist situation (EAC = 1.4 percent, APL = 30 percent, δ = 14 percent), the C-B ratio is 1:2.53.

Table A1.14: EAC 1.4% GDP

		30%	40%	50%
Discount rate	6%	1:3.26	1:4.27	1:5.28
	10%	1:2.87	1:3.76	1:4.64
	14%	1:2.53	1:3.23	1:4.10

Table A1.15: EAC 2.0% GDP

		30%	40%	50%
Discount rate	6%	1:4.38	1:5.76	1:7.14
	10%	1:3.85	1:5.07	1:6.28
	14%	1:3.41	1:4.47	1:5.56

Sensitivity Analysis of Scenario 2

Scenario 2 is also robust since the C-B ratio associated with the worst-case scenario (EAC = 1.4 percent, APL = 30 percent, δ = 14 percent) is 1:1.48. The C-B ratio fluctuates between 1:1.48 and 1:3.36 and, thus, investment in Scenario 2 is justifiable under all possible situations (see Table A1.16 to Table A1.18).

Table A1.16: EAC 1.4% GDP

		30%	40%	50%
Discount rate	6%	1:1.65	1:2.17	1:2.69
	10%	1:1.56	1:2.05	1:2.54
	14%	1:1.48	1:1.94	1:2.41

Table A1.17: EAC 1.70% GDP

		30%	40%	50%
Discount rate	6%	1:1.94	1:2.55	1:3.17
	10%	1:1.83	1:2.30	1:3.00
	14%	1:1.73	1:2.28	1:2.84

Table A1.18: EAC 2.0% GDP

		30%	40%	50%
Discount rate	6%	1:2.23	1:2.94	1:3.66
	10%	1:2.10	1:2.77	1:3.45
	14%	1:2.63	1:3.28	1:3.28

Sensitivity Analysis of Scenario 3

Similar conclusions are reached for Scenario 3, since the estimated C-B values range from 1:1.35 to 1:3.36 (Table A1.19 to Table A1.21).

Table A1.19: EAC 1.4% GDP

		30%	40%	50%
Discount rate	6%	1:1.51	1:2.00	1:2.47
	10%	1:1.42	1:1.88	1:2.34
	14%	1:1.35	1:1.77	1:2.22

Table A1.20: EAC 1.70% GDP

		30%	40%	50%
Discount rate	6%	1:1.77	1:2.35	1:2.92
	10%	1:1.68	1:2.2	1:2.76
	14%	1:1.60	1:2.11	1:2.62

Table A1.21: EAC 2.0% GDP

		30%	40%	50%
Discount rate	6%	1:2.04	1:2.70	1:3.36
	10%	1:1.93	1:2.56	1:3.18
	14%	1:1.83	1:2.43	1:3.02

A.5. Conclusions

The proposed hydromet investments generate significant benefits by reducing damage losses from extreme hydrological and meteorological events and increased production efficiency, particularly for agriculture, by implementing an end-to-end system for forecasting and warning that maximizes lead time, accuracy, and reliability of delivering services to meet most users' needs (Table A1.22).

Table A1.22: C-B Ratios for Each Scenario

	Scenario 1	**Scenario 2**	**Scenario 3**
NPV (US$, millions)	6.607	7.279	9.081
C-B ratio	1:4.2	1:2.3	1:2.2

These results justify obtaining the financial support to improve existing hydromet activities as well as to modernize the system so as to implement state-of-the-art data, forecasting, and warning services.

The results also indicate that a sequential implementation of the scenarios may be a favored approach. This is particularly important due to the actual low effectiveness in reducing potential damages and increasing production efficiency due to

(a) Technical limitations of data availability and forecasting tools;

(b) Lack of data exchange mechanisms;

(c) Lack of up-to-date forecasting models;

(d) Insufficient education and training skills of the forecasters; and

(e) Lack of website dissemination capabilities.

Scenario 1 focuses on the short-term improvement of St. Lucia's effectiveness to increase the benefits from hydromet services.

It is important to note that not all economic benefits have been estimated, and thus these results represent a lower-bound estimate. Some of the nonquantified benefits are

(a) Reduced morbidity and mortality;

(b) Increased water supply security; and

(c) Increased ecosystem conservation.

