Caribbean Handbook on Risk Information Management

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CHaRIM Project
St Vincent National Flood Hazard Map Methodology and Validation Report

DRAFT 1.1

St VINCENT & GRENADINES

DRAFT VERSION

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1.1 Caribbean flash floods

The Caribbean islands are frequently plagued by floods as a result of heavy rainfall during tropical storms and hurricanes. These floods are termed "flash floods", from their rapid onset and relatively short duration, and are directly caused by runoff produced during a rainfall event. The islands mostly consist of a central mountain range, with small catchments ranging from the center part of the island to the sea. These catchments can be anything from 5 to 50 km^2 in size. Hydrologically speaking, each island is made up of up to 50 larger catchments, with various types of land cover and soils, determining the hydrological behavior.

In tranquil conditions the rivers have a low baseflow level, fed by local groundwater bodies constrained to the valleys. During a tropical storm, the soils on the slopes quickly saturate and literally overflow, or the rainfall intensity can be so high that the infiltration capacity of the soil is not sufficient. Hence severe overland flow and erosion may take place, leading to flooding along the river channels. The water level can rise from 0.5 m to more than 4 m at given locations, within 2 hours' time (sometimes much less) from the start of the rainfall. Since many valleys are inhabited, especially near the coastline, these flash floods can cause great damage and casualties. The shape and condition of the river channel has a large influence of the flood behavior: small and narrow channels quickly overflow, or channels that have a decreased size because of sediment may overflow much more quickly.

Flooding circumstances can be aggravated by man-made decisions or behavior such as:

- channels that are blocked by debris (e.g. at bridge locations) and are not regularly cleaned;
- channels that are diverted to circumvent habitation, leading to unnatural bends and flow paths that cannot handle extreme discharges;
- culverts and bridges at road crossings may be under-dimensioned, leading to backflow and rising water levels;
- Individuals extend their property into the river channel flood plain, thus narrowing the potential flow path.

It is a mistake to think that only the lowest areas in a catchment, i.e. the villages on the coastline, are subject to flooding. Also in the upstream valleys in the hills flooding occurs, which are often inhabited and the major valleys have important transport corridors that allow you to cross over the island. Moreover, upstream flooding may actually be considered positive if a valley is uninhabited, as the temporary retained flood water would otherwise contribute to the hazard downstream. It is therefore important to consider flood hazard as part of an integrated catchment analysis, and not focus on single isolated occurrences.

Given these conditions where the flood hazard is directly related to the rainfall-runoff processes in the catchments, a national flood hazard map for the islands should be based on a flood hazard model that takes these into account.

1.2 The national flood hazard map

The national flood hazard map shows the *potential* flood hazard of all the catchments and locations on the island where flooding may take place. The information shown is *flood extent* only, water depth information is not included in this map. At this scale and resolution, water depth information is not accurate enough to make a hazard classification combining depth and extent. The flood extents relate to design rainfall events that have a return period of 1:5, 1:10, 1:20 and 1:50 years. The map is produced on a scale of 1:50,000 based on GIS raster data layers used in the flood model with a gridcell resolution of 20x20m.

This effectively means that the map can only be used as an indication of where flood may occur, and be used to check which settlements and areas are exposed to floods. The infrastructure and buildings are deliberately shown in a generalized way, as is common with 1:50000 scale maps.

In chapter 6 of this report, a quality analysis is done based on a visual inspection and evaluation by the stakeholders in this project. Also the results are compared to two detailed flood hazard analysis projects that were done before. Based on this it can be concluded that:

The CHARIM national flood map of 2016 has been evaluated by government representatives and according to their judgement it offers a reasonable amount of detail. It correctly indicates places that are flooded regularly. It is consistent with earlier hazard analyses executed in St Vincent, and at times even very similar to detailed site analysis that were performed in those studies, especially in the floodplains near the coast. In the upper reaches of the catchments, the flood analyses may be somewhat exaggerated, as the accuracy of the DEM and the presence of an actual stream channel determines the flood hazard.

As such, the national flood hazard map is a tool to gain more understanding on flood hazard on an island level, as an input for national planning, risk reduction and disaster preparedness. The map gives an indication of exposure of built up areas and infrastructure to flood hazard. It can be used to judge which communities should prepare themselves for a given hazard magnitude.

However, at this scale it has inherent uncertainties due to reasons explained below (in points 3 and 4). Therefore, the map and associated information is indicative and cannot be used to provide details for individual properties or engineering design. It can be used as a first approximation, and serve as guidance to locate where a more detailed site investigation should be done to reduce local risk.

The methodology is based on the following considerations:

1. **Rainfall**: the frequency and magnitude of the floods is assumed to be the same as the frequency and magnitude of the rainfall that causes it. In the model simulations, the island is subjected to a rainfall event that covers the entire island at the same time, without spatial differences. These are statistically derived artificial rainfall events (so called design storms), that do not resemble the dynamics of a real storm with a moving weather front and erratic variations in intensity. Therefore this map does ***not*** show what will happen exactly during a real event of a comparable magnitude. The return periods used are 1:5, 1:10, 1:20 and 1:50 years. The rainfall return period analysis (chapter 4) is based on the two stations that have longer time series, Canefield and Melville Hall, which have 32 and 39 years of daily data. Further extrapolation to 1:100 years or more was not considered statistically sound given the rainfall database.
2. **Land use and soils**: the differences in flooding between the catchments for a given rainfall are caused by differences in relief, land use/land cover and soils. Especially soil moisture storage

capacity and infiltration rates determine how a catchment reacts to rainfall). The initial moisture content on the entire island is set to 85% of the porosity, which is generally half way between field capacity and saturation. These conditions apply in the wet season when most hurricanes and tropical storms occur.

3. **Buildings and infrastructure**: on a national scale, certain details cannot be simulated, such as the effect of bridges and culverts, as well as the presence of debris and excessive sediment from previous storms in the river channel. The effect of buildings is included to a certain extent (explained in section 5.3).
4. **Spatial data quality**: the quality of the model results depends to a large extent on the quality of the input data. Care has been taken to use the existing data as much as possible, so that the results are close to the island circumstances. Where needed literature values are used, or values measured on the other islands in the CHARIM project (for instance soil hydrological data on St Vincent).

1.3 Return periods

It is important to realize what exactly a return period (or recurrence interval) of 1:X years actually means. A 1:5 year storm means that ***on average*** over a long period, a storm of a given magnitude and duration ***is exceeded*** once every 5 years. This does ***not*** mean that a 5-year storm will happen regularly every 5 years, or only once in 5 years, despite the connotations of the name "return period". In any given 5-year period, a 5-year event may occur once, twice, more, or not at all.

This can be explained as follows. Statistically the probability of a 1:5 year storm occurring is 0.2 per year, and therefore each year it has a probability of 0.8 of ***not*** occurring. If the storm hasn't happened several years in a row, the probability that it will occur in the following year increases. If it hasn't happened in 2 years, the probability of not occurring is reduced to 0.8*0.8=0.64. If it hasn't happened 5 years in a row, the probability of the storm not occurring has reduced to 0.8^5 = 0.33, and so forth. The probability that it will occur after 5 years of not occurring is 1-0.33 = 0.67. In other words, there is a 67% chance that a 1:5 year storm occurs after the next 5 years. Continuing this reasoning it is 99% certain that such a storm will happen within the next 20 years.

1.4 The 2015 Draft version of the national flood map

A draft flood hazard map was created with LISEM simulations in 2015 and discussed with the partners from St Vincent. A second set of simulations were done based on these discussions, and the request of the World Bank to use the latest land cover maps. The following changes were made to the database:

- The 2015 flood hazard map was created using as input an earlier (2009) land cover map (shape file) and certain assumptions on the channel dimensions. The latest land cover map is created by the British Geological Survey in 2014 based on a supervised classification of high resolution images (5m resolution). The land use directly influences soil physical parameters in the modelling setup (explained in chapter 5).
- A relation was found in literature to derive channel dimensions from catchment size (Allen and Pavelsky, 2015), which seem to fit field observations better for the island of St Lucia and St Vincent. The relation was not checked on St Vincent but in the interest of using a unified method for the islands in CHARIM it was also used there. Field visit checking of channel cross section measurement, showed that the channels in the first database were generally too narrow. Section

5.1 explains in more detail how the channel dimensions (width and depth) are created. A wider channel changes the flood hazard as there is less chance of overflow.

1.5 Calibration and verification

Every model needs calibration to see if the choices in making the input dataset and translating basic data to model data have been done correctly. Normally this is done either by checking simulated discharges against measured discharges in a none flood situation, or checking flood extent and flood depth for a number of locations when there has been a flood.

Discharge is measured on St Vincent by the Ministry of Agriculture, but the data was not obtained in this project. It is not known what type of measurements are done (water levels and or discharge), where the stations are or what the frequency of measurements is. In order to be useful for flood modelling, the frequency of the measurements during a high discharge should be high, preferably on a 10 minute interval or less. Anything else will not capture a discharge wave properly and mostly measure baseflow. Calibration against known discharge was therefore not possible.

Often early warning systems are installed on the islands, it is not known if St Vincent has these too. Surprisingly, while these EWS monitor water level constantly, the data is not stored and used, which means an important opportunity is missed to understand flash floods better.

The flood extent maps were verified in a discussion with counterparts in 2015. In general all known flood locations were considered to be correct, but the draft version of the map from 2015 was considered to give too much flood hazard, in locations that normally did not flood in the experience of the agencies. In chapter 6, the new flood hazard map is discussed and also compared to an earlier flood hazard analysis. In the east part of the island north of Grenville the flood hazard is still too extensive, which may be caused by the low quality DEM in that area and the absence of correct channel dimensions (including retaining walls).

2 Methodology

2.1 Requirements for the flood model

Based on the physiography and topography of St Vincent, the following terms of reference for the flood hazard assessment were used:

1) There is no viable discharge data, therefore rainfall is used to simulate the flash flood process. This means that a flood model has to be able to simulate the surface hydrology of entire catchments, both upstream and downstream areas. Since settlements are also spread out over the islands, flooding occurs not only near the coast (where the largest villages are) but also in higher valleys.
2) The flood model has to be able to use the existing national spatial datasets, so that when better data becomes available, simulations can be done again relatively easily. Formats used are standard GeoTIFF. Data gaps are filled by knowledge and data pooled from the islands and from literature. Thereby we rely as little as possible on variables/constants/assumptions from general worldwide datasets, acquired in environments that are very different.

Based on these requirements we selected the integrated flood model **LISEM** (freeware and open source developed at the Utrecht University (1992-2006) and subsequently by the ITC (2006-current), in the Netherlands. LISEM is a model that was initially developed to simulate the effect of land use changes at farm level for sustainable land management, to combat erosion and desertification. Recently a 2D flood module was added to enable integrated flood management. It is a spatial event based model that operates at timescale of < 1 minute and spatial resolutions of < 100m grid cells. It does not model groundwater and evapotranspiration because it focuses on the consequences of single rainfall events.

