Terms of reference

Consultancy Services for Development of Pre-Feasibility and Feasibility Studies for Flood Mitigation Measures in Castries and Anse La Raye

Saint Lucia Flood Risk Project

1. Background

Saint Lucia is a volcanic mountainous island country of the West Indies in the Eastern Caribbean between latitude 14°N and longitude 61°. The island area measures 617 km^2. Its population amounts to nearly 180,000 people located mainly in the coastal zones.

Saint Lucia's climate is classified as tropical rainforest, with a wet season running administratively from 1 June to 30 November under the influence of southeast trade winds and a dry season from 1 December to 31 May when the trade winds shift to the northeast. The average annual rainfall is about 2000 mm, and the temperature is fairly constant throughout the year varying between 30 °C during the day and 24 °C at night.

Located in the Atlantic Hurricane Belt, the island is exposed to tropical storms and hurricanes. Flash floods from heavy rainfall are the most dominant source of flooding, exacerbated by the tide and storm surges, which impede gravity drainage in the coastal zone. Recent extreme flooding events took place in 1980 (Hurricane Allen), 1994 (Tropical Storm Debby), 2010 (Hurricane Tomas), 2013 (Christmas Eve trough), and recently on 6 November 2022 (heavy rains). These events caused major damage, particularly in the low-lying coastal zones where most of the population lives.

Under the World Bank's Global Facility for Disaster Reduction and Recovery's (GFDRR) Global Program of Nature-Based Solutions (NBS) for Climate Resilience, an opportunity scan for this methodology was carried out for Castries and Anse La Raye 2023 (see Figure 1) in October 2023. The Saint Lucia Flood Risk Project is a follow-up to the scan aiming at the design of adequate, cost-effective, environmental, and social friendly, sustainable flood protection and urban drainage interventions to reduce the risk of flooding in the Project Areas, by limiting its probability and reducing the vulnerability for current and future climatic conditions.

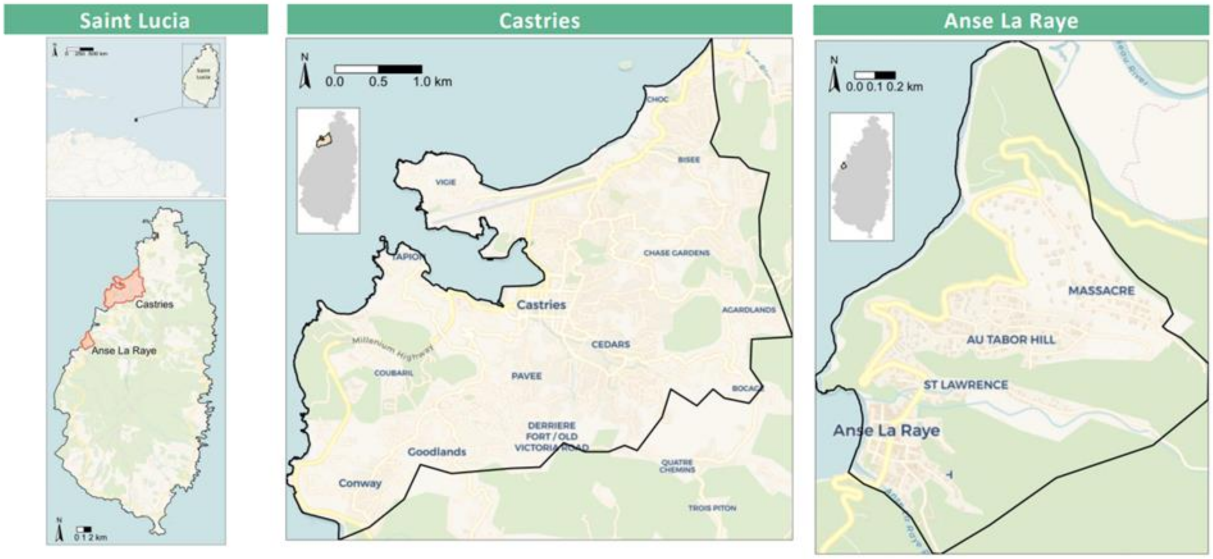

Figure 1. Layout of the Project Areas Castries and Anse La Raye

2. Project Areas

Project Area ***Castries*** (Figure 1), covers the capital of Saint Lucia, where about 1/3 of the island population lives. This heavily urbanized area is drained by the Castries River, from part of the coastal zone. Its basin is bordered by the catchments of the Choc (northeast) and Cul de Sac (south) Rivers. Most vulnerable to flooding is the area along the river and, particularly, the low-lying Central Business District between King Georg V Gardens (designated as a retention pond) and the river mouth, where pumping stations, when functional/operational, assist in the evacuation of flood water(See Figure 2). Flood water discharge is often impeded locally by clogged drains (sediment and debris), blocked trash screens (solid waste) and limited capacities of culverts and bridges. Given the high degree of urbanization in Castries, the opportunities for stream renaturation to reduce flood risk may be limited. However, NBS opportunities exist for the creation of open green and multipurpose spaces (e.g. King Georg V Gardens), bioretention areas, and green corridors.