These were not included due to data limitations and time restrictions that allowed assessments based on secondary data. In future assessments, it will be important to consider these.

However, these benefits will not materialize if the actual decrease in O&M budgets of hydromet services providers continues over time and if there is no commitment to allocate the required O&M budgets. O&M budgets for hydromet data producers reduced 75 percent between 2014 and 2015, falling from US$60,000/year to US$15,000/year, and this has not recuperated. O&M budgets for the proposed scenarios are 8.5, 32.5, and 34.5 times the actual O&M allocated budget. If the required budget is not satisfied as of year 7, the NPVs of the investment in all scenarios will significantly decrease and the C-B ratios will fall below 1:1.

A.6. Economic Data

A.6.1. St. Lucia's GDP

Table A1.23: St. Lucia's GDP (US$, millions)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
National	844.80	902.76	914.47	954.78	950.37	943.25	949.47	937.97	918.53	912.53	924.41
Agriculture, livestock, forestry, fishing	29.57	32.51	32.69	41.89	40.08	28.33	24.97	27.81	29.26	25.95	27.77
Hotels and restaurants	95.52	93.42	93.99	90.95	90.13	96.63	91.55	92.64	96.99	101.14	101.12
Transport	103.60	100.03	117.70	120.34	120.01	119.02	112.75	110.74	109.51	120.46	124.32

Source: St. Lucia Economic Review Appendix 2015.

Table A1.24: Sectoral Shares of GDP (%)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Agriculture, livestock, forestry, fishing	3.5	3.6	3.6	4.4	4.2	3.0	2.6	3.0	3.2	2.8	3.0
Hotels and restaurants	11.3	10.3	10.3	9.5	9.5	10.2	9.6	9.9	10.6	11.1	10.9
Transport	12.3	11.1	12.9	12.6	12.6	12.6	11.9	11.8	11.9	13.2	13.4

Source: St. Lucia Economic Review Appendix 2015.

A.6.2. Damage and Loss Assessments and Emergency Expenses

Table A1.25: Emergency Expenses (US$, millions)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Total	—	3.35	3.44	0.20	3.74	1.97	1.31	1.98	—	1.53	1.75
Share of GDP	—	0.37%	0.38%	0.02%	0.39%	0.21%	0.14%	0.21%	—	0.17%	0.19%

Table A1.26: Extreme Weather Loss Assessments

Weather Event	Date	Economic Damage		References
		Total Damage (US$, millions)	% GDP	
Hurrican Allen	1980	400	305	World Bank 2015
Hurrican Debby	1994	95	18	World Bank 2015
Storm Lily	2002	20.0	2.2	Harmeling and Eckstein 2012; Kreft et al. 2013
Hurricane Ivan	2004	2.6	0.3	Harmeling and Eckstein 2012; Kreft et al. 2013
Hurricane Dean	2007	18.8	2.1	World Bank 2015
Drought	2011	1.3	0.2	MALFF/FAO 2011
Hurricane Tomas	2010	336.2	43.4	Eclac 2011
Christmas Trough	2013	99.9	10.9	World Bank 2014

Torrential Rains	2014	34.3	3.8	MIPSAT 2014
Heavy Rains	2015	1.3	0.2	MIPSAT 2015
Hurricane Mathew	2016	164.9	17.7	MIPSAT 2016