2.2 National scale hazard assessment methodology

Figure 1 shows the framework that is used to create the flood hazard map (each step is explained in detail in subsequent sections):

- A frequency magnitude analysis of daily maximum rainfall of all stations that had 20 years or more of daily rainfall data. Generalized Extreme Value distributions were fitted to these datasets to determine the daily rainfall with return periods of 5, 10, 20 and 50 years.
- Design events were created using the network of 8 tipping bucket rainfall stations on Saint Lucia, which have datasets between 5 and 11 years. Using the rainfall depth from the maximum daily values, and duration and intensity data form the tipping bucket stations, design curves were created using a Johnson Probability Density Function. These equations are used for St Vincent but fitting them to match the daily totals belonging to the return periods of St Vincent
- The DEM was used directly in the modelling but also to correct the vector based river network. This is explained in section 5.
- The land use map and soil class map were used to derive a number of soil physical and vegetation parameters used for the surface water balance of the model.
- The infrastructure, i.e. the road network and buildings were taken from the shape files in the national database.
- The model output consists of the maximum flood level reached during the event, the maximum water velocity the duration of the flood, the time since the start of the rainfall when a pixel is first inundated, and statistics about the total surface of buildings in different flood depth classes. From this data the extent was used for the flood hazard map, using a flood level above 10 cm to eliminate water on the surface that will not be considered hazardous. The 4 flood extent maps were combined into a hazard map with 4 zones (corresponding to areas flooded with the 4 design events).

3 Model software – LISEM

The method is based on the open source integrated watershed model LISEM. This model is based on the well-known LISEM erosion/runoff model (see e.g. Baartmans et al., 2012, Hessel et al., 2003, Sánchez-Moreno et al., 2014), combined with the FullSWOF2D open source 2D flood package from the University of Orleans (Delestre et al., 2014). As a runoff model LISEM has been used in many environments, European humid and semi-arid areas, islands (Cape Verde), East Africa (cities of Kampala and Kigali), India, Indonesia, Vietnam and Brazil.

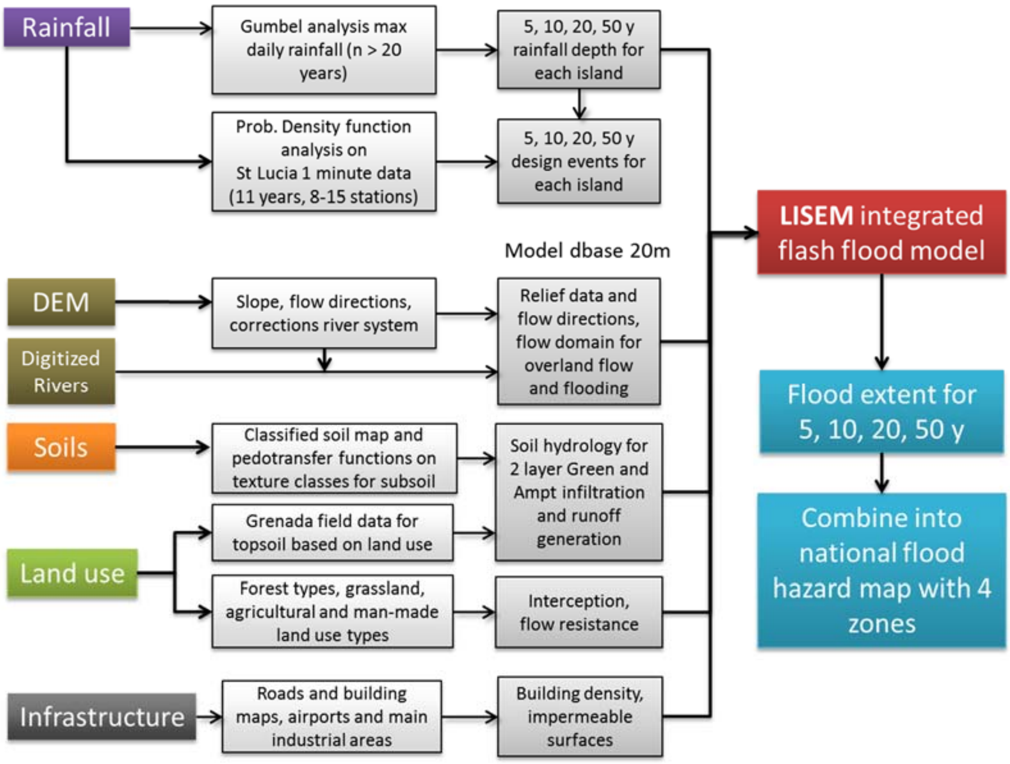


Figure 3.1. National scale flood hazard assessment methodology: basic information layers to the left are used for hydrological information that is given to the model. Rainfall for different return periods results in different flood simulation results. These are combined in hazard information databases, and also reproduced as cartographic products.

LISEM is a hydrological model based on the surface water and sediment balance (see fig 3.1). In CHARIM only the water processes are used, erosion and sedimentation is not simulated. It uses spatial data of the DEM, soils, land use and man-made elements (buildings, roads, channels) to simulate the effect of a rainfall event on a landscape. Above ground processes are interception by vegetation and roofs, surface ponding and infiltration. The resulting runoff is derived from a Green and Ampt infiltration calculation for each gridcell, and routed as overland flow to the river channels with a 1D kinematic wave. The routing takes surface resistance to flow into account. The water in the channels is also routed with a kinematic wave (1D) but when the channels overflow the water is spread out using the full St Venant equations for shallow water flow. Runoff can then directly add to the flooded zone. Figure 3.2 shows schematically the steps in the model from runoff to flooding. Since it is an event based model, LISEM does not calculate evapotranspiration or groundwater flow.

Figure 3.4 shows how LISEM deals with sub gridcell information. Layers with objects smaller than a gridcell can be added, which are then defined as a fraction (buildings and vegetation) or by their width (roads and channels). Roads, houses and hard surfaces (e.g. airports runway) are considered impermeable, smooth and have no vegetation interception. Houses are impermeable but have roof interception and to some extent obstruct the flow. LISEM 'looks' vertically along all the information layers to determine the hydrological response of each gridcell.

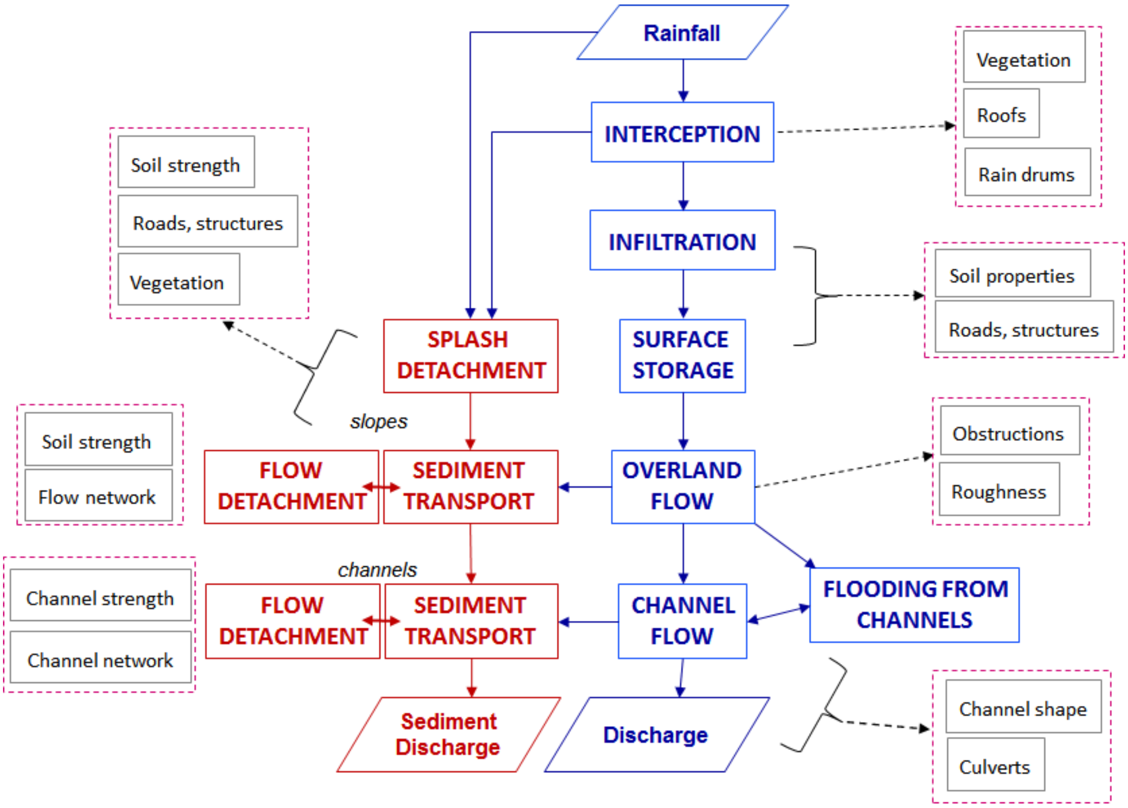


Figure 3.2. Flowchart of the water and sediment processes in LISEM. In dashed lines the main parameters are given. In CHARIM only the water processes are used (in blue).

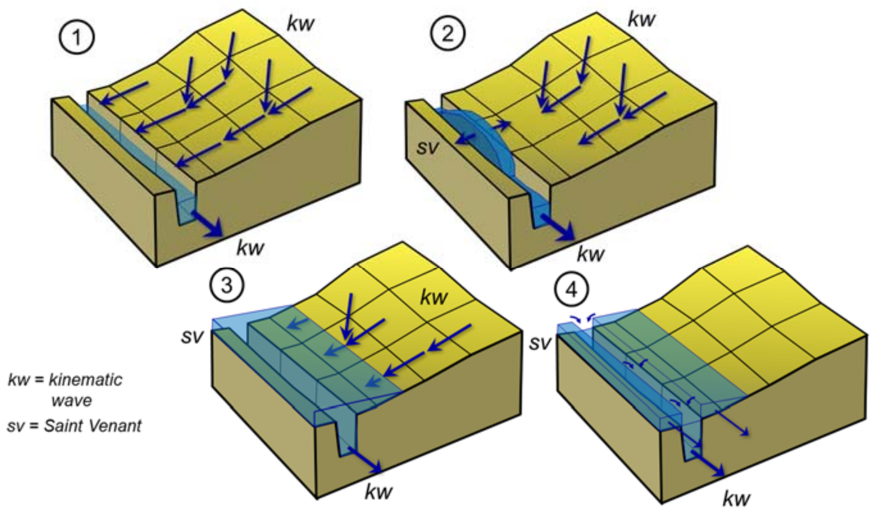


Figure 3.3. Schematic representation of flow processes from 1D kinematic wave runoff and channel flow (1), to overflow of channels (2), spreading out of water from the channels outward using 2D full Saint-Venant equations (3), and flowing back into the channel when water levels drop, most likely the runoff has stopped by now (4). Runoff continues to flow into the flood zone for a short distance.

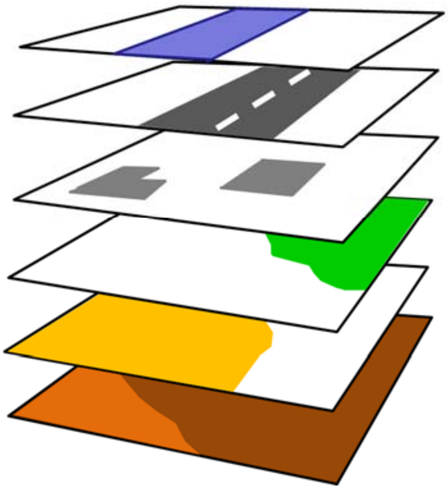


Figure 3.4. Different information layers are combined into one set of information per gridcell. Vegetation and building information is given as a fraction per cell, roads and channels are given as width in m. The soil layer is the base layer so that we always know what for instance the infiltration beside a road or house is. Infiltration and flow resistance are determined as a gridcell weighted average response.