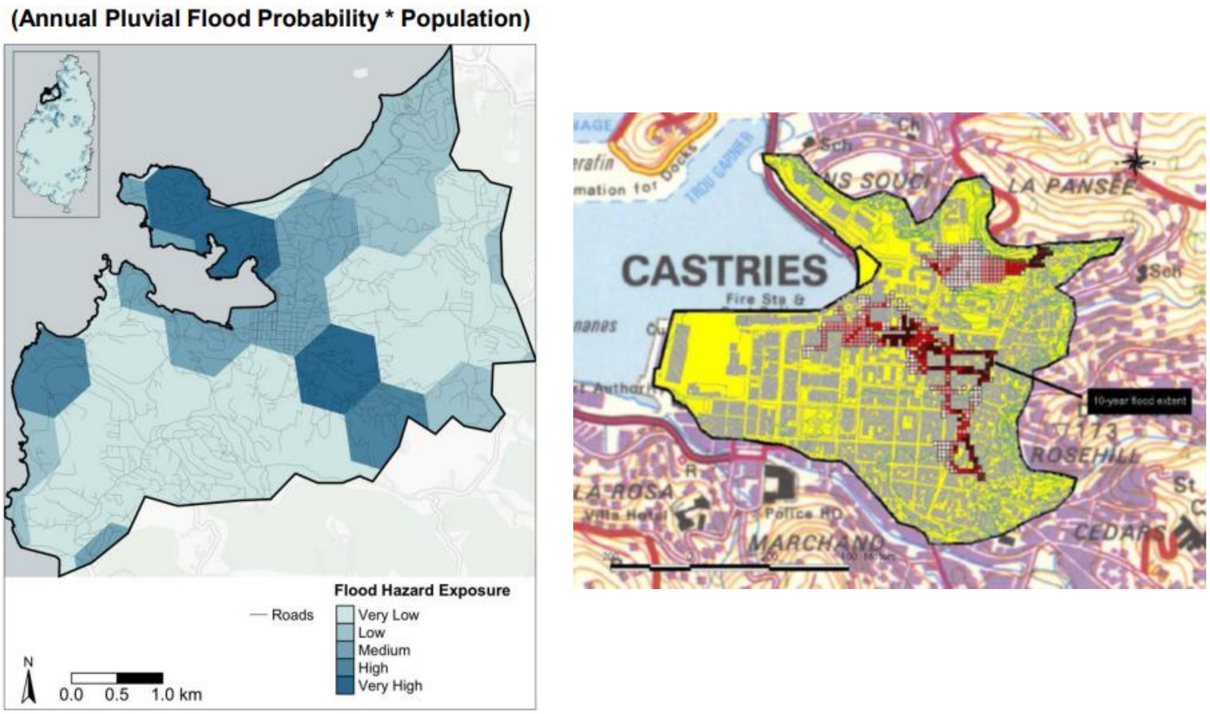

Figure 2. Flood Hazard Exposure Castries

Project Area ***Anse La Raye*** (Figure 1) comprises the fishing town of Anse La Raye. It is located some 16 km south of the capital. The village has a population equal to 10% of the Castries area. The northern part of this rural area is drained by the Petite Rivière and the southern part by the Grande Rivière. The Project Area borders the catchment of the Roseau River, which, area-wise, is the largest of the island. The flood hazard in this project area is high, mainly along the Petite Rivière, due to insufficient conveyance capacity towards the mouths of both rivers in the village, caused by flow obstructing culverts and road crossings (Figure 3). There are opportunities for NBS to reduce the flood risk, particularly in the upper reaches.

In both project areas, the tide, which defines the downstream water level boundary, at times hampers the discharge of flood water by backwater, particularly in combination with wind. Flooding along the coastal zone due to high tidal levels exacerbated by storm surge may, in the future, become an additional risk factor.

Waste water management in the Project Areas is cumbersome. Only a very limited number of households are connected to a sewer system (in 2010 the percent of households was 9.7 % in Castries and 1.4 % in Anse La Raye). Most households have a septic tank or make use of pit latrines. Treatment of the waste is limited and disappears either in the environment or in the open water drains. These conditions worsen the vulnerability of flooding, which may have serious consequences for public health and the water quality conditions in the city and coastal zone.

Landslides are also a serious problem in Saint Lucia. Areas exposed to them have been identified, and soil stabilization needs to be addressed to safeguard private property and public infrastructure

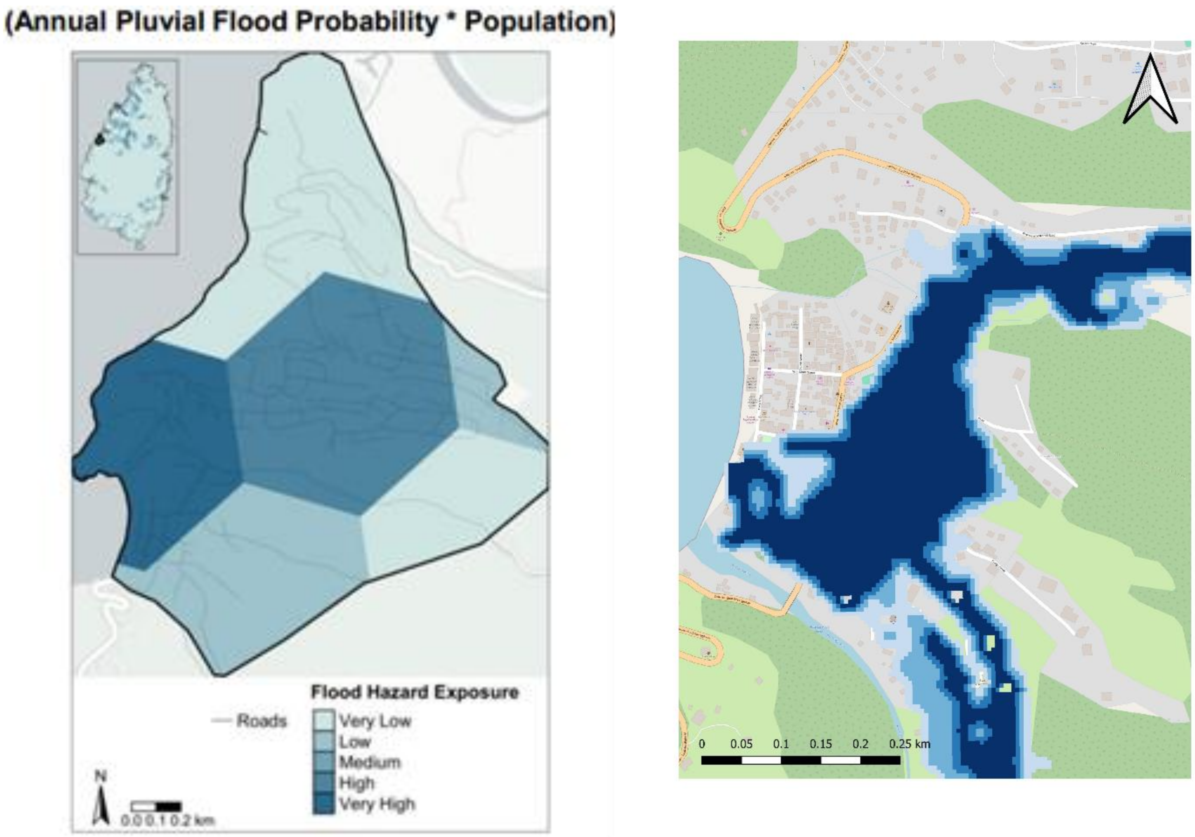

Figure 3. Flood Hazard Exposure Anse La Raye

3. Project objectives

The objectives of the Saint Lucia Flood Risk Project include:

- Mapping, describing, and assessing the existing flood protection and micro and macro drainage infrastructure, its bottlenecks, and maintenance conditions.
- Analyzing the current and future flood risk in the two Project Areas with the aid of an appropriate computational framework;
- Identifying all possible flood risk mitigation interventions for the two Project Areas by applying suitable hydrological/ hydraulic model/s;
- Developing, in close interaction with the Stakeholders, sustainable flood protection and drainage interventions, structural and non-structural (including NBS), that are adequate, cost-effective, environmentally and socially friendly, and economically feasible for the country, ideally to manage flood risk;
- Conducting feasibility studies for the identified flood risk mitigation interventions;
- Evaluating/upgrading the flood early warning system;
- Evaluating/upgrading the drainage system maintenance instructions/ manual;
- On-the-job training of counterpart staff to build capacity in flood risk analysis, in the development and design of interventions, and the execution of the necessary maintenance activities.

4. Approach

To achieve the above objectives, the following approach should be followed:

1. Phase I: Inception Phase
2. Phase II: Development of the computational framework
3. Phase III: Determination of the flood risk baseline conditions under current and future climatic conditions
4. Phase IV: Pre-feasibility study of possible sustainable urban drainage systems (SUDS) interventions and NBS solutions

The consultancy input will be stepwise, covering:

- Phases I,II,III and IV

The Terms of Reference cover the consultancy required for the execution of Parts 1 and 2 to determine the feasibility of a set of effective flood protection including SUDS and NBS interventions ready for design that are economically viable/affordable for the country.