Annex 2: Hydrometeological Stations in St. Lucia

Station_ID	Ownership	Functionality	Type	Watershed	Station_Name
36-R-1	WRMA station	Nonfunctional	Rain gauge	Bois D'Orange	Trouya
36_WL_1	WRMA station	Nonfunctional	Water level radar Sensor	Bois D'Orange	Corinth Water Level
36_WL_2	WRMA station	Nonfunctional	Water level radar Sensor	Bois D'Orange	Grand Riviere Water Level
36_R_2	WRMA station	Nonfunctional	Rain gauge	Bois D'Orange	Monier
27-R-1	WRMA station	Nonfunctional	Rain gauge	Canaries	Desraches
27-AWS-1	MET station	Functional	AWS	Canaries	Desraches
27-AWS-2	WRMA station	Functional	AWS	Canaries	Canaries
14-WL-1	WRMA station	Nonfunctional	Rain gauge	Canelles	Canelles
37-R-1	WRMA station	Nonfunctional	Rain gauge	Cap	Cap Estate
34-M-1	MET station	Functional	Agromet Station	Castries	Vigie Airport
34-R-1	WRMA station	Functional	Rain gauge	Castries	Government House
34-M-2	WRMA station	Functional	Rain gauge	Castries	George V Park
35-AWS-1	MET Station	Functional	AWS	Castries	Bocage
34_WL_1	WRMA station	Functional	Water level radar Sensor	Castries	Marchard
35-M-1	WRMA station	Functional	Agromet Station	Choc	Union Agr Station
35-SP-1	WRMA station	Functional	Soil Mositure Probe	Choc	Union Soil Probe
22-R-1	WRMA station	Nonfunctional	Rain gauge	Choiseul/Trou Barbet/Tro	Delcer School
23-R-2	WRMA station	Functional	Rain gauge	Choiseul/Trou Barbet/Tro	Barthe Nursery
33-R-1	WRMA station	Nonfunctional	Rain gauge	Cul de Sac	Soucis
33-R-2	WRMA station	Functional	Rain gauge	Cul de Sac	Bexon
33-WL-1	WRMA station	Nonfunctional	Rain gauge	Cul de Sac	Deglos
33-AWS-1	MET Station	Functional	AWS	Cul de Sac	Forestierre
33-AWS-1	MET Station	Functional	AWS	Cul de Sac	Soucis
4-AWS-1	MET Station	Functional	AWS	Cul de Sac	Piton Flore
3-AWS-1	WRMA station	Functional	AWS	Dauphins	Monchy Rain Guage
3-WL-1	WRMA station	Functional	Water level radar Sensor	Dauphins	Monchy Water Level
3-SP-1	WRMA station	Functional	Soil Mositure Probe	Dauphins	Monchy Soil Probe
7-R-1	WRMA station	Nonfunctional	Rain gauge	Dennery	Errard Estate
7-AWS-1	MET Station	Functional	AWS	Dennery	Errard Estate
7-AWS-2	MET Station	Functional	AWS	Dennery	Bordelais, Dennery
21-M-1	WRMA station	Non Functional	Rain gauge	Doree	Saltibus
21-SP-1	WRMA station	Functional	Soil Moisture Probe	Doree	Doree Soil Probe
33-R-3	WRMA station	Nonfunctional	Rain gauge	Cul de Sac	Barre de L'Isle