This setup needs a lot of data, because in a raster GIS, that is essentially what LISEM uses, each property is defined in a new map layer. For instance the channel is characterized by 7 maps, for width, depth, angle of the channel sides, bed slope, flow resistance, and areas with imposed maximum flows (for bridges and culverts). The total number of input maps for LISEM looks daunting at a first instance, but they are all derived from 6 basic maps and several tables with soil and vegetation properties. This is explained in detail below. In the CHARIM project, a GIS script is created to do this automatically. The GIS used is the freeware GIS PCRaster developed at the Utrecht University, the Netherlands (pcraster.geo.uu.nl). This is just for convenience, in principle LISEM can use data from other GIS systems if it is in GeoTIFF format.

4 Rainfall data analysis, return periods and design storms

LISEM needs rainfall intensity in mm/h, preferably for small timesteps (<15min), so that it can calculate accurately infiltration and runoff. Many islands have daily data, sometimes hourly and sometimes minute data. Of the islands, only Saint Lucia has an extensive network of daily total rain gauges, and also automatic tipping bucket rain gauges, which give 1 minute intensities data since 2003 (but not operational 100% of the time). These were used to create design rainfall events for 5, 10, 20 and 50 year return periods, as is explained below.

A frequency magnitude analysis is done on the annual maximum daily rainfall of available stations with records of at least 20 years or longer. This gives us the maximum daily rainfall for different recurrence intervals. Subsequently, design storms are created with 5 min intensities that have a total rainfall depth corresponding to the daily maximum values.

4.1 Rainfall data quality

St Vincent has several stations but of only one station data was obtained in this project: Joshua Airport at Arnos Vale (fig 4.1). Of this station, 21 years of daily data (1987-2008) was used in a frequency magnitude analysis, using a Gumbel analysis and Generalized Extreme Value analysis. Because of the limited time series, the maximum return period considered was 1:50 years. This is also consistent with the other islands in the CHARIM project.

Figure 4.1. Location of the ET Joshua Airport rainfall station used in the return period analysis.

A Gumbel distribution was fitted to the data of the station, which is a special case of Generalized Extreme Value distributions, suitable for right hand skewed datasets (such as rainfall, which cannot be less than 0, but can have extreme maxima). The Gumbel distribution assumes a double logarithmic relation between the maximum rainfall R and the return period T. The return period is the inverse of the occurrence probability P. Figure 4.2 shows the Gumbel analysis of the Joshua Airport station with a reasonable linear fit between the log-log values of the return periods and the maximum daily rainfall.

The highest 3 maximum daily rainfall values are related to known tropical storms and hurricanes. Hurricane Ivan in 2004 passed over the island and caused a lot of devastation. Hurricane Lili caused devastation on St Lucia and Dominica, and also St. Vincent and the Grenadines were heavily damaged, especially compared to other islands in the area. Several hundred homes and two schools were damaged, and the Rose Hall Police Station's roof was lost (NOAA hurricane data).

Similar to the other islands a Generalized Extreme Value (GEV) analysis was done to determine return periods. The GEV analysis is better suited to extremely skewed distribution than the Gumbel analysis (Gumbel is a special case of GEV). In the interest of consistency of method, the results are shown in figure 4.3. The GEV fit parameters of the Joshua Airport station are: mu = 83.0, sigma = 27.7 and k = 0.299.

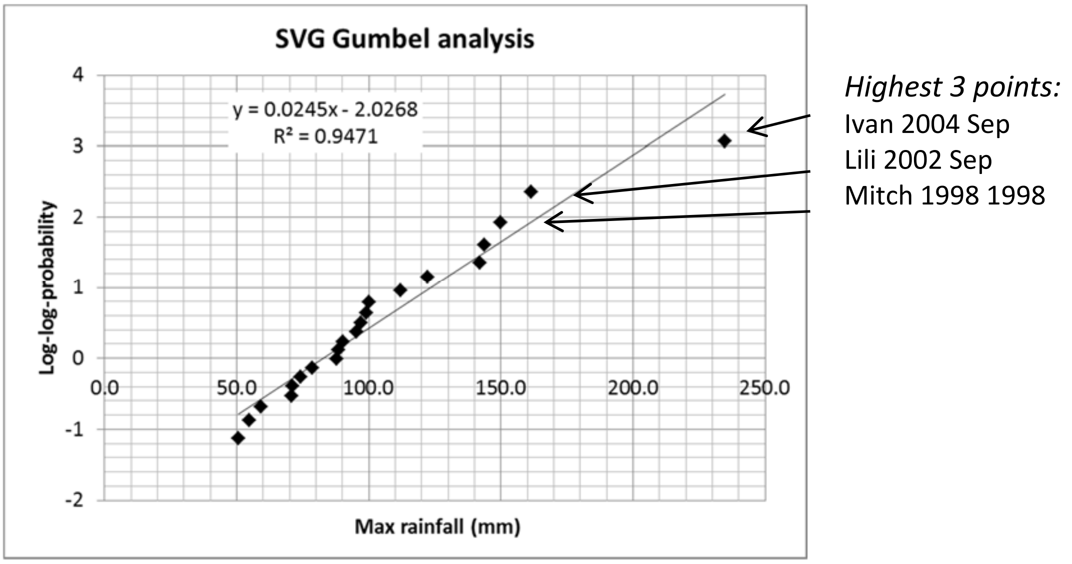


Figure 4.2. Gumbel analysis of maximum daily values of Joshua Airport station (21 years: 1987-2008). The highest 3 maximum daily rainfall are related to known tropical storms and hurricanes.

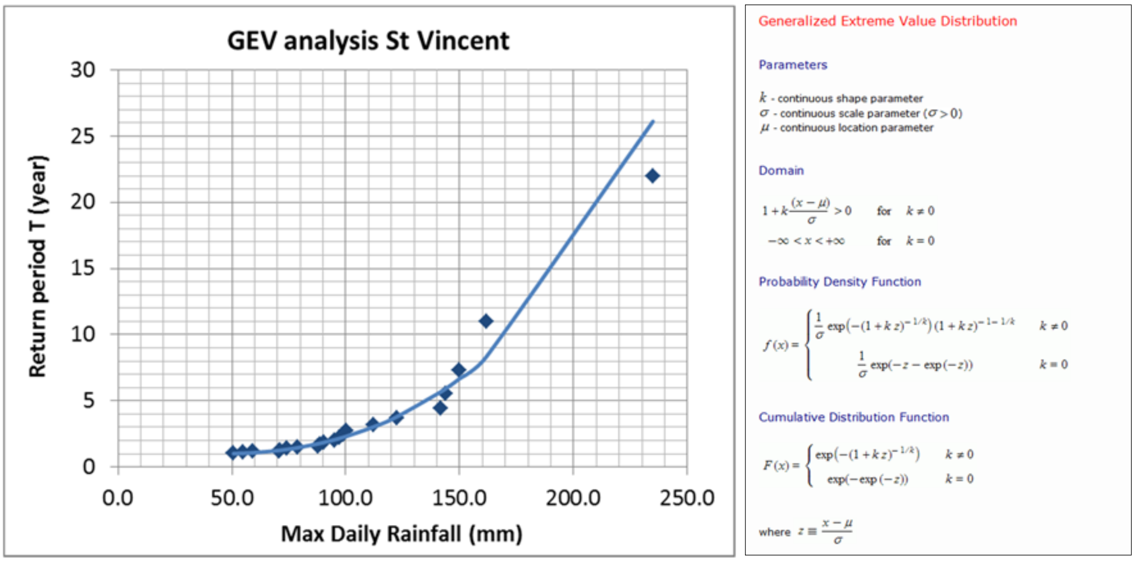


Figure 4.3. GEV analysis of the Arnos Vale station and resulting daily total values.

It is not known if this is representative for the west coast and east coast of the island, although possibly the exposure to hurricanes form the Atlantic might be a reason for higher rainfall at the east coast. This is speculative as the entire weather system of the Caribbean is affected by Hurricanes and tropical storms. On St Lucia and Dominica analysis exist that shows that there is an increasing rainfall towards the interior with the orographic effect of the central mountains, at least for the annual totals. Whether that is also true for individual rainfall events is not known, but some of the hurricanes and tropical storms are far larger than the islands and orographic effects may not be present for these magnitudes.

Looking at the return period analysis of the four islands in CHARIM (Grenada, St Vincent and the Grenadines, St Lucia and Dominica), a north south gradient can be clearly seen in the design storm depth based on the analysis of daily maxima (fig 4.4). A possible explanation lies in the nature of hurricanes and severe tropical storms, they cross the Atlantic at the equator and veer north due to

Coriolis forces. They influence local weather systems as well, which possibly leads to a North-South gradient in amount of rainfall in the Caribbean. However, it should be noted that apart from Saint Lucia, the other islands have only 1 or 2 stations with long records, normally near the airport or the capital. A north-south trend should be seen as a possible indication at best.

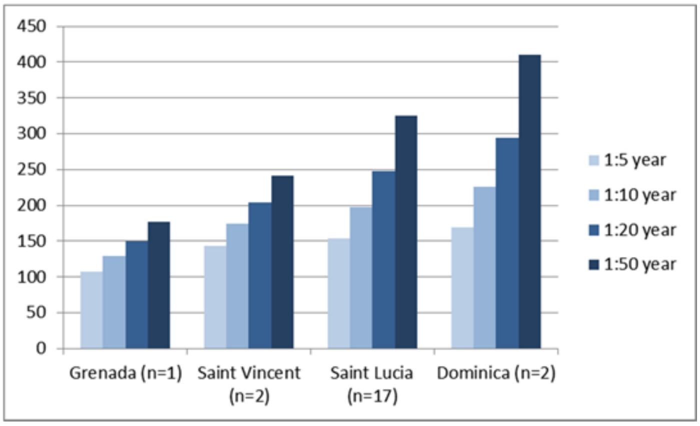


Figure 4.4. Return periods and daily maxima from GEV analyses of rainfall stations at the 4 islands in CHARIM.

4.2 Design storms

A hazard analysis cannot be done on actual rainfall events because this would make the comparison between events of different magnitude impossible, if they are spatially very different. Design rainfall event have to be used. Design storms are used mostly in civil and construction engineering to calculate proper dimensions of channels, culverts and bridges. These are events that correspond to a certain shape, size and duration for each return period that is needed (in this case 5, 10, 20 and 50 years). The total size of the design events (the rainfall depths) should be identical to the GEV analysis sizes in Figure 10.

A common way to create a design event is from intensity-duration-frequency curves, or IDF curves. A few such curves exist for the region, but mainly for the northern part of the Caribbean. Lumbroso et al. (2011) constructed IDF curves for the Bahamas (fig 4.5). They also included St Vincent and the Grenadines in their analysis, but the data is not suitable to derive information for 5, 10, 20 and 50 year events. IDF curves also exist for the Florida but those are considered not representative as they are too far north and the climate might be dominated by the US landmass and are likely not representative for St Vincent.

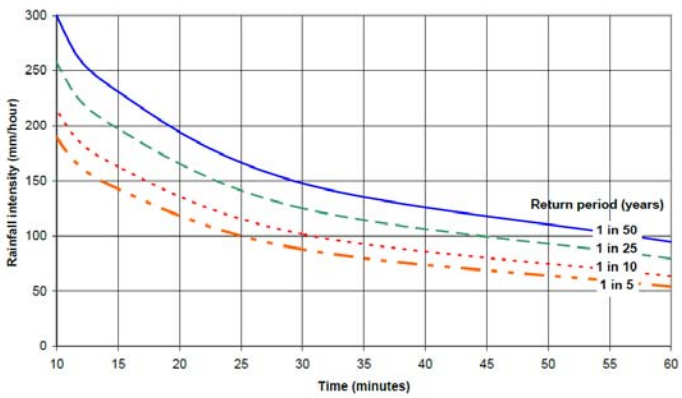


Figure 4.5. IDF curves for the Bahamas (Lumbroso et al., 2011).