5. Phase I: Inception Phase

Tasks

In this phase, an Inception Mission will be conducted, including the following activities:

- Start-up meeting with the Client and relevant Stakeholders (see list below).
- Site visits to the Project Areas and inspection of known bottlenecks.
- Collection and review of existing information/documents/previous flood study reports; reference is made in Annex 1, 2 and 3.
- Discuss with the Client and Stakeholders:
    - the findings of the Mission,
    - the proposed project execution plan, and
    - the capacity building program.
- Drafting of the concept Inception Report.
- Evaluation of comments on the draft and finalization and submission of the Final Inception Report.

Deliverables

A comprehensive Inception Report, including:

- The findings of the Mission, initial identification of bottlenecks, and ideas for possible solutions;
- Summary of previous drainage, flood, vulnerability, and risk studies;
- Data availability relevant to the execution of the flood risk study;
- Assessment of information gaps, procedures to fill the gaps, additional surveys, and data acquisition;
- A detailed execution plan of all Project activities;

- Stakeholder engagement plan, which includes the list of stakeholders (those included in this ToR and any others that the Consultant may identify as relevant) and the general communications strategy that will be utilized;
- Capacity building program.

Stakeholders

The Stakeholders for this flood risk project are listed below, with influential one's highlighted:

- ***Department of Economic Development*** (Project Coordination Unit for World Bank Projects)
- ***Department of Infrastructure*** (development and maintenance of road and drainage infrastructure)
- ***Water Resources Management Agency (WRMA)*** (monitoring and management of water resources)
- ***Central Statistics Office*** (social and economic data and population and housing of 2020 census)
- ***Association of Professional Engineers of Saint Lucia*** (Key stakeholder for the project, covers a.o. civil, structural, geotechnical, mechanical, electrical engineering)
- ***National Integrated Programme and Planning Unit (NIPP),*** Department of Finance
- ***Castries City Council*** (responsible for solid waste management, maintenance of infrastructure)
- Physical Planning Section, DPDUR (implementation agency for Development Control Authority (DCA)). This agency is responsible for the permitting process for developments, monitoring and control of unauthorized development and forward planning)
- Water and Sewerage Company (WASCO) (water distribution and wastewater management services)
- Saint Lucia Electricity Services LTD (LULELEC) (electric utility company)
- Survey and Mapping Section DPDUR (custodians of topographic data, Lidar, orthophotos)
- National Emergency Management Organization (NEMO) (disaster management)
- Saint Lucia Meteorological Services (weather forecasting and meteorological database)
- Saint Lucia Institute of Architects (info on projects affected by floods)
- Ministry of Agriculture (farmer support for engineering solutions drainage, irrigation, erosion control)
- Forestry Division (management of forest reserves and terrestrial wildlife)
- National Utility Regulatory Commission (NURC) (regulator for electricity, water supply and waste water utilities)
- Saint Lucia Chamber of Commerce
- Caribbean Public Health Agency (CARPHA)
- Ministry of Health, Wellness and Elderly Affairs (Environmental Health) (surveillance of waste disposal)
- Saint Lucia Solid Waste Management Authority (SLSWMA) (waste collection and management).

References

For available data and reports reference is made to:

- Annex 1: 'Flood Assessment Baseline.docx',
- Annex 2: 'Data and Information Availability Assessment.xlsx' and
- Annex 3: 'WB SLU NBS Flood Data Assessment', for overviews of data availability and previous flood studies.

6. Phase II: Development of the computational framework

Definitions

- A ***hazard*** is defined as anything that could cause harm.
- ***Flood hazard*** refers to harm caused by flood levels, inundation depth, flood duration, flow velocity, hydrograph shape, water quality, sedimentation, erosion, etc.
- ***Flood risk*** is the product of the probability of flood hazards and the seriousness of the impacts (combination of exposure and vulnerability).

6.1 Objectives

The objective of Phase II is to develop models and databases for flood hazard and risk assessment and to design and analyze measures/interventions.

The computational framework will be comprised of the following components:

a. ***Flood hazard module***, including:

   a) Urban/rural storm water drainage models
   b) Database for:

      i) GIS layers of geophysical data and hydraulic structures
      ii) Meteorological data
      iii) Hydrological data, water levels, discharge, and water quality
      iv) Morphological data

b. ***Flood risk module***, including:

   a) Exposure database
   b) Vulnerability curves, and
   c) Risk model.

6.2 Flood hazard module

Tasks

The development of the flood hazard module involves the following activities:

a. Setup of a hydrologic-hydraulic storm water drainage model

For the assessment of the current flood risk and effectiveness of proposed interventions under current and future climatic conditions, storm water drainage models for the two Project Areas shall be developed. Two types of models are envisaged:

- For the ***macro-drainage system*** a basin- wide hydrodynamic model for event based detailed flood flow modelling, 1D for in-bank river/conduit flow and 2D for overbank/overland flow, and;
- for the ***micro-drainage system***, a state-of-the-art physically-based urban stormwater drainage model for storm events and continuous modeling of water levels, velocities, discharge, and water quality.

The flood flow modelling in the Project Areas is preferably done using a 1D2D hydrodynamic model, to produce a ***detailed*** picture of flow levels, depth, volumes, and velocities on the land (2D) and in the channels (1D) needed for flood damage assessment. The 2D model resolution shall closely follow the topography to arrive at the required detail of the flood parameters. Generally, in flood damage analysis only the flow depth/duration is used in combination with exposure type. However, in these basins with varying steepness, it is anticipated that under extreme conditions locally high flow velocities will occur exerting significant forces endangering the stability of structures, a factor to be considered for flood damage estimation. Therefore, overbank/overland flow should be treated 2D ***hydrodynamically***. Rainfall abstractions shall be simulated by physically based infiltration methods using soil characteristics. The modelling tool shall be capable of dealing with wind shear effects on levels and runoff given the location of Saint Lucia in the Atlantic Hurricane Belt.

The urban storm water drainage model will be used to analyze and design local micro drainage systems. It shall be able to accurately simulate the following processes: infiltration, surface runoff, surface ponding, groundwater flow, pipe/channel flow, and water quality routing and will incorporate all components of the micro-drainage infrastructure for storm water and sewerage discharge (in separate and/or combined systems). Recently, the PCSWMM model was used for storm water drainage simulation in the Assessment and Rehabilitation of Major Rivers in Saint Lucia Study, carried out by CBCL. This software covers the required features for the simulation of micro-drainage systems. For this assignment, either modelling with this freely available tool or alternatives with the same or better qualifications may be proposed.

b. Database for GIS layers of geophysical data and hydraulic structures

Topography

The primary official source of topographic information is the Survey and Mapping Section of the Department of Physical Development and Urban Renewal.