6-WL-1	WRMA station	Nonfunctional	Rain gauge	Fond D'or	Mabouya
33-R-3	MET Station	Functional	AWS	Cul de Sac	Barre de L'Isle
6-WL-1	WRMA station	Functional	Water level radar Sensor	Fond D'or	Alba Bridge Water Level
6-M-1	WRMA station	Nonfunctional	Agromet Station	Ford D'or	CARDI
4-AWS-2	MET Station	Functional	AWS	Grand Anse/Louvet	Desbarras
29-R-1	WRMA station	Nonfunctional	Rain gauge	Grande Riviere de Anse	Anse la Raye
29-AWS-1	MET Station	Nonfunctional	AWS	Grande Riviere de Anse	Anse La Raye #1
29-AWS-2	MET Station	Functional	AWS	Grande Riviere de Anse	Anse La Raye #2 (aka Venus)
23-R-1	WRMA station	Functional	Rain gauge	L'Ivrogne	Union Vale Estate
10-AWS-1	WRMA station	Functional	AWS	Mamiku/Patience	Patience Estate
9-R-1	WRMA station	Functional	Rain gauge	Mamiku/Patience	Mamiku
26-R_1	MET Station	Functional	AWS	Mamin/Mahaut	Bouton
4-R-2	WRMA station	Functional	Rain gauge	Marquis	Marquis Babonneau
14-R-1	WRMA station	Functional	Rain gauge	Micoud/Ravine Bethel	Blanchard
13-R-1	MET Station	Functional	AWS	Micoud/Ravine Bethel	Blanchard
15-M-1	MET station	Functional	Agromet Station	Roame/Rugeine/Palmiste/S	Hewanorra Airport
15-M-1	MET Station	Functional	AWS	Roame/Rugeine/Palmiste/S	Hewanorra Base Station
15-AWS-1	MET Station	Functional	AWS	Roame/Rugeine/Palmiste/S	Moule A Chique
31-M-1	WRMA station	Functional	Rain gauge	Roseau	Roseau
31-R-2	WRMA station	Functional	Rain gauge	Roseau	Millet
31-AWS-1	MET Station	Functional	AWS	Roseau	Millet
1-AWS-1	MET station	Functional	AWS	Salee/Lapins	Rodney Bay
1-R-1	WRMA station	Functional	Rain gauge	Salee/Lapins	Rodney Bay
25-R-2	WRMA station	Functional	Rain gauge	soufriere	Soufriere
12-R-1	WRMA station	Nonfunctional	Rain gauge	Troumassee	Troumassee Estate
12-R-1	WRMA station	Nonfunctional	Rain gauge	Troumassee	Edmund Forest
12-R-2	WRMA station	Nonfunctional	Rain gauge	Troumassee	Mahaut
12-AWS-1	MET Station	Functional	AWS	Troumassee	Edmund Forest
12-AWS-2	MET Station	Functional	AWS	Troumassee	Mahaut
16-R-2	WRMA station	Functional	Rain gauge	Vieux Fort	Grace
16-R-1	MET Station	Functional	AWS	Vieux Fort	Grace

Annex 3: Sample Hydromet Survey

Hydrologic Services Survey for St Lucia
September 28, 2016

This survey is a general questionnaire that was created for users of both meteorological and hydrological (weather, water and climate) products and services. The prime use of this survey is to understand users' general use and satisfaction of the current products and services they receive as well as determining what additional data, information or forecasts users would like to receive to improve their decision making and use of the forecasts to either improve productivity or reduce risk. Your answers will be used to generate user needs demand, gaps and priorities which will then be used assess current hydromet services for St. Lucia. Based on the needs assessment, resultant recommendations will be produced in a Road Map or Strategic plan to improve the quality and delivery of hydromet services for the country.

The World Bank WPP of the Water Global Practice and the Bank's Global Facility for Disaster Risk Reduction (GFDRR) are conducting a global hydrologic services assessment for selected countries around the world that will include St. Lucia. Information is needed on the types of hydromet data collected, processed, and distributed as well as forecasts and products generated. Tables are included to be filled out that define both hydrologic and meteorological information that are collected. For users that also collect primarily hydromet data, forecasts, and products additional information is needed. Tables are included to be filled out that define your organization's collection of either hydrologic and meteorological information or both, in addition to information you receive from both WRMA and SLMS. If you operate your own rain gage, stream gage, or weather observation network, this information needs to be collected from separate tables not included in this survey. Separate tables are located in file labeled "Users that are also data producers." Please only fill out those tables that are applicable for your organization. For example, if you have no stream gages, ignore the respective table.

1) Name of your organization, Type of organization (governmental, non-government, private, association, educational, international, etc.), Address, Name of representative

2) What does organization do? Ex. Farming, energy production, flood control, water resources management, Disaster Risk Reduction

3) What kind of Hydromet information products and services do you now receive from WRMA or SLMS? How is this information used?

4) Is the service provided at the right times and with the right frequency? Or do you need information earlier and/or more frequent?

5) Are the products and service providing you with information at the right locations/area? And is the resolution (number of locations) good enough?

6) Do you currently use any verification/calibration metrics in order to check how accurate an observation, forecast or warning is? Is this type of accuracy information used in your decision making process?

7) Is the format in which the information is provided to you sufficient or do you want information presented in a different way (e.g. a map or a graph)?

8) How easily accessible is information? Should the dissemination of the information be organized differently?

9) Is the information provided easy to use, or should it be more concise, more detailed, and easier to read?

10) Provide an overall rating for the service you receive.

1: End-User operations/activities can only be performed on a very rudimentary level,

2: End-users operations/activities can be performed on a satisfactory level,

3: End-users needs are fully met.