Analyzing the detailed rainfall data on st Lucia, there were in total 35 rainfall events of 90 mm and larger, based on the 1-minute intensity data of 15 stations over a period of 3 to 11 years (depending on the station). These events were grouped according to total depths. Of course the larger events only have a few realizations, a summary is given in Figure 4.6. Average depth and duration are well correlated, while the average maximum intensity does not show any correlation with event size. In other words, larger rainfall events are longer in duration, but not necessarily more intense. In reality they are very complex with temporal and spatial variability.

Event	average size	min	mm/h	n
350-550 mm	463.7	1481.5	144.0	4
250-300 mm	258.6	837.6	172.8	5
200-250 mm	202.1	870.0	132.0	2
150-200 mm	160.2	628.3	147.0	4
100-150 mm	119.3	388.6	150.0	8

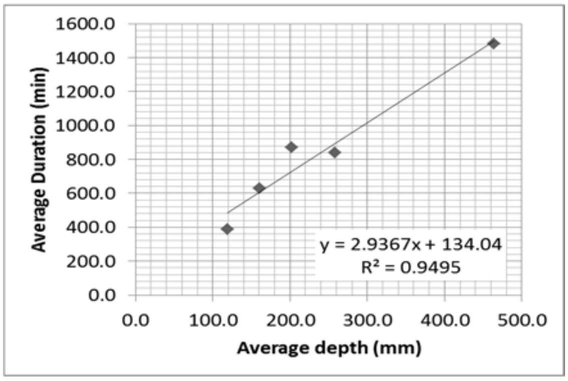


Figure 4.6. Summary characteristics of the 23 largest events, from 15 stations in 10 years. Average depth and duration are well correlated, while the average maximum intensity does not show any correlation with event size.

Within each class the events were fitted with a probability density function, for which a Johnson SB distribution was used. To do this events were from all stations in each class and converted to relative cumulative data (relative rainfall depth versus relative duration). This allows all events to be fitted with a similar set of parameters. The procedure also has a smoothing effect compared to the more erratic real rainfall distribution of an event. Figure 4.7 shows an example from Cardi station on St Lucia.

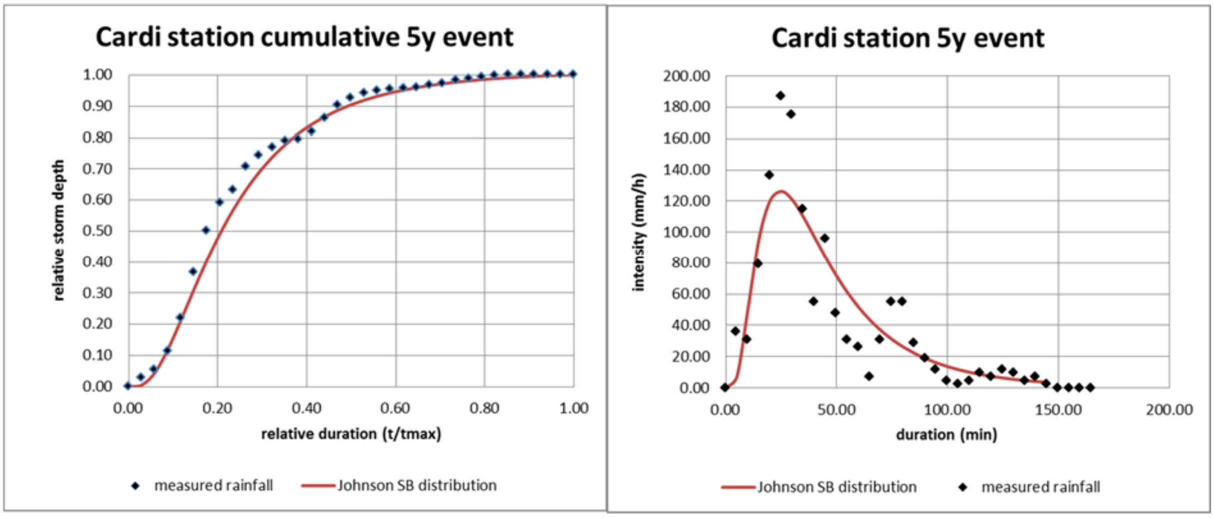
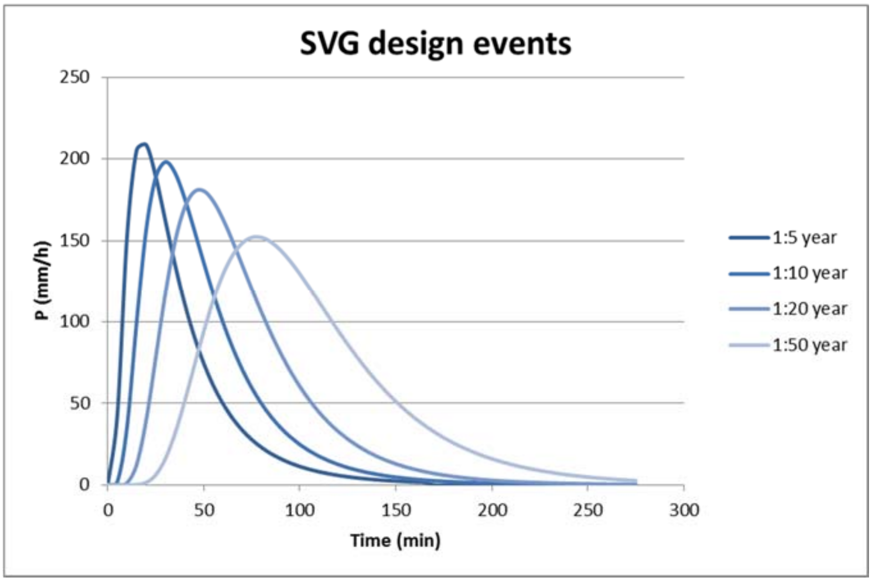


Figure 4.7. An example of fitting a Johnson SB probability density function to an event from Cardi station. Left: relative cumulative event used for fitting; right: the real event and design event shape.

This resulted in a set of Johnson SB distribution parameters for each class. These were then scaled up so that the curve describing the rainfall event has a depth and intensity close to the measured average maximum intensities. This resulted in the design events shown in fig 4.8. There is a gradual decrease in peak intensity from 5 to 50 years return period, and a larger storm depth. The duration of the design storms is considerably shorter than the real average duration as shown in Figure 4.8, which is because in the real events there are frequently short periods with low amounts of rainfall while the design events is a single closed event.



	1:5 year	1:10 year	1:20 year	1:50 year
Depth (mm)	143.9	174.6	204.0	242.0
Max Intensity (mm/h)	208.8	198.2	180.5	152.0
Duration (min)	195	265	330	400

Figure 4.8. Design storms for St Vincent for 4 return periods, based on a Johnson SB distribution fit to representative rainfall events in the classes shown in fig 4.6.

5 Spatial database

LISEM uses input data directly to determine the hydrological processes that it simulates. There are very few built-in assumptions. For instance, LISEM does not handle units like "Maize" or "Forest". This information is broken down into hydrological variables related to interception of rainfall and resistance to flow. The user has to break these classes down into hydrological variables for cover, infiltration related parameters and surface flow resistance.

Nevertheless, in this project a PCRaster script is made to create the 5 data groups for a model run (columns in fig 5.1), for which basic maps are needed (row 1). Using a combination of field data and literature (row 2) the input database for the model is created (row 3). Table 5.1 describes briefly the main base maps, their origin if known, and how they are used in LISEM.

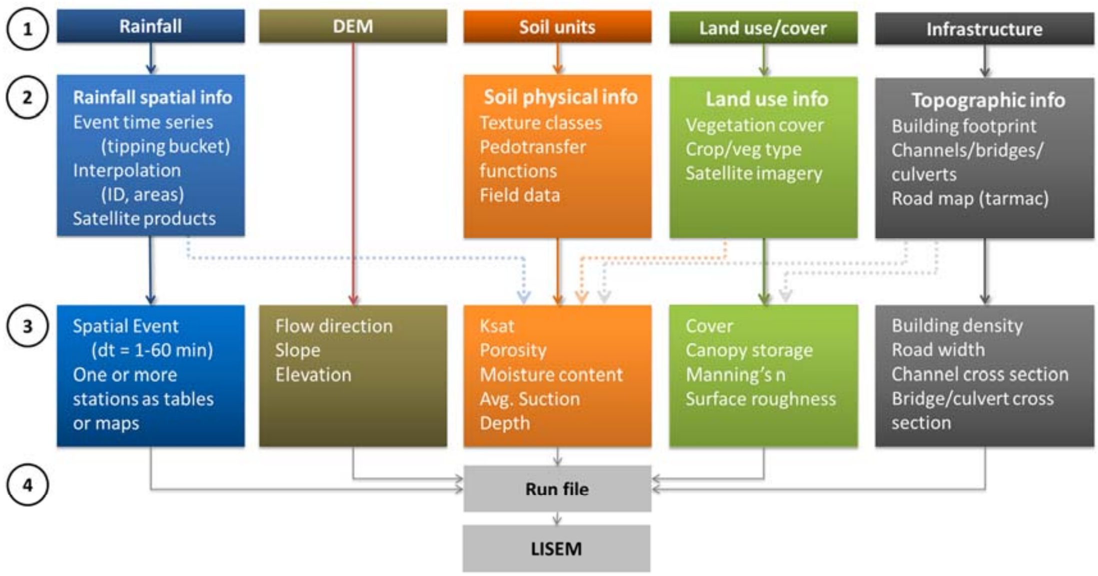


Figure 5.1. Flow chart of the creation of an input database for LISEM from 5 basic data layers. The database is generated automatically in a GIS (PCRaster) with a script that is tailor made for CHARIM islands

5.1 DEM and derivatives

The DEM is used for overland flow directions and slope in the runoff part of the model, and the elevation is used directly in flood modelling. It is partly based on LIDAR data, but the flightpaths did not cover the entire island. Within CHARIM the 5m LIDAR DEM was patched using SRTM elevation data (fig 5.2 left). The DEM was subsequently resampled to 20m, using the average of 2x2 cells. The patched area does not greatly influence the flood hazard as this is mainly an uninhabited area (Soufriere reserve) and only affects the upstream hydrology to some degree (fig 5.2 right).

Basic data	Created from	Method
DEM	Created in CHARIM by merging different LiDAR data sets (5m), and filling gaps with SRTM data (30m).	Resampled to 20m.
Soil Map	Shape file. Origin 1966 soil map made by UWI Imperial College of Tropical Agriculture.	Soil types have a texture class indication which are converted to soil physical parameters with pedotransfer functions by Saxton and Rawls (1986).
Land cover map	Based on classified images 2014, Pleiades and RapidEye images, British Geological Survey.	Has 18 classes for land cover information, interpreted directly to hydrological parameters.
Road map	Shape file, 4 road classes, highway, main roads, other roads, footpaths	Translated to a width and foot paths are considered as partly compacted grid cells
Building map	Topologically corrected, and updated building footprint maps, representing current situation with information on building use and population estimate	Converted to building fraction per 20x20m gridell.
River map	A vector map of main rivers exist.	The main channels were rasterized.

Table 5.1. List of main data layers for St Vincent, their origin and main operations for hydrological database preparation.