A DSM and a DTM of the Project Areas are available based on the 2020 conducted LiDAR survey under the WB Disaster Vulnerability Reduction Project. The surveyed area covered the coastal zone of Saint Lucia including the entire Project Area except Castries harbor area, which was not captured due to poor visibility. The accuracy achieved in this survey was vertically 10 cm and horizontally 20 cm. Furthermore, orthophotos of Saint Lucia are available at 10 cm resolution for the year 2022. This includes RGB (Red-Green-Blue) and CIR (Colored Infrared) Imagery. Orthophotos are also available in 2009 at 25cm resolution up to 15cm resolution in some developed areas. Missing parts shall be completed. Additional surveys will be outsourced, for which Consultants shall specify the required accuracy and extent.

With the DTM available, the catchments and sub-catchments in the Project Areas and their drainage infrastructure will be delineated.

Bathymetry

The Department of Infrastructure is responsible for the design and supervision of maintenance and construction of public infrastructure, including roads, bridges, drains, and culverts.

The bathymetry of open drains/river channels in the drainage models is available from the Digital Surface Model, bathymetric contours, and classified Point Cloud Imagery from the same LiDAR survey mentioned above. Additionally, orthophotos are available at 10 cm resolution for the year 2022. This includes RGB and CIR Imagery. Field checks will have to be carried out on the validity of the derived cross-sections.

Channel bed and bank characteristics (bed material, type of vegetation, stability, local scour /sedimentation) will be inventoried.

The November 2003 Halcrow Study Report, 'Improvement of the Drainage Systems in Castries and Anse La Raye,' provides an overview of the dimensions of the covered box drains in Castries. The Department of Infrastructure will be consulted on its completeness and validity. The reported inventory comprises all box drains in the Central Business District.

Additional bathymetric surveys will be outsourced, for which Consultants shall specify the required accuracy and extent.

Hydraulic structures

Data on hydraulic structures, dimensions, and types of drains, bridges, culverts, channels, embankments, gates, pumping stations and controls are available from the Department of Infrastructure. All structures relevant for the modelling shall be inspected. Particular attention should be given to the availability of trash screens and the shaping of the approach and outlet of the culverts and bridges to be able to determine the head losses at these structures. The operational strategies for the operation of the structures' pumping stations and pump capacities will be collected.

Additional surveys of structure dimensions will be outsourced, for which Consultants shall prepare the specifications.

Soil maps

Soil data are important for infiltration computations, sediment loss estimation, land slide sensitivity analysis, and structural design. The most comprehensive soil data for Saint Lucia is found in the Soil and Land Use Surveys prepared in 1966 by the University of the West Indies. Soil characteristics profiled in this study have been converted into a GIS shapefile.

Geological maps

Saint Lucia is part of a volcanic archipelago located in the Antillean arc along the eastern section of the Caribbean plate, where it converges with the North and South American Plate. The island consists almost exclusively of volcanic igneous rock. The most comprehensive study of the geology of St. Lucia was undertaken in 1965 by W.R. Newman, and updated in 1984 by Los Alamos National Laboratory. The Geology dataset is also available in a GIS format.

Land Use and Land Cover maps

A land use/cover map for Saint Lucia was generated in 2015 by the British Geological Survey, Natural Environment Research Council (NERC), based on image classification. The maps are available on Geocris (see Figure 4). The land cover map is important for estimation of the hydraulic roughness of overbank/overland flow.

There is no land use plan in Saint Lucia; the Development Planning and Development Act no. 29 of 2001 empowers the Physical Planning Section to zone lands.

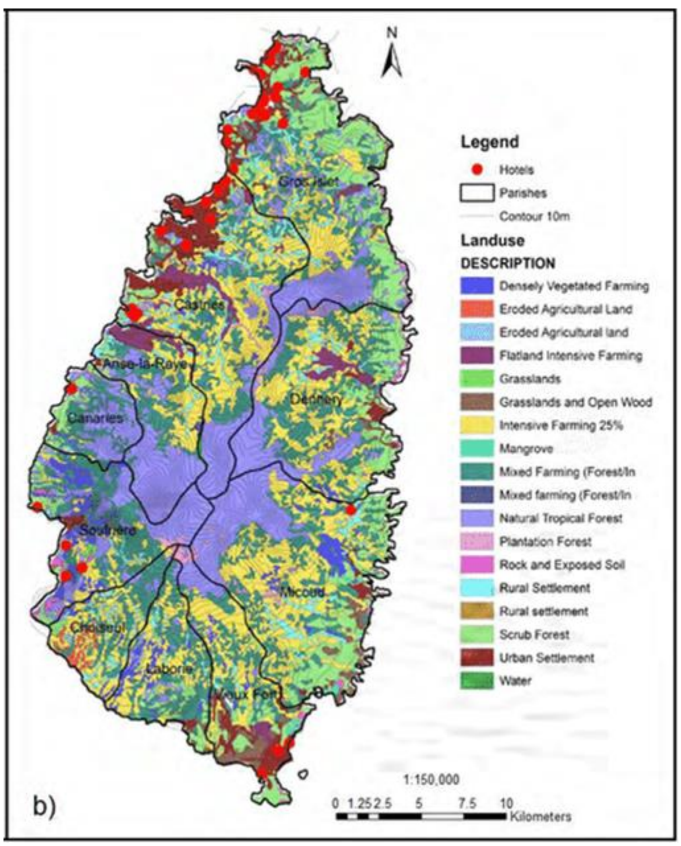

Figure 4. Land Use/Cover Map

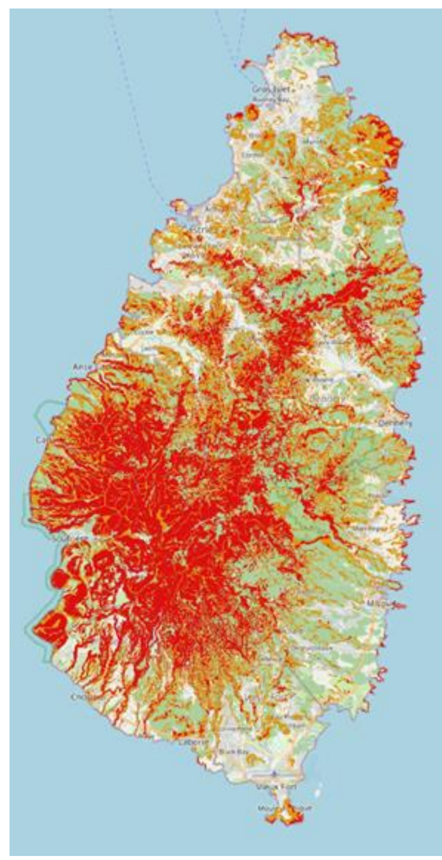

Figure 5. Land Slide Susceptibility Map

Flood maps

For recent extreme flood events, flood maps will be prepared to be used in the calibration and validation of the hydraulic models by comparing the calculated flooding with the observed flooding. This should be given special attention, since water level data is nonexistent in Anse La Raye and at only one location for Castries. This will require site visits, interviews, and identification of flood marks. Flood maps are also available from the CHARIM project (www.charim.net) hosted on the GeoCRIS portal of CDEMA. Satellite images of recent floods shall be inspected if needed, (costs to be included in the provisional survey sum).