11) If a hydromet or hydrology forecast or warning service is inaccurate, not on time, or not for the right community or river, what is the magnitude of the consequences for you as a user organization?

12) What Hydro-Met Services would you like to receive in order to improve your agency’s performance?

13) Do you foresee any new activity for your Agency in the future that requires “NEW” Hydro- Met Services/Products? If yes, please provide a description of both the process/tasks and Hydro-Met Service/Products.

14) In your opinion how would you like to receive Hydrologic Services/Products (please describe the type of service/product, format, frequency, etc.)

15) Any other useful suggestions to improve the quality and quantity of data or forecast service

Annex 4: References

Adams, R. M., K. J. Bryant, B. A. Mccarl, D. M. Legler, J. O'Brien, A. Solow, and R. Weiher. 1995. "Value of Improved Long-Range Weather Information." *Contemporary Economic Policy* 13: 10–19.

Adams, R. M., L. L. Houston, B. A. Mccarl, M. Tiscareño, J. Matus, and R. F. Weiher. 2003. "The Benefits to Mexican Agriculture of an El Niño-Southern Oscillation (ENSO) Early Warning System." *Agricultural and Forest Meteorology* 115: 183–194.

ADB (Asian Development Bank). 2002. *Songhua River Flood Management Sector Project*. Asian Development Bank.

Cabot Venton, C., and P. Venton. 2010. "Disaster Preparedness Programmes in India: A Cost Benefit Analysis." Humanitarian Practice Network Paper 49. Overseas Development Institute, Humanitarian Practice Network, London. http://odihpn.org/wp-content/uploads/2004/12/networkpaper049.pdf.

Carsell, K. M., N. D. Pingel, and D. T. Ford. "Quantifying the Benefit of a Flood Warning System." *Natural Hazards Review* 5: 131–140.

CCRIF (Caribbean Catastrophe Risk Insurance Facility). 2013. *Country Risk Profile Saint Lucia*. *Country Risk Profiles.* Grand Cayman, Cayman Islands: Caribbean Catastrophe Risk Insurance Facility.

ECLAC (Economic Commission for Latin America and the Caribbean). 2011. *Macro Socio-Economic And Evironmental Assessment of the Damage and Losses Caused by Hurricane Tomas: A Geo-Environmental Disaster Towards Resilience.* Trinidad and Tobago: Subregional Headquarters for the Caribbean ECLAC.

EWC III (Third International Conference on Early Warning). 2006. *Developing Early Warning Systems: A Checklist.* Bonn, Germany: EWC III.

Freebairn, J. W., and J. W. Zillman. 2002. "Economic Benefits of Meteorological Services." *Meteorological Applications* 9: 33–44.

García, Luis E., Diego J. Rodríguez, Marcus Wijnen, and Inge Pakulski, eds. 2016. *Earth Observation for Water Resources Management: Current Use and Future Opportunities for the Water Sector*. Washington, DC: World Bank Group. doi:10.1596/978-1-4648-0475-5. License: Creative Commons Attribution CC BY 3.0 IGO. Available as a PDF e-book in the World Bank Open Knowledge Repository (OKR): https://openknowledge.worldbank.org/handle/10986/22952

GFDRR (Global Facility for Disaster Reduction and Recovery). 2010. *Disaster Risk Management in Latin America and the Caribbean Region: GFDRR Country Notes. St. Lucia*. Washington, DC: World Bank.

Gunasekera, D. 2003. "Measuring the Economic Value of Meteorological Information." *Bulletin of the World Meteorological Organization* 52: 366–372.

Hallegatte, S., and V. Przyluski. 2010. "The Economics of Natural Disasters: Concepts and Methods." World Bank Policy Research Working Paper Series, 1: 29.

Harmeling, S., and D. Eckstein. 2012. “Global Climate Risk Index 2013: Who Suffers Most From Extreme Weather Events? Weather-Related Loss Events in 2011 and 1992 to 2011.” Briefing Paper. Germanwatch, Onn, Germany.