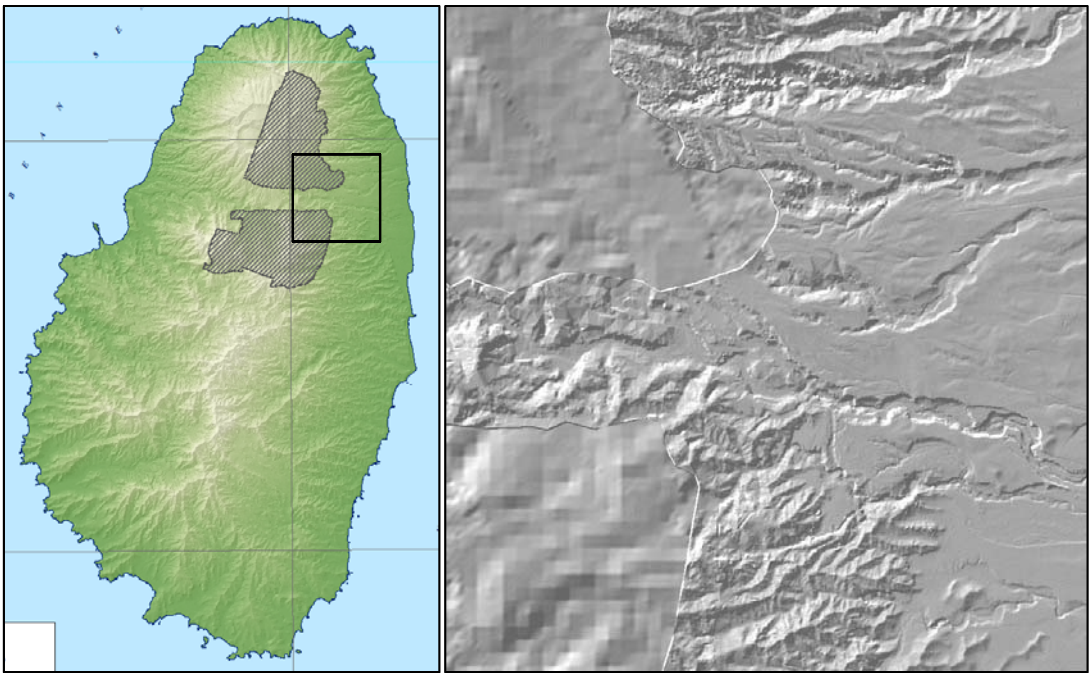


Figure 5.2. DEM in 5m resolution. Left: hashed area has no LIDAR information and is repaired with SRTM elevation information. Right: the difference in detail can be clearly seen, this affects the upstream hydrology/runoff but there is little flooding in this area and no inhabitation.

The DEM quality influences the flood hazard simulation on the east coast, north of Grenville. This further explained in chapter 6.

Soil depth

The soil depth is unknown and in spite of the simplicity of the parameter, it is not well studied and few algorithms exist to generate a soil depth map. Kuriakose et al., (2009) generated soil depth for a mountainous catchment in the southern India, in the Ghats mountains. The research was part of a landslide research where soil depth was one of the more important parameters. The situation is very similar to the Caribbean islands: tropical wet climate (Monsoon driven), soil formation due to weathering, although not from volcanic origin, and rapid denudation that causes slopes with thin soils and valleys that are filled up with debris over time, by erosion and mass movement. Derived from the this research, the following GIS operation was used to create a soil depth map (in m):

Soil depth $= a((1-S) - b\,D_{river} + c\,D_{sea}{}^{d})^{e}$

where:

S = terrain slope (bounded 0-1)

D_{river} *= is the relative distance to the river channel (0-1)*

D_{sea} *= the relative distance to the sea (0-1)*

Scaling parameters: a=1.5, b=0.5, c=0.5, d=0.1, e=1.5

The logic is that steeper slopes have shallower soil, closer to the river the soil depth increases, and closer to the sea the soil depth decreases. Visual field checks have not been done on St Vincent, but on the islands of St Lucia and Grenada have been done, although limited to observations of river depth (surface to bedrock) Fig 5.4 shows the soil depth for an example area. The river depth is simply the soil depth in the channel pixels.

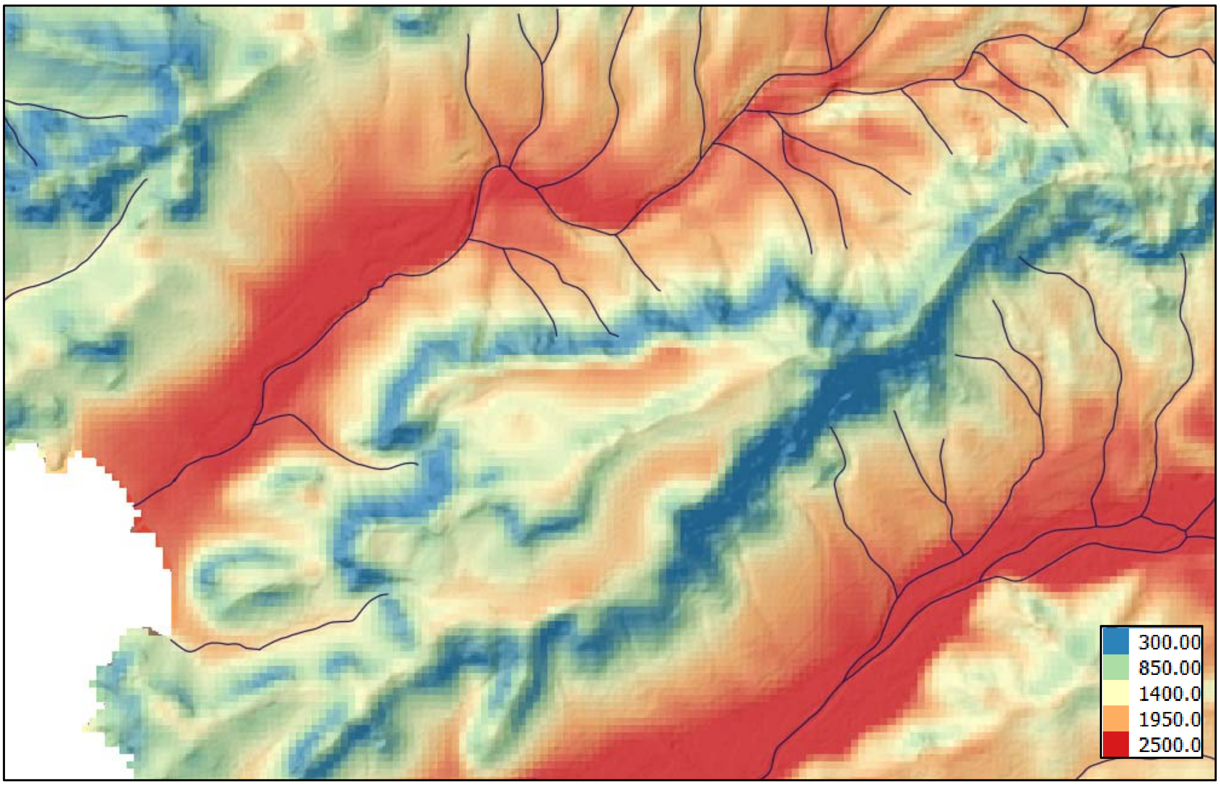


Figure 5.3. Example of soil depth (in mm) generated from the DEM, river system and proximity to the sea. Steeper slopes have shallower soil, valley floors accumulate soil.

River network and channel dimensions

Since LISEM generates floods by overflowing channels, accurate channel maps are important. A shape file with the rivers exists in the St Vincent database, which is based on airphoto or high res image digitization. This means that some river branches are not connected to the main channel where they are not visible (for instance under the forest canopy). Nevertheless the river network is of a high quality. The 5m DEM from the LIDAR data is accurate enough to follow the main river channels and a few corrections have to be done in the river network. Figure 5.5 gives an example Kingstown. Manmade channels such as road drainage are not included as they are not available, but they would not be used in the national flood hazard map anyway. The river network follows all valleys and may have been automatically generated, and therefore may not depict actual river channels in the first order branches. On the national scale the first order branches were omitted, because if these exist they are often small and their cross sections poorly defined. Following the same principle of not including man-made road drainage systems and gutters at this scale, so are the first order channels not included in the river network for flooding.

From the river network at 20m, the channel dimensions are derived automatically. It is assumed that the river dimensions increase from the source to the outlet near the see. Note that LISEM has the restriction that the river channel cannot be wider than the gridcell, because the flow is a 1D kinematic wave in the converging channel network. The algorithm used is based on Allen and Pavelski (2015) who show that for large North American river systems there is a good correlation between total rive length and river width. They further extrapolated their data to smaller river systems, using the total river surface area, and correlated that to river width ($r^2 = 0.996$, $p < 0.001$):

$$\text{Area} = 3.22e4 * W^{-1.18}$$

This equation is used in the dataset, whereby the river area is approximated as the accumulation of cell area from the river source to the outlet.

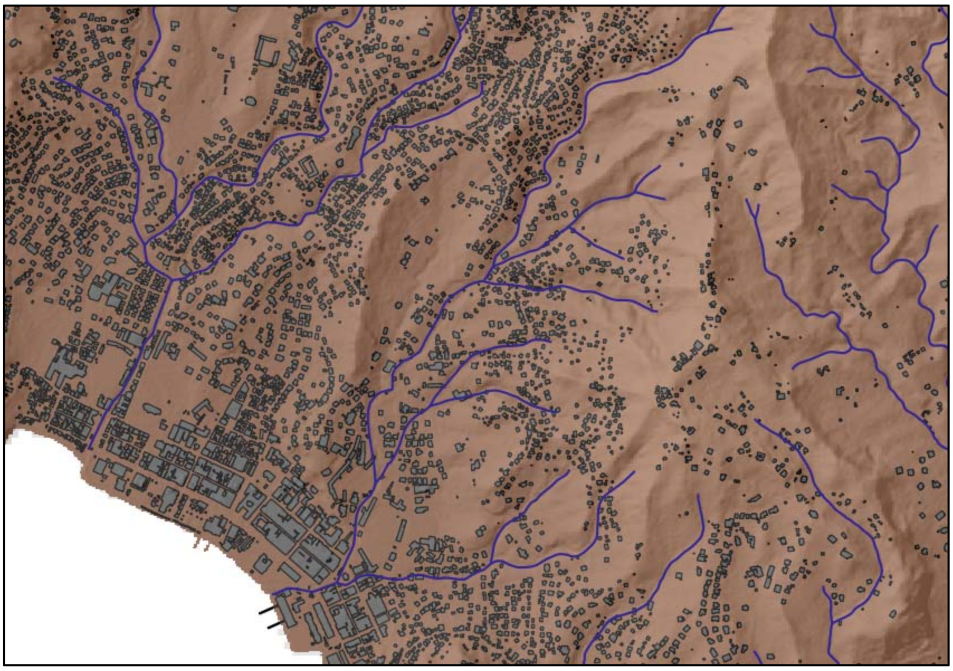


Figure 5.4. Stream network example showing that the stream follow the 5m LIDAR relief very well.

Everywhere it is observed that the river has eroded until bedrock, apart from the last few kilometers or so near the mouth of the river, where sedimentation takes place and the river widens. This river depth was estimated by using the soil depth as river depth (explained above).

Important: at the national scale sedimentation of sand and debris in the river beds is not included. Occasionally this may cause obstruction of culverts and bridges, or greatly decrease the storage capacity of the channels. Hence the flood map shows the situation with clear rivers with maximum capacity, using the assumptions of dimensions as explained above.