Landslide maps

National scale landslide susceptibility maps of Saint Lucia generated by (ITC-Twente) in the frame of the CHARIM project, are available. In the development of these maps, bivariate statistical analysis, spatial-multicriteria evaluation, and manual editing was used. The dataset has been reclassified to align GFDRR landslide susceptibility. The landslide layers produced from this consultancy and the associated datasets are hosted on the GeoCRIS portal of CDEMA (See Figure 5).

General

One geo-reference system and vertical reference (MSL) shall be applied in the geospatial database.

c. Meteorological data

Data sources

The two agencies in Saint Lucia responsible for hydro-meteorological data are:

- the Water Resources Management Agency and
- the Saint Lucia Meteorology Service.

The agencies maintain a network of manual and automatic weather stations across the islands. The AWS rely on VHF, GOES, or cellular network. The meteorological network layout, location, type of equipment and data availability shall be inventoried (see Figure 4). A Hydromet Portal was developed and established under the WB DVRP but this portal does not have much data.

Rainfall

Rainfall data in this project are required for:

- calibration and validation of the drainage models;
- development of design rainfall events for current and future climatic conditions;
- assessment of suitability of rainfall forecast sources for early flood warning.

For the calibration and validation of the drainage models in the Project Areas historical storm events shall be collected (including the December 2013 ‘Christmas trough’ storm). For these events, also wind speed and direction, flood maps and tidal levels shall be available. This should include recent storms for which concurrent data are likely available, such as the November 2022 storm.

For design rainfall development an extensive rainfall study, the ‘Assessment and Rehabilitation of Major Rivers Study’ carried out by CBCL in 2022. Historical daily, sub-daily, and sub-hourly rainfall data were collected from WRMA sources and subsequently validated. This database shall be made available by WRMA and shall be updated with the latest data including the November 2022 extreme rainfall event. It appeared that the historical rainfall series were generally far from complete, and sub-hourly data were limited, requiring a number of disaggregation procedures to arrive at short interval extremes. In the application, no areal reduction in the point rainfall values was made, which seems acceptable given the small size of the watersheds. Hourly GsMaP and 30-min. IMERG satellite based rainfall records of 2000-2020 with a 10 km resolution showed slightly higher disaggregated 5 min amounts, but underestimated the storm total and were therefore discarded. It is noted that there are more global re-analyzed satellite-based data sets, but all have about a 10 km resolution, representative for 100 km^2 basin areas, much larger than the Project Areas, and all will also require disaggregation.

The validation and analysis procedures used in the above study to develop representative IDF curves for return periods ranging from 2 to 100 years shall be critically reviewed, adapted when required, or adopted when found suitable. Design storms shall be developed using alternating block method. A realistic location of the peak value of the design storm is to be taken as representative for the shape of historical hyetographs of extreme storms, also in relation to infiltration conditions.

A real time flood early warning system for Saint Lucia exists in the form of the Saint Lucia Flash Flood Guidance System (SLFFGS). The system uses several data sources including:

- Gridded Global Hydro-Estimator (GHE) Satellite Precipitation
- Gridded Micro-wave Adjusted GHE (MWGHE) Satellite Precipitation
- Real-time Automatic Weather Stations data (Trilynx systems via NovaStar 5)
- Gridded Meteo-France AROME Forecast Data

This model serves as a tool to assist forecasters in the prediction of flash flood occurrences to allow appropriate actions to be taken to reduce the impact of flash floods on life and property. The system is currently accessible by the SLMS and WRMA and has been functional since 2021. In 2023, the system was further enhanced through the incorporation of LiDAR and RADAR data. However, the system is not yet used to inform flash flood response.

The availability of statistics on the quality of the forecasts in comparison to the ground stations shall be checked with the forecasting center. In addition, high resolution rainfall forecasts 10 – 15 days in advance are produced by ECMRWF, which shall be considered when analyzing the forecast procedures.

Climatic data

The following climatic data are required:

- Evaporation, using Penman-Monteith method, requires global radiation, temperature, windspeed, relative humidity, and relative sunshine duration. This information is required to determine in combination with infiltration the duration of the ponding after the storm.
- Wind speed and direction during extreme rainfall events for hydraulic modelling.

Climate projections for the above parameters will be in accordance with the latest IPCC reports based on a realistic and pessimistic scenario.

d. ***Hydrological data***

The required hydrological data comprise:

- Water levels
- Discharges
- Water quality parameters
- Tidal levels

Figure 6. Weather Stations

Figure 7. Marchand Water Level Sensor

Figure 8. Layout of the Sewer System of Castries Operated by WASCO (note: there is no sewer system in Anse la Raye).

Water levels

Water level monitoring in the basins is the responsibility of the Water Resources Management Agency. Water levels in this project are required for calibration and validation of the storm water draining models.

- Within the Castries watershed the Marchand Water Level Sensor exists (See Figure 7. This Radar WL station was installed approximately two years ago under the DVRP and replaces a WL station previously operational. It implies that at least for the November 2022 storm water level data for Castries is available to be collected from WRMA.

- In Anse La Raye no water levels are monitored—indicating that existing flood maps shall be used for model calibration (See under 6.2.b 'Flood maps').

Discharges

No regular discharge measurements are made in the project area. Therefore, a discharge rating curve will have to be developed for Marchand with the aid of the hydraulic model for the river section controlling the water levels at the station. With the rating curve, a discharge series will be made for the period water levels at the site are available.

Water quality parameters

Water quality data (BOD, COD, etc.) representative for the water quality state of the drainage system and the grey and blackwater outlets shall be collected from the Water Resources Management Agency and WASCO. This data will be applied in the urban storm water drainage system to determine its spreading in the drainage system. The layout of the sewer system of Castries is presented in Figure 8.

Tidal levels

There are the four tidal stations in Saint Lucia of which two are on the West Coast. Station Ganters Bay Castries has the longest record. The other station on the West Coast at Soufriere was installed in 2021 under the DVRP. The tidal records will be collected from the Ports Authority to be used for calibration/validation of the hydraulic models and design calculations. For design purposes, the entire series will, after thorough validation, be subjected to harmonic analysis to separate the mean, tidal component, and residual non-tidal component. Extreme value distribution for the residual non-tidal component will be developed. The joint probability of heavy rainfall and high tidal levels shall be investigated.

Sea level rise projections will be in accordance with the latest IPCC reports based on a realistic and pessimistic scenario.

e. Morphological data

Sediment samples will be collected from the micro- and macro-system channels and grain size distributions determined for the purpose of hydraulic roughness estimation and scouring around structures. A sedimentation profile will be made based on existing information and a survey of select deposits to quantify significant sediment accumulation.

f. Calibration and validation of the macro and micro system storm water drainage models

Macro system model

The macro drainage system will be derived from the DTM and the bathymetry of the channels/conduits. The hydraulic roughness of the channels, land surface, and flood plains shall be determined from channel bed and wall cover/conditions and land cover maps. The head losses at the structures will require due attention. Infiltration characteristics shall be derived from soil maps. Initial soil moisture conditions will be estimated from rainfall weeks before the storm. Observed rainfall and tidal water levels (including the November 2022 storm conditions) are used in the 1D2D hydrodynamic model for calibration and verification. Apart from a quality check of the simulation of the observed flood extents in both Project Areas, only for Castries, a comparison with observed water levels and discharges can be made.