Hsiang, S. M., and A. S. Jina. 2014. *The Causal Effect of Environmental Catastrophe on Long-run Economic Growth: Evidence from 6,700 Cyclones*. National Bureau of Economic Research.

Kite-Powell, H. L., and A. R. Solow. 1994. A Bayesian Approach to Estimating Benefits of Improved Forecasts. *Meteorological Applications* 1: 351–354.

Kreft, S., D. Eckstein, L. Junghans, C. Kerestan, and U. Hagen. 2013. “Global Climate Risk Index 2015: Who Suffers Most from Extreme Weather Events? Weather-Related Loss Events in 2013 and 1994 to 2013.”

Lambert, D. K., B. A. Mccarl, Q. He, M. S. Kaylen, W. Rosenthal, C.-C. Chang, and W. Nayda. 1995. “Uncertain Yields in Sectoral Welfare Analysis: an Application to Global Warming.” *Journal of Agricultural and Applied Economics* 27: 423–436.

Lazo, J. K., R. S. Raucher, T. J.Teisberg, C. J. Wagner, and R. F. Weiher. 2008. “Primer on Economics for National Meteorological and Hydrological Services.” Sponsored by the World Meteorological Organization Voluntary Cooperation Program, managed by the National Weather Service International Activities Office and National Center for Atmospheric Research, Societal Impacts Program. February 27.

Letson, D., D. S. Sutter, and J. K. Lazo. 2007. “Economic Value of Hurricane Forecasts: An Overview and Research Needs.” *Natural Hazards Review* 8: 78–86.

Lindell, M. K., and C. S. Prater. 2003. “Assessing Community Impacts of Natural Disasters.” *Natural Hazards Review* 4: 176–185.

Malik, A. S., G. S. Amacher, J. Russ, E. E. Esikuri, and K. Ashida Tao. 2015. *Framework for Conducting Benefit-Cost Analyses of Investments in Hydro-Meteorological Systems.*

MIPSAT. 2014. *Damage Assessment Report Heavy Rains* 2014. Saint Lucia: Technical Department, MIPSAT.

———. 2015. *Report On Damages Caused By Heavy Rains Of November 6*. 2015. Saint Lucia: Technical Department, MIPSAT.

———. 2016. *Post Storm Matthew Assessment*. Saint Lucia: Technical Department, MIPSAT.

NEMO (National Emergency Management Organisation) 2014. *Saint Lucia: Country Document for Disaster Risk Reduction*. Saint Lucia: NEMO.

O’Brien, J. 1993. *Report of the Workshop on the Economic Impact of ENSO Forecasts on the American, Australian, and Asian Continents*. Tallahassee, FL: Florida State University.

Parker, D. J., S. J. Priest, and S. M. Tapsell. 2009. “Understanding and Enhancing the Public's Behavioural Response to Flood Warning Information.” *Meteorological Applications* 16: 103–114.

Pelling, M., A. Özerdem, and S. Barakat. 2002. "The Macro-economic Impact of Disasters." *Progress in Development Studies* 2: 283–305.

Perrels, A., T. Frei, F. Espejo, L. Jamin, and A. Thomalla. 2013. "Socio-economic Benefits of Weather and Climate Services in Europe." *Advances in Science and Research* 10: 65–70.

Rasmussen, T. 2006. "Natural Disasters and their Macroeconomic Implications." In *The Caribbean: From Vulnerability to Sustained Growth.* IMF.

Ray, Patrick A., and Casey M. Brown. 2015. *Confronting Climate Uncertainty in Water Resources Planning and Project Design: The Decision Tree Framework.* Washington, DC: World Bank. doi:10.1596/978-1-4648-0477-9. License: Creative Commons Attribution CC BY 3.0 IGO. Available as a PDF e-book in the World Bank Open Knowledge Repository (OKR):https://openknowledge.worldbank.org/handle/10986/22544

Rogers, D., M. I. Smetanina, and V. V. Tsirkunov, 2016. "Improving Weather, Climate, and Hydrological Services Delivery in Central Asia (Kyrgyz Republic, Republic of Tajikistan, and Turkmenistan)." Working Papers. World Bank, Washington, DC.