The river network in LISEM is characterized by two more parameters: the slope of the river bed and the resistance to flow (Manning's n). The slope of the river bed is obtained by taking the slope of the DEM in its steepest downstream direction. The Manning's n is taken from comparing observations in the field with literature values. Morgan et al. (1998) has compiled a large number of values for different surfaces, and the USGS websites provides visual references: http://wwwrcamnl.wr.usgs.gov/sws/fieldmethods/Indirects/nvalues/. Generally the riverbeds are either sedimented or rocky with boulders, which gives a Manning's n of 0.03-0.04, and the banks are overgrown with abundant natural vegetation, so the value was increased to 0.05.

5.2 Soil map and derivatives

The soil map was developed in 1959 by the Soil Research Unit of the University of the West Indies, St. Augustine, Trinidad. The soil base map was digitized in 2007 in the he national land Information Management Project (NALIMP). The geological bedrock is also relatively young, therefore time, has not yet been an import soil-forming factor. The digital soil map was classified into 46 soil unit types (fig 5.5).

The soil mapping was primarily based on topography, drainage, parent material and not according to pedology which emphasizes how the soils originated. The approach taken by the surveyors reflected the need to produce a survey that would be of most use for the agricultural community, not for its potential use in geotechnical investigations (CDERA, 2006). The classification system follows the US convention of assigning a "typical soil profile" and giving them a name based on the type location, such as "Brighton Sandy Clay" or "Soufriere Loamy Sand". Each of these units has a texture class indication according to the USDA texture class triangle, and the class average grain size distribution was assumed. Based on the texture class the soil physical parameters Saturated Hydraulic Conductivity (Ksat in mm/h), Porosity (cm^3/cm^3) and average initial matric suction (kPa) were derived, using the pedotransfer functions of Saxton and Rawls (1986), see fig 5.7.

Figure 5.5 shows the 46 main classes in the St Vincent soil map, which are translated to 10 texture classes in table 5.3 and 3 additional units: water, urban area and rock outcrops. These are the main hydrological units used in the model for the water balance.

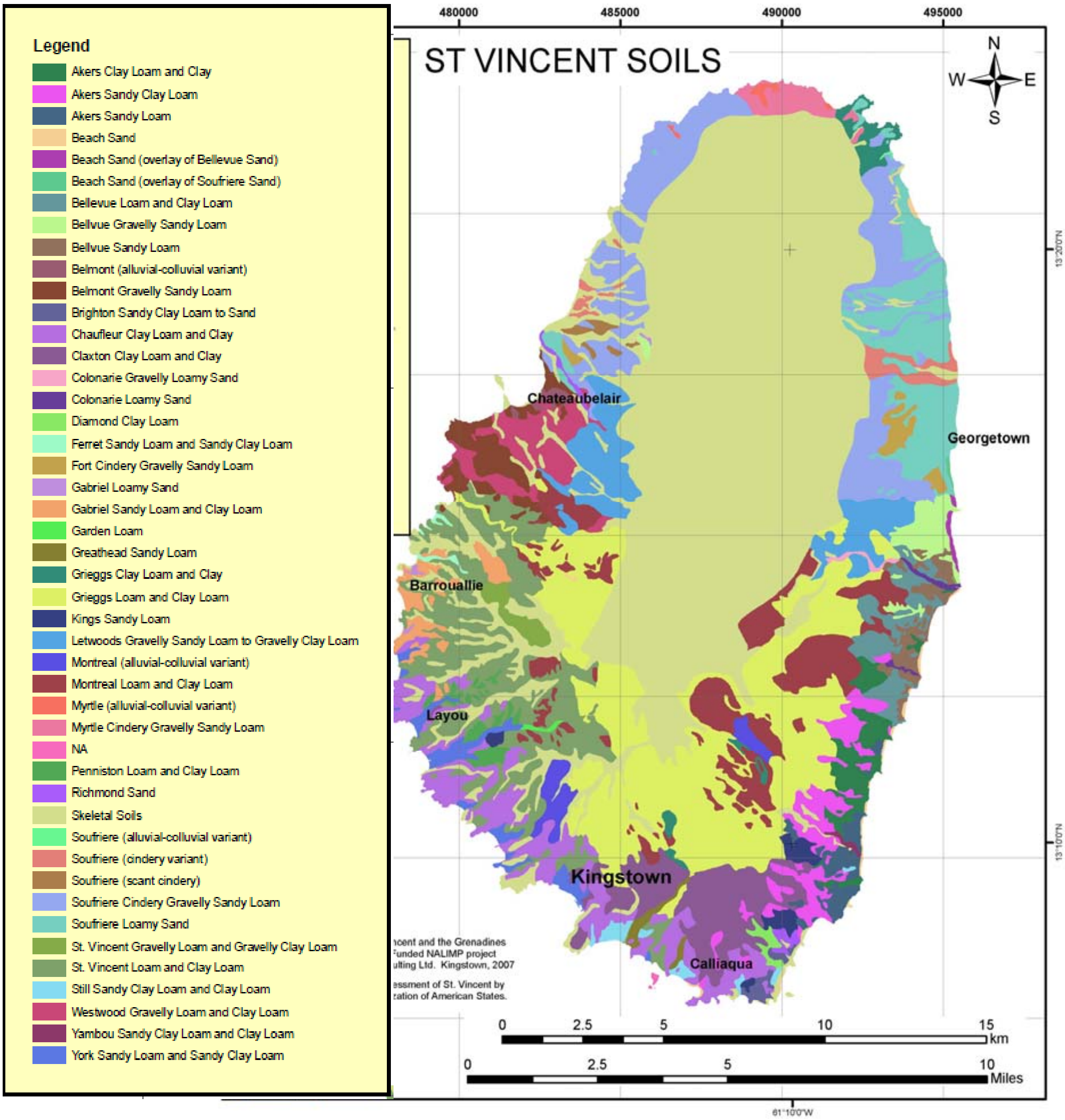


Figure 5.5. An overview of the soil types of St Vincent (EU NALIMP project 2007).

The pedotransfer functions are largely texture based, with effect of stoniness and organic matter. The stoniness is information given for each soil class in the soil map which causes a small effect on Ksat and somewhat larger on porosity (Saxton and Rawls, 1986):

$$Ksat_{eff} = Ksat*(1 - stone)/(1 - 0.85*stone)$$

$$Pore_{eff} = Pore*(1-stone)$$

It is known however that the soil structure has a large effect on the Ksat and porosity. Normally a soil classification system is not based on the top soil as this is often affected by agriculture and building activities. The texture indications are valid for both top soil and subsoil, but under natural vegetation the top soil has a much more open structure. The clayey soils, derived from weathered volcanic material, form strong and stable aggregates under natural conditions, that give the soil an open structure with a high porosity and high saturated hydraulic conductivity. This means that the top soil can absorb quickly large amounts of water, depending on how dry it is. Under agricultural circumstances the tops soil is more massive during most of the year, for instance as in the frequently occurring Banana plantations. Trampling of the soil destroys its structure. In fig 5.6 it can be seen that the natural vegetation occupies a large part of the island (red color) and the flood hazard in these catchments is lower than in the rest of the island.

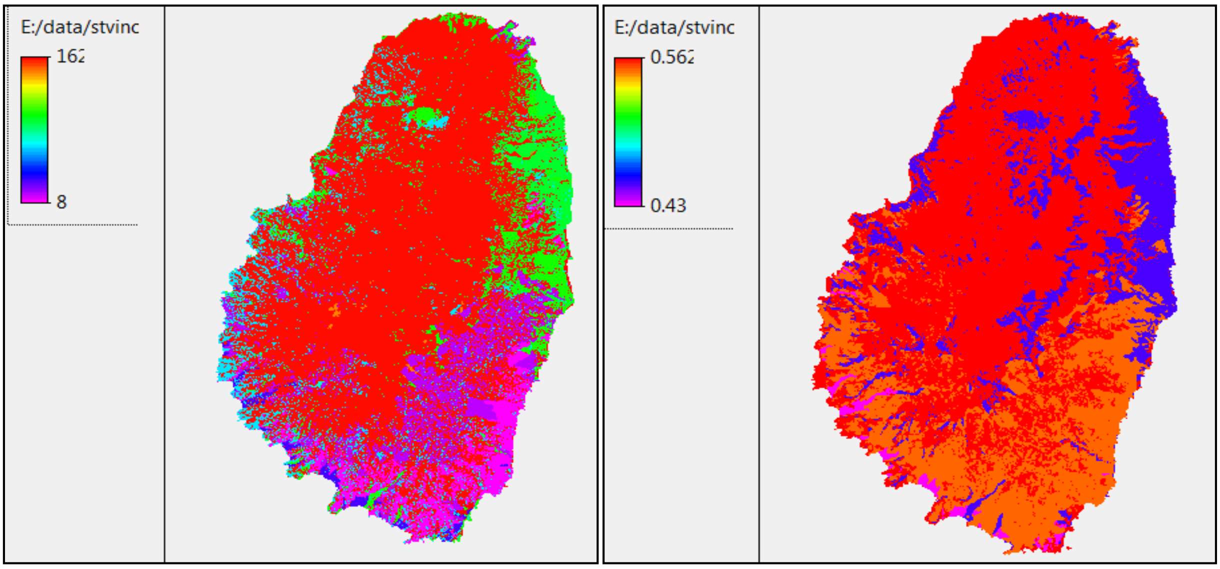


Figure 5.6. Left: Maps of saturated hydraulic conductivity (ksat, mm/h) and right: porosity (-) . Values are given in tables 5.2 and 5.3.

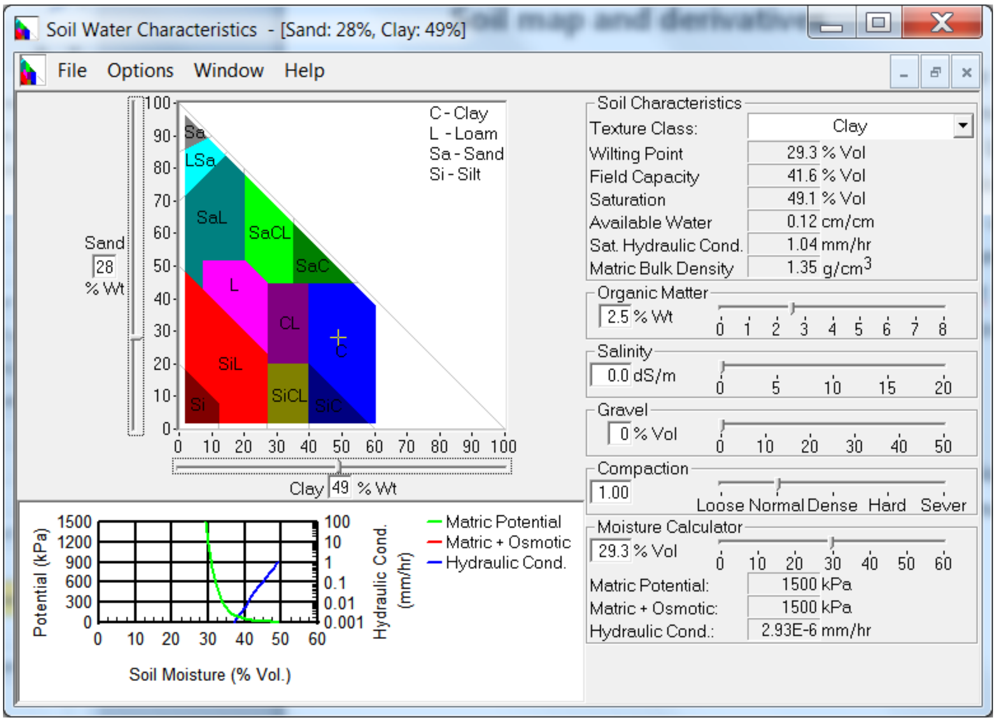


Figure 5.7. Pedotansfer functions by Saxton and Rawls (1986) used in SPAW model software.