Micro system model

The catchments will be divided into many sub-catchments with unique parameters derived from the topographical, bathymetric, soil and land use/cover maps. Drain dimensions and hydraulic structures will be incorporated. The infiltration parameters shall be derived from the soil maps as for the macro system model; similarly, initial soil moisture conditions will be estimated based on the rainfall before the selected extreme storm event. The hydraulic roughness of the terrain and drains shall be determined based on land cover and bed and wall conditions of the conduits. Observed rainfall and tidal levels will be used for calibration and verification purposes. The derived flooding shall be compared with the observed flood extent and for Castries also with the water level and discharge hydrographs at Marchand hydrological station. The flood extent results obtained with both models shall be compared.

g. Deliverables

The following deliverables shall be produced:

- A structured database on the open source platform for:
    - Database for GIS layers of geophysical data, hydraulic structures, floods and landslides;
    - Climatic data and time series (rainfall, evaporation, wind);
    - Hydrological data and time series (water levels, compiled discharges, and water quality);
    - Morphological data;
    - Sets of boundary conditions for calibration/validation and design.
- Calibrated and validated 1D2D hydrodynamic and urban storm water drainage models for the Project Areas' macro and micro drainage systems.
- Report describing the database contents, data sources, and applied validations, the development of the drainage models, their calibration and validation and design boundary conditions of rainfall, tidal boundary and wind speed and direction. Report to be stored on online open source platform.

It is essential that a proper, easily accessible database is developed and regularly updated in order to facilitate current and future studies/ investigations. Protocols for the maintenance of the database should be agreed upon.

6.3 Flood risk module

The Central Statistics Office is a main source of information for developing the flood risk module. Relevant information on flood risk assessment in the Project Area is also provided in the thesis 'Assessment of physical vulnerability to flood in Saint Lucia. Case studies: Castries old Central Business District and Dennery Village' by Anne Chinyere Uwakwe (2015).

a. Exposure database

The objective is to develop exposure datasets at appropriate resolution to be used as input to the risk model. A geospatial database of exposures shall be built, including population, residential buildings, industrial establishments, government buildings (e.g., schools, hospitals, public administration buildings), roads, bridges, electric power stations, infrastructure, agricultural lands, environmental assets, etc. The list of exposures should comprise all that are affected by floods in the Project Area.

Tasks

The following data compilation activities will be employed:

1. ***Population data***: compilation of a geospatial database of population, including available details such as gender, age, income level, and other socio-economic indicators.

2. ***Residential buildings and industrial establishments***: compilation of a geospatial database of

residential buildings, industrial establishments and structures, including available details such as number of units and stories, floor area, inhabitants per building, date and materials of construction, and replacement value. Buildings shall be characterized by attributes.

3. ***Government buildings/assets***: compilation of a geospatial database of government buildings, with emphasis on critical infrastructure such as; schools, health care facilities and government administrative buildings. Buildings shall be characterized by the same attributes as employed for the Residential database, supplemented as appropriate for the special characteristics of schools, health care facilities and government buildings. Data shall include replacement value as well.

4. ***Infrastructure***: compilation of a geospatial database of selected infrastructure:

    a. ***Roads and bridges***: information on primary (and where data is available secondary) paved and unpaved public roads (number of lanes, pavement type) and bridges (with as much information as possible on the number and size of spans, type of bridge, material, date of construction) shall be compiled. The value of the infrastructure shall also be part of the data.
    b. ***Electric power stations and transmission***: transmission lines (routing of circuits and locations and type of towers), substations (locations, voltages, types of equipment) and their values shall be compiled.
    c. ***Hydraulic infrastructure***: additional information for vulnerability assessment in extension to the data collected for hazard modelling, including information on coverage and type of bank protections, hydraulic structures, etc.

5. ***Agriculture***: information on area coverage of current agricultural land and future expected changes. The type of crops grown in each area, cropping calendars, and crop yield per hectare should be collected.

6. ***Environmental assets***: protected areas, national parks, natural reserves, sanctuaries, forest reserves, habitats.

Thorough data validation will carried out including visits to selected areas to "ground-truth" a representative subset of the geo-referenced asset data, derived from non-primary (remote sensing, and statistical) sources. A database of all the exposures outlined above shall be delivered with GIS data layers for each aspect of exposure, including appropriate metadata.

b. Vulnerability Curves

The objective is to develop vulnerability datasets at appropriate resolution that characterize the vulnerability of physical assets and exposed populations to various hazards for use as input in the risk model. Vulnerability functions may be based on engineering analysis, empirical data, or expert opinion but in all cases shall be demonstrated to be relevant and appropriate to constructions and conditions in Saint Lucia.

Tasks

The following activities shall be employed:

1. ***Population***: development of vulnerability functions that relate mortality and morbidity rates in the study river basins.

2. ***Direct damage***: development of vulnerability functions showing damage ratios for all the exposures developed in the previous section, including residential buildings, industrial establishments, government buildings, infrastructure, and agriculture.

3. ***Indirect damage***: development of vulnerability functions for disruption ('downtime') of critical sectors and services.

4. ***Environmental damage***: development of vulnerability functions for damage due to floods to environmental values.

The vulnerability curves for flood losses/damages with detailed mathematical formula, including uncertainty margins, shall be properly documented in a technical report.

c. Risk model

The objective is the development of risk models at appropriate resolution to be able to undertake risk and impact analysis and to compute the probable physical and agricultural losses, mortality and morbidity rates, and environmental damage by making use of state-of-the art flood risk modelling methodology and compiled data sets.

Tasks

The following activities shall be employed:

1. ***Development of a risk model*** to determine probabilistic losses/damages due to floods. Its application involves the computation of a stochastic set of losses/damages for each element of the exposure set. These losses/damages are measured as appropriate, including:
    - Mortality and morbidity
    - Direct damage (i.e., cost of repair or replacement)
    - Indirect damages (disruption time)
    - Environmental damages
    - Critical infrastructure impacts

    The size of the stochastic set shall be sufficient to assure stability of results. The stochastic set shall be used to develop loss/damage exceedance curves for the selected study basins at appropriate resolution. Model output shall comprise maps for selected frequencies of loss/damages, and tables and associated maps of Average Annual Loss (AAL) at any level of aggregation.

2. **Validation:** loss estimates developed above shall be validated by comparison with historical events with documented losses.

d. Deliverables

The following deliverables shall be produced on online open-source platform:

- A risk model, including operation manual
- A geo-spatial database of all exposures sets
- A database of all vulnerability curves and datasets
- A technical report documenting:
    - Compiled exposure data

        - Population distribution and composition,
        - Typologies of residential buildings, industrial establishments, government buildings and infrastructure,
        - Spatial and temporal (seasonal) variation of agricultural outputs,
        - Environmental assets, and
        - Replacement costs, and the costs associated with partial/full retrofit required to improve flood resilience.
    - Developed vulnerability curves
    - The risk model with all developed damage/loss functions and applied validation.