Solow, A. R., R. F. Adams, K. J. Bryant, D. M. Legler, J. J. O'Brien, B. A. Mccarl, W. Nayda, and R. Weiher. 1998. "The Value of Improved ENSO Prediction to US Agriculture." *Climatic Change* 39: 47–60.

Sorensen, J. H., and D. S. Mileti. 1988. "Warning and Evacuation: Answering Some Basic Questions."

Stewart, T. R. 1997. "Forecast Value: Descriptive Decision Studies." In *Economic Value of Weather and Climate Forecasts,* edited by R. W. Katz and H. Murphey. New York: Cambridge University Press.

Tammelin, B. 2015. *Strengthening the Hydromet Services in South Eastern Europe*. South Eastern Europe Disaster Risk Migitation and Adaptation Programme, World Meteorological Organization.

Tanner, T., S. Surminski, E. Wilkinson, R. Reid, J. Rentschler, and S. Rajput. 2015. "The Triple Dividend of Resilience: Realising Development Goals through the Multiple Benefits of Disaster Risk Management." *GFDRR*.

Tsirkunov, V. 2008. "Use of Economic Analysis in Strengthening NHMS." WMO Regional Seminar on Strategic Capacity Development of NMHS in Redgional Association II (Asia). Tashkent, Uzbekistan.

Tsirkunov, V., S. Ulatov, M Smetanina, and A. Korshunov. 2007. *Customizing Methods for Assessing Economic Benefits of Hydromet Services and Modernization Programmes: Benchmarking and Sector-specific Assessment.* Geneva, Switzerland: World Meteorological Organization.

Tsirkunov, V. V., A. Korshunov, M. Smetanina, and S. Ulatov. 2006. *Assessment of Economic Efficiency of Hydro-meteorological Services in the Countries of the Caucasus Region*. Report prepared as part of Weather/Climate Services pilot study in the countries of Europe and Central Asia. World Bank.

UNISDR (United Nations International Strategy for Disaster Reduction). 2015. *Making Development Sustainable: The Future of Disaster Risk Management.* Global Assessment Report on Disaster Risk Reduction. Geneva, Switzerland: United Nations Office for Disaster Risk Reduction (UNISDR).

Van Westen, C. J. 2016. “National Scale Landslide Susceptibility Assessment for Saint Lucia. CHARIM Caribbean Handbook on Risk Information Management.” World Bank GFDRR, ACP-EU Natural Disaster Risk Reduction Program, 94.

Vivo, G. 2015. “Strengthening Hydro-met Services to Enhance Resiliency of Small Island States.” World Bank.

Weiher, R., J. K. Lazo, and L. G. Chestnut. 2002. *Economic Value of Current and Improved Weather Forecasts in the US Household Sector.* Boulder: Stratus Consulting.

World Bank. 2005. “Project Appraisal Document On A Proposed Loan In The Amount Of US$80 Million To The Russian Federation For A National Hydromet Modernization Project.” World Bank.

———. 2014. *Flood Event of December 24–25.* 2013. A Report by the Government of Saint Lucia and the World Bank. Washington, DC: World Bank.

———. 2015. *Summary Diagnostic Report Saint Lucia Disaster Risk Financing Technical Assistance Project.* Washington, DC: World Bank.

———. 2016. *Saint Lucia Hurricanes And Earthquakes Risk Profile. Country Disaster Risk Profile.* World Bank.

WRMA (Water Resources Management Agency). 2004. “National Water Policy of St. Lucia.”

WRMU (Water Resources Management Unit). 2001. *National Report on Integrating the Management of Watersheds and Coastal areas in Saint Lucia.* Ministry of Agriculture, Forestry, and Fisheries Government of St. Lucia.

Wu, X., G. Wei, L. Yang, J. Guo, H. Lu, Y. Chen, and J. Sun. 2014. “A Comprehensive Estimation of the Economic Effects of Meteorological Services Based on the Input-Output Method.” *The Scientific World Journal*.

Zimmermann, M., and F. Stössel, 2011. *Disaster Risk Reduction in International Cooperation: Switzerland‘s Contribution to the Protection of Lives and Livelihoods.* Bern: Swiss Agency for Development and Cooperation.