As is common in tropical environments, the organic matter rapidly decreases with depth because of the high degree of decomposition. This was confirmed by Pratomo (2015), who determined the saturated hydraulic conductivity from 64 sample rings and porosity from 72 sample rings on Grenada, in the Gouyave and St John watersheds as part of a comparative catchment study in the CHARIM project. It is clear from figure 5.9 and table 5.2, that the saturated hydraulic conductivity value (ksat in mm/h) under natural vegetation is a lot higher than the statistical values for the clays and silty clays in the area (table 5.3). This is attributed to the high organic matter content and open structure of the forest soils. The agricultural area was clearly closer to the statistical values found by Saxton and Rawls (1998), although there is a large spread as is also common for conductivity. The porosity values are generally high which is also common to clay rich soils and there is much less variation.

It was therefore decided to use a two layer Green and Ampt infiltration model in LISEM, whereby the top layer of 15 cm, has larger values of Ksat and porosity than the second layer for all land cover types that consist of natural vegetation (see table 5.4, column 4 and 5). This results in the maps shown in figure 5.10 for the top 15 cm of the soil.

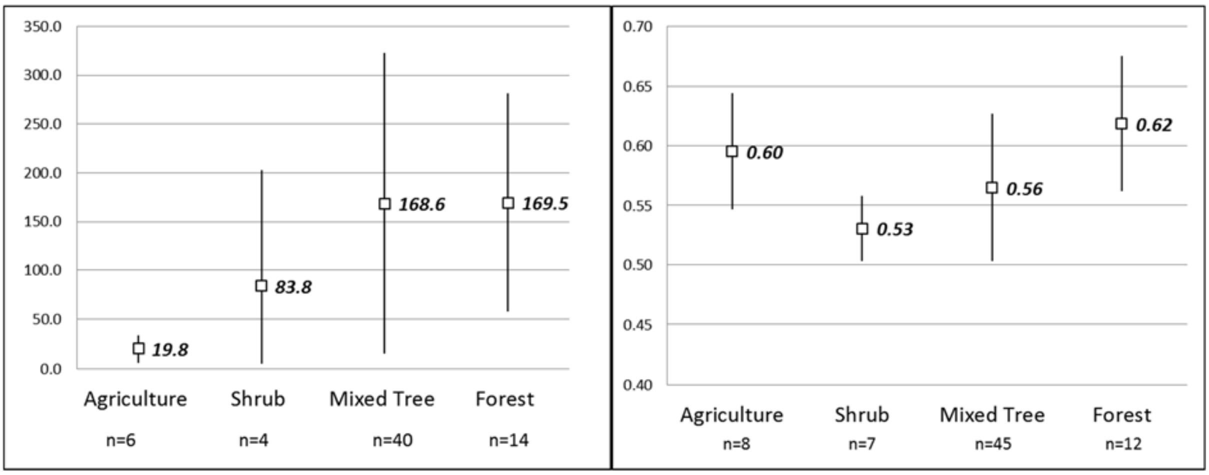


Figure 5.8. Left: saturated hydraulic conductivity (mm/h) and right: porosity (-) organized per main land cover type. The measurements are from Grenada, taken in the Gouyave and St John watersheds (Pratomo, 2015). The values in bold are the average, the lines show one standard deviation around the mean.

	Ksat (mm/h)				Porosity (cm3/cm3)			
	Agriculture	Shrub	Mixed Tree	Forest	Agricultur	Shrub	Mixed Tree	Forest
min	5.4	5.4	10.7	21.4	0.50	0.50	0.44	0.53
-std	6.1	5.3	14.5	57.4	0.55	0.50	0.50	0.56
avg	**19.8**	**83.8**	**168.6**	**169.5**	**0.60**	**0.53**	**0.56**	**0.62**
+std	33.5	202.5	322.6	281.6	0.64	0.56	0.63	0.68
max	42.9	257.1	492.9	321.4	0.65	0.57	0.70	0.70
n	6	4	40	14	8	7	45	12

Table 5.2. Basic statistics of soil physical parameters measured in Grenada in the Gouyave and St John catchments, in clays and silty clays (Pratomo, 2015).

nr	Unit	Ksat mm/h	Pore -	Field Capacity -	Wilting Point -
1	C	9.0	0.56	0.40	0.25
2	CL	16.0	0.54	0.35	0.20
3	L	74.0	0.48	0.25	0.10
4	S	161.0	0.45	0.11	0.06
5	SCL	31.0	0.43	0.28	0.15
6	SL	102.0	0.45	0.18	0.06
7	Si	73.0	0.46	0.30	0.06
8	SiC	15.0	0.56	0.41	0.24
9	SiCL	22.0	0.50	0.38	0.18
10	SiL	48.0	0.48	0.30	0.09
20	Water (W)	1.0	0.00	0.00	0.00
21	Urban (A)	15.0	0.40	0.30	0.06
23	Rock/outcrops (R)	1.0	0.30	0.11	0.06

Table 5.3. Main classes derived from the soil map and assumed saturated hydraulic conductivity (Ksat in mm/h), Porosity (pore in cm3/cm3), field capacity and wilting point (cm3/cm3), after Saxton and Rawls (1986).

The advantage of this approach is that the forested areas have a larger buffering effect than would be evident form the soil texture alone. Also land use changes have a larger effect on the hydrology and flood dynamics than if soil units are directly used, which is assumed to reflect the reality better. The Green and Ampt infiltration process in LISEM needs the matric suction at the wetting front, based on the initial moisture content that is assumed. All simulations of the flood hazard use an initial moisture content (θi) of 0.75 of the porosity (θs), which is approximately at field capacity (θfc) or slightly wetter. Since the porosity is adapted to the presence of natural vegetation, the initial moisture content is adapted as well.

The matric suction (psi in kPa) is calculated directly from the initial moisture content using the following set of equations (Saxton and Rawls, 1986):

$$psi = a\, \theta i^{-b}$$

where:
$$b = (\ln(1500)-\ln(33))/(\ln(\theta fc)-\ln(\theta wp))$$
$$a = \exp(\ln(33)+b\,\ln(\theta fc))$$
1500 and 33 = matric suction for resp. wilting point and field capacity (kPa)

5.3 Land cover and infrastructure

Land cover map and hydrological parameters

A 2014 land cover map of St Lucia was created by the British Geological Survey as part of the framework of the European Space Agency (ESA) “Eoworld 2” initiative. The following description is provided (CHARIM Data management book, section basic data collection):

“The satellite data comprised Pleiades imagery (acquired between 2013-2014) and RapidEye imagery (acquired 2010-2014). These datasets have a spatial resolution (pixel size) of 2m and 5m, respectively, for the multispectral waveband images. Additionally, the Pleiades datasets includes a very high-resolution 0.5m panchromatic image. To enable the most detailed information to be resolved, the Pleiades imagery was used as the primary dataset for generation of the new land use/land cover maps for the three AOIs; thus achieving a spatial resolution of 2m, which is equivalent to a mapping scale of 1:10,000. For each of the AOIs, land use/land cover was mapped using a combination of automated image classification, rule-based refinement and manual digitization. The existing 30m maps were used to define the different land use/land cover types and identify representative areas in the imagery to help guide the initial automated classification and to subsequently validate the mapping. Water features and the basic road networks were manually digitized at 1:10,000-scale from Pleiades imagery that had been pan-sharpened to 0.5m resolution using the panchromatic image. Wherever available, existing vector layers were utilized as baseline information during mapping.

"The land use/land cover maps were validated using a standard remote sensing approach, which involves comparing the land use/land cover class identities of a sample of pixels in the map with their 'true' land use/land cover class. The 'true' land use/land cover classes of these pixels were determined using a combination of the pan-sharpened Pleiades imagery and existing maps. Consequently, the maps for St. Lucia, Grenada, and St. Vincent and the Grenadines were found to have accuracies of 84.9%, 84.8% and 80.8%, respectively; which are within the desired target accuracy of 80-90%. Additional validation of the maps for St. Lucia and Grenada was achieved using point-sampled field observations at a number of locations." (BGS, 2014)

The parameters derived from the land cover are those affecting the soil surface structure, which affects infiltration, and roughness, which affects the surface runoff. Also the canopy storage for interception is derived from the land cover type. A soil cover that does not change in time is assumed, which is less realistic for agricultural areas. Cover influences the interception of rainfall by the plant canopy. This is usually in the order of 1-2 mmm (De Jong and Jetten, 2007). The variables *Ksat_nat* and *Pore_nat* (table 5.4) are used for the top layer Ksat and porosity under natural vegetation (see section 5.2).

Land Cover Type	Roughness	Manning's	Cover	Ksat_nat	Pore_nat
Elfin and Sierra Palm tall cloud forest	1.0	0.10	0.95	168.4	0.62
Evergreen forest	1.0	0.10	0.95	168.4	0.62
Mangrove	2.0	0.10	0.95	n.a.	n.a.
Wetland	2.0	0.10	0.95	n.a.	n.a.
Semi-Deciduous, coastal Evergreen and mixed forest or shrubland	1.0	0.10	0.95	83.3	0.53
Lowland forest (e.g. Evergreen and seasonal Evergreen)	1.0	0.10	0.95	83.3	0.53
Golf course	1.0	0.15	0.95	n.a.	n.a.
Woody agriculture (e.g. cacao, coconut, banana)	1.0	0.07	0.95	n.a.	n.a.
Pastures, cultivated land and herbaceous agriculture	1.0	0.03	0.95	n.a.	n.a.
Buildings	0.5	0.02	0.2	n.a.	n.a.
Concrete pavement	0.5	0.02	0	n.a.	n.a.
Roads and other built-up surfaces (e.g. concrete, asphalt)	0.5	0.02	0.5	n.a.	n.a.
Bare ground (e.g. sand, rock)	0.5	0.02	0.1	n.a.	n.a.
Quarry	0.5	0.02	0	n.a.	n.a.
Water	0.1	0.03	0	n.a.	n.a.

Table 5.4. Average vegetation parameters based on field observations. From left to right: roughness is the micro surface roughness (cm) for surface storage, Manning's n is the flow resistance (-), Cover is the vegetation canopy cover (used in interception), "Ksat_nat" (mm/h) and "Pore_nat" (cm3/cm3) are top soil values under natural vegetation.

The values that are used for anthropogenic cover (built up area, concrete, roads etc.) represent the value of soils adjacent to a house or road. As explained in figure 3.3, LISEM uses different layers with information on houses, roads, parking lots etc. as fractions of surface occupied, and the model needs to know the hydrological characteristics of the surface in between these structures, or next to the road in a cell.

Building density map

A building footprint only exists for Roseau, the buildings for the rest of the island have been created by van Westen in the CHARIM project (2015). Apart from Roseau the buildings are indicated by their center point. For these buildings, an average size was used of 70m^2. In LISEM the buildings have an effect on the hydrology by assuming there is rainfall interception from the roof, no infiltration and they obstruct the flow to a certain extent (adding 0.2 as Manning's n by 2 for the fraction of the building covering the pixel.