6.4 Workshops, presentation of results

Consultants shall convene a workshop with Stakeholders and engineering experts from Saint Lucia on the development of the hazards and risk models, as well as collection of exposure data and development of vulnerability curves to ensure ownership consensus on these models as well as to build capacity in the engineering community. Feedback should be incorporated into the development of the hazard and risk models etc. Before Consultants can proceed with Phase III, Client, and Stakeholders should give their approval for the use of the developed modelling tools.

7. Phase III: Determination of the flood risk baseline conditions under current and future climate

The objective of Phase III is to provide the flood profile of the Project Areas by presenting an overview of the current and future flood risk with the existing and projected drainage infrastructure and institutional setting. It will identify current bottlenecks and shall serve as a reference for evaluation of the effectivity of proposed interventions.

Two future climatic scenarios shall be considered: (1) realistic and (2) pessimistic, to be able to investigate the sensitivity of the drainage system for assumed development scenarios.

Tasks

1. Flood hazard and risk analysis shall be executed for the Project Areas with the developed modelling tools for (1) the current climatic conditions and (2) future climatic scenarios for present and projected basin conditions, as follows:

    a. current climate and current land use and hydraulic infrastructure (Case 1, Base Case);
    b. future climate (2 scenarios) and current land use and hydraulic infrastructure (Cases 2, 3);
    c. future climate (2 scenarios), and projected urban extension and land use (Cases 4, 5).

    The following hazard and risk maps (layout to be determined in consultation with the Client) are envisaged:

    - flood extent for selected annual exceedance probabilities (25, 50, 100 year return period),
    - inundation depth, duration, and flow velocity per selected annual exceedance probability,
    - economic: average annual loss at appropriate resolution(s) (minimum, mean, maximum),
    - social: average annual number of persons affected at appropriate resolution(s),
    - social: for social hot spots (hospitals, schools, retirement homes, etc.) probability of being flooded,

- environment: average annual environmental damage risk,
- multicriteria flood risk maps: weighting of economic, social and environmental criteria.

2. Evaluation of the modelling results and identification of bottlenecks. Attention should be given to the flood dynamics and flood wave celerities in the channels determining the time wise development of the flooding in the Project Areas, essential for developing effective flood mitigation measures by accelerating or delaying lateral inflows to stretch the base of the flood wave in which nature-based solutions could be effective.

3. Review of the performance of the Saint Lucia Flash Flood Guidance System (SLFFGS), regarding the state of flood risk awareness (population informed, identified vulnerabilities), storm detection (monitoring network, forecasting tools, lead time), advance warning (responsibilities of involved organization, dissemination, communication) and response (evacuation plans/centers, rescue organization, relief goods).

Deliverables

a. Flood hazard and risk maps for the distinguished scenarios as specified above. Consultants shall summarize the results of the risk and event analyses in a report in which the risk profile (e.g., hazards, population losses, direct and indirect damage losses, loss exceedance curves, and annual average loss at appropriate aggregation levels) is presented and areas at risk delineated.
b. Identified bottlenecks shall be presented in a report with directions for the development of risk reduction measures and do's and don'ts regarding flood risk for basin development planning presented.
c. Data/ information sharing platform: Consultants shall develop an online, open-source platform (geo node/geo server type) to host all the data (raw and outputs) and the technical reports organized in a structured way that can be accessed by all Stakeholders.
d. Flood early warning performance report and suggested improvements when required.

Consultants shall convene a workshop to present and discuss the results of the flood risk assessment and its implications for the development of risk reduction measures with the Client and Stakeholders. Feedback from workshop participants should be incorporated into suggested risk reduction measures.

8. Phase IV: Pre-feasibility study of possible interventions

The objectives of this task are:

- to identify at pre-feasibility level effective flood risk mitigation measures / interventions to achieve the agreed flood return period with due attention to SUDS and nature based solutions, including their costs and benefits and social and environmental implications, and
- to select the preferred mitigation measures / interventions through multi-criteria analysis and Stakeholder input for further analysis.

From the flood risk analyses under Task III in the current hydraulic infrastructure setting a number of potentially effective measures structural and non-structural will emanate, a mix of measures reducing the flood hazard and reducing vulnerability (aiming at multiple layers of safety: prevention, protection, preparedness).

It is noted that envisaged investments for the interventions are in the order of US $15-20 million for Castries and US $2-5 million for Anse La Raye.

Tasks

The following activities will be employed:

1. Develop in consultation with the Client not less than four comprehensive risk reduction alternatives for each study basin, structural and/or non-structural measures that reduce the flood hazard, exposure, and vulnerability for further analysis at pre-feasibility level.

2. Run the hydraulic and risk models for each alternative for the same boundary conditions (Cases 1-5) as for the base line analysis to determine the flood extent and damage parameters for selected annual exceedance probabilities (25, 50, 100 year return periods) and map the difference between base line and alternative.

3. Investigate the effectiveness of each alternative at ***pre-feasibility level*** on changing the loss exceedance probabilities/reducing average annual flood damage, cost of construction/ implementation, operation and maintenance, and its social and environmental implications. Cost-benefits analysis of each alternative shall be carried out.

4. Apply multi-criteria analysis based on economic, social, and environmental indices to select promising alternatives for in depth investigation at feasibility level. Criteria weights are to be selected in consultation with the Client and Stakeholders.

Deliverables

a. Pre-feasibility reports for identified mitigation measures, including for each alternative
    - Full lay out of each measure, dimensions, required construction materials, etc to allow a proper estimate of the construction and maintenance costs
    - flood hazard and damage maps
    - flood hazard and damage difference maps in comparison with the base line conditions
    - cost benefit analyses
    - social and environmental implications.

b. Results of the multi-criteria analysis for each alternative on flood hazard reduction, flood damage reduction, costs, benefits, cost-benefit ratios, environmental impact, social impact. Different sets of weights shall be applied to account for preferences, financially, environmentally, and socially.

The results of the analyses shall be properly documented in a technical report, which includes all steps taken and assumptions made in the pre-feasibility studies.

The results shall be presented and discussed in a ***workshop*** with the Client and Stakeholders. A final selection of the most promising risk reduction alternatives fulfilling the requirements of SUDS and NBS shall be made for investigation at the feasibility level.

9. Phase V: Feasibility study of most promising interventions

The objective of this task is to investigate the economic feasibility of the selected risk reduction alternatives and their social and environmental impact. Through multicriteria analysis the Government of Saint Lucia will make a final selection. Phase V stated here is for information purposes only and not subject to submission of EOI or at the proposal submission stages.

Tasks

The following activities shall be employed:

1. ***Feasibility study***. Execution of feasibility studies of the selected alternatives, including:

   a. detailed technical analyses of the measure;
   b. sensitivity analyses to evaluate robustness of the measure;
   c. investigation of morphological consequences of the measures on the river channels, with special attention to scouring around structures, and near revetments, maintenance implications;
   d. risk analyses with the measure in place to assess reduction of average annual damage costs;
   e. investments required for implementation of the measures for a range of safety levels;
   f. economic optimization of the measures by minimizing total costs of risk and investments (construction, operation, maintenance), and
   g. conduction of cost-benefit analyses.

2. ***Social and Environmental Impact Analysis****.* The selected alternatives shall be subjected to a Social and Environmental Impact Analysis to a level suitable for preparing the indices for a detailed multicriteria analysis. As a minimum, features of E&S importance that may be affected by the alternatives shall be identified and the E&S benefits and potential impacts of each option described and evaluated sufficient to inform the decision-making process.

3. ***Multi-criteria analysis****.* Social, environmental, and economic indices will be weighted to select the most promising alternative for implementation.

Deliverables

a. Feasibility study reports for selected alternatives including all analyses:
   - Full lay out of each measure, dimensions, required construction materials, etc to allow a proper estimate of the construction and maintenance costs
   - flood hazard and damage maps

- flood hazard and damage difference maps in comparison with the base line conditions
- cost benefit analyses,
- social and environmental features maps, and associated descriptions.

b. Social and environmental impact analysis reports for the alternatives.
c. Results of the multi-criteria analysis of the selected alternatives on flood hazard reduction, flood damage reduction, costs, benefits, cost-benefit ratios, environmental impact, and social impact. Different sets weights shall be applied to account for preferences, financially, environmentally and socially.

The results of the analyses shall be properly documented in a detailed feasibility report and be discussed in a workshop with the Client and Stakeholders. The final selection will be made in consultation with the Client and Stakeholders and requires the approval of the Government of Saint Lucia.

d. Drafting the Terms of Reference for the detailed design of the selected interventions that specifies:
    - Required input of technical/landscaping/environmental/social experts
    - Additional field surveys of the locations of the interventions
    - Geotechnical investigations for structural design
    - Detailed design and preparation of all design drawings of the selected structural and non-structural interventions in agreement with the local construction and environmental regulations
    - Additional Social and Environmental Impact Assessment to inform the designers of appropriate measures for inclusion that will eliminate/minimise any negative impacts in compliance with local legislation, Good International Industry Practice and World Bank requirements (such as may be found in the WBG Environmental Health and Safety Guidelines)
    - Preparation of BoQ's
    - Preparation of tender documents for implementation of the designed measures.
    - Drafting of maintenance guidelines to ensure adequate functioning of the drainage infrastructure.

10. Technical and Financial Proposals and Contracting Modality

The Consultant will provide complete technical and financial proposals for Phases I-IV only. The contract will cover Phases I-IV and will be a lump-sum contract. At the end of Phase IV, the exact scope of Phase V will be finalized, and the selected firm may be invited to submit a technical and financial proposal for Phase V contingent upon the performance of the consultant under the first contract and the acceptability of the Phase V technical and financial proposals to the Government. The Government reserves the right and may decide to adopt a competitive selection process for Phase 5.

11. Tentative implementation timelines

A tentative timeline for the implementation of the distinguished Project Phases is shown in Table 1 with a total turnaround time of about nine months. The project is scheduled to start in August 2024. Consultants shall prepare a detailed timetable for the execution of the activities and of their staff input.

Table 1. Tentative Project Implementation Table

		months								
Phase	Activity	1	2	3	4	5	6	7	8	9
I	Inception Phase	■								
II	Computational framework		■	■						
III	Base line conditions				■	■				
IV	Pre-feasibility study						■	■		
V	Feasibility study								■	■
	Report	↑		↑		↑		↑		↑
	Meetings/Workshops	↑		↑		↑		↑		↑

12. Staffing and required qualification of Key Staff

The Consulting Firm shall have extensive experience and an excellent reputation in the execution of flood risk projects in developing countries (including in the Caribbean Islands) as well as in the design of sustainable urban/rural drainage systems (SuDS) including the application of nature based solutions (NBS).

Consultants shall propose well qualified staff for the execution of the Project recruited from its own staff for appropriate home office back up. The proposed staffing should comprise at least the following key staff with the required qualifications:

Urban Drainage Expert/River Basin Modeller/Team Leader: the expert should have a master's degree in storm and wastewater drainage engineering and at least 20 years of experience in urban drainage design. The expert should be acquainted with the development of SUDS and their drainage solutions (e.g. proposed in CIRIA's SUDS Manual). Experience with engineering projects in developing Caribbean countries is necessary. Excellent management, training, and reporting skills are required.

GIS Expert: the expert should have a master's degree in geo-informatics and at least ten years of experience in the development of geographical information systems, collection, analysis, distribution as well as the use of spatial data, spatial information for assessing natural hazards and disaster risk. Excellent training and reporting skills are required.

Hydrologist: the expert should have a master's degree in hydrological engineering and at least 15 years of experience in this field including execution of projects in developing Caribbean countries. The expert should be very experienced in hydrometry, hydro-meteorological data validation, processing and frequency and time series analysis, analysis of extremes, execution of urban flood studies, and rainfall-runoff and groundwater modelling. Excellent training and reporting skills are required.

Hydraulic and Water Quality Modelling Expert: the expert should have a master's degree in civil/hydrological and hydraulic engineering and at least 15 years of experience in the development, calibration, validation and application of flood flow and inundation models in urban and rural areas. The modelling skills comprise urban storm and wastewater modelling, 1D, 1D2D and 2D hydraulic modelling and water quality modelling. Experience should include the execution of projects in developing countries. The expert should be conversant with bathymetric and hydrometric surveys and should have extensive experience with the application of GIS. Excellent training and reporting skills are required.

Structural Design Engineer: the design engineer will have a master's degree in civil engineering and has at least 20 years of experience in the design of hydraulic structures for flood drainage and control, in structural design of SUDS, geotechnical engineering, and in the preparation of design and tender documents. Excellent training and reporting skills are required.

Economist: the expert should have a master's degree in economics at least 15 years of experience in the execution of cost-benefit analyses for urban drainage systems, assessment of flood damages, and development of social, environmental, and economic indexes for multi-criteria analysis. Experience should extend to developing Caribbean countries. Excellent training and reporting skills are required.

Social and Environmental Expert: the social and environmental expert should have a master's degree in social and environmental sciences and have at least 15 years of experience in leading and executing of social and environmental impact and risk assessment studies, and development, implementation, and elaboration of field surveys. They should have experience in designing and/or delivering SUDS and NBS measures to alleviate flood risk. Experience should extend to developing Caribbean countries. Excellent training skills and reporting skills are required.

Landscape Architect: the landscape architect should have a master's degree in spatial planning/landscape architecture and have at least 15 years of experience in urban and regional planning and the design of SUDS. The expert should have experience in the application of Geographical Information Systems. Excellent training skills and reporting skills are required.

Consultants shall prepare a detailed plan for participation and training of the counter staff and required qualifications.

Guidance to Consultants

The Client will provide the following facilities free of charge to the Consultant:

1. Suitable air-conditioned office space;
2. Suitable office furniture;
3. Suitable communication means with fast internet;
4. All relevant data for the execution of the required tasks will be timely made available to the Consultant free of charge.