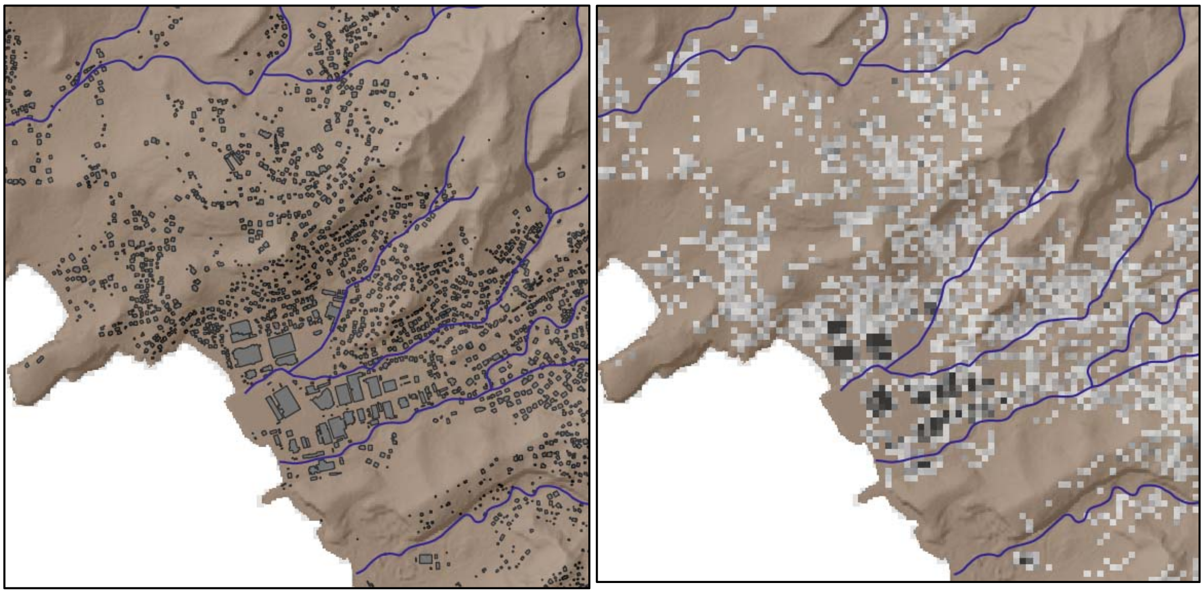


Figure 5.9. Left: Building footprint of Campden Park bay, right: 20m resolution building fraction map used in LISEM (darker grey means higher fraction). Buildings have roof interception, no infiltration and obstruct the flow.

Roads, bridges, dikes

The road shapefile has three types: 1 is the main highway, 2 are primary roads and 3 are secondary roads. All roads in the shape file are tarred roads or paved with concrete slabs. Therefore they are hydrologically smooth, impermeable and have no virtually surface ponding. The roads are reclassified to the LISEM input map according to their width. The highway is assumed to be 10m wide, the primary roads 6m wide and the secondary roads 4m wide.

Note that at the national scale, the road drainage channels are not included, as they are too small. Also the fact that at some locations the road is elevated above the flood plain like a dike, is not included, as that information is not available.

6 Model output and Hazard maps

Hydrological response

The hydrological response of the model with respect to the rainfall is such that the areas that are built up (roads, paved surfaces) generate runoff first, then the soils with a high clay content under non-natural vegetation, and finally the forested areas contribute (see fig 6.1). The overall runoff fraction (average of the island) of a 1:5 year event is 15% and increases to 20% for a 1:50 year event.

All major valleys have flooding effects upstream in the hills. While this is of course dangerous for locations where there are settlements, there is also a hydrological effect of these flooded areas. Flooding upstream generally decreases and slows down the streamflow decreasing the flood hazard downstream near the coast. Site investigations that are based on models that need an incoming discharge to operate, should take this into account. Catchment models that generate a discharge as input for flood models overestimate the discharge when this is not taken into account.

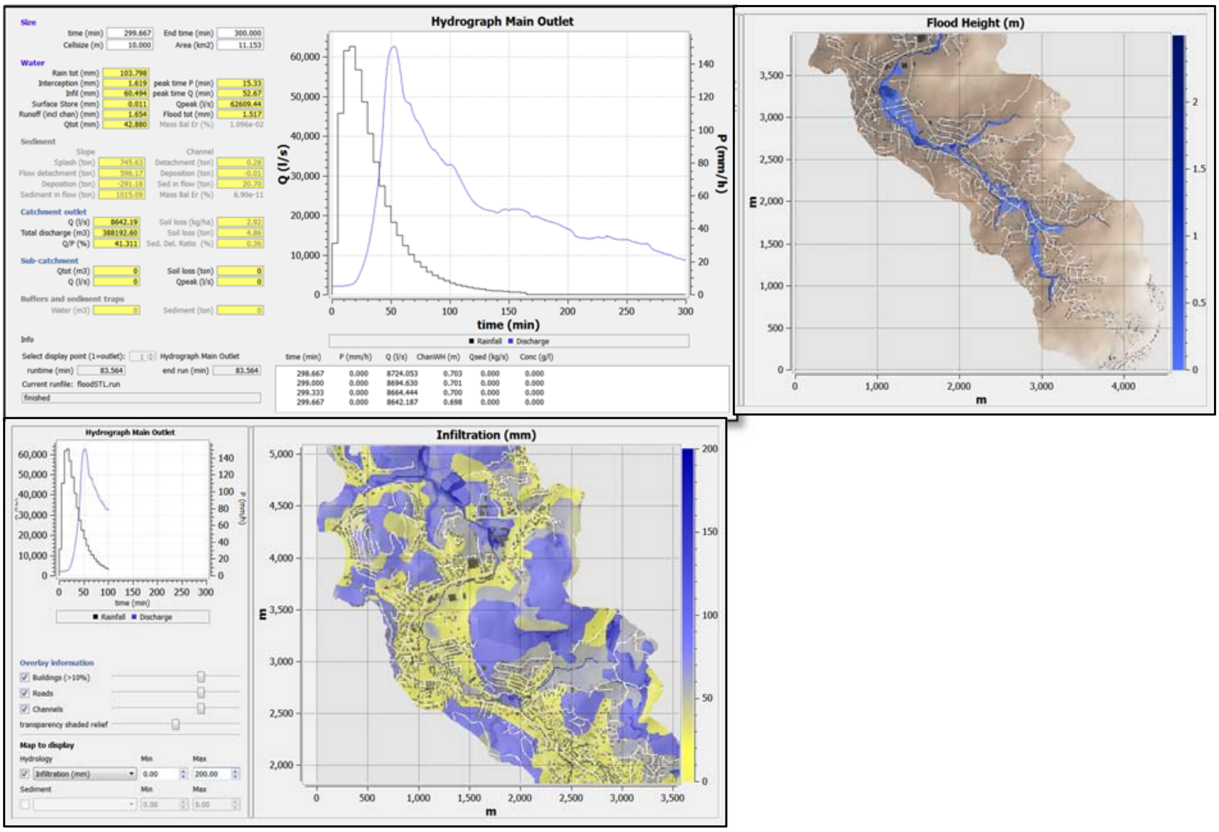


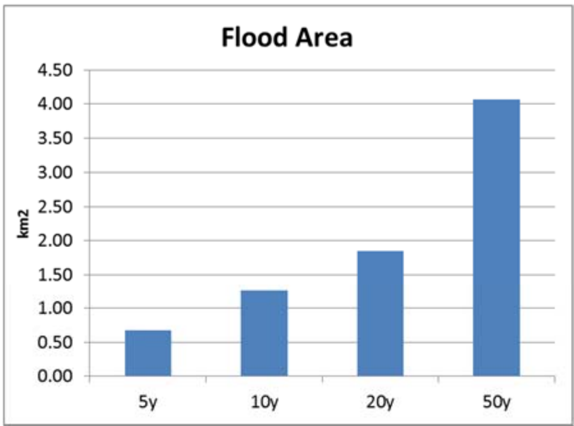
Figure 6.1. Example of the hydrological response in LISEM: top left a hydrograph (discharge in l/s) at a selected channel, top right a flooded area around a channel (flood depth in m), and bottom left the cumulative infiltration (mm) at approximately 100 minutes. The infiltration shows the soil and land use pattern of this catchment for less infiltrating areas (yellow) to more infiltrating areas (blue). The example is from Bois d'Orange catchment on St Lucia.

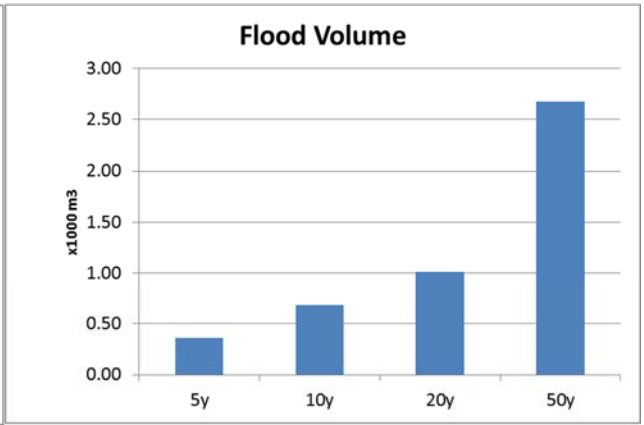
6.1 Summary flood hazard statistics

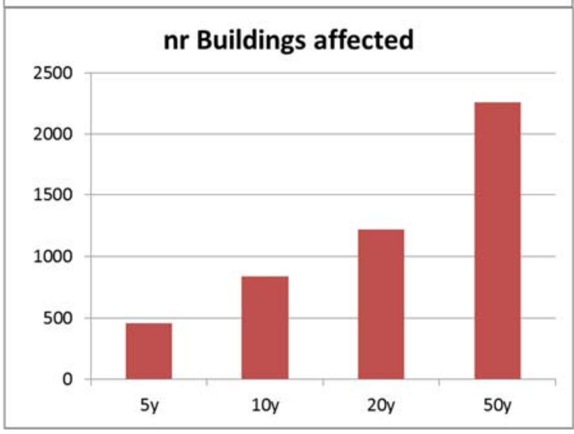
Figure 6.2 shows the summary statistics for the flood hazard for 4 return periods. Note that for these statistics, areas inundated by less than 10 cm were considered not flooded. In total the area flooded increases from 0.7 to 4.1 km^2 while the flood volume increases from 0.4 to 2.7 million m^3.

The average building size in the national flood database is approximately 75 m^2, LISEM does not deal with individual buildings, only with built up area per grid cell area. Based on this average number, the approximate number of buildings affected is 459 for 1:5 years and rises to 2260 for 1:50 years. This analysis gives no indication of the flood depth at the location of these buildings, which can be anything from 0.1 to over 2 meters.

Generally in rapid damage assessment after a hurricane the number of houses damaged is a lot less. The modeled flood hazard says nothing about the potential damage. Houses may well withstand the flood, or due to the inaccuracy of the modelling at national scale, these numbers should not be seen as an indication for actual damage or destruction of houses, but as the number of buildings in the vicinity of the flood water.







	Area (km2)	Volume (10^6 m3)	nr Buildings
5y	0.68	0.36	459
10y	1.26	0.68	837
20y	1.85	1.01	1215
50y	4.07	2.67	2260

Figure 6.2. Summary statistics of the national flood hazard map for the 4 return periods. Note that the building nr. affected is an approximate number based on an average building size of 75 m^2.

6.2 Stakeholder evaluation of Draft Flood hazard map

Although floods and flood damage is reported after hurricane Ivan (2004), Thomas (2010) and the December through (2013), no flood hazard map of Saint Vincent could be found. Reports of multi-hazard analysis and vulnerability did not show any attempt at flood mapping. A reference is made to a 2006 flood risk study by DLN consultants in the GFDRR rapid damage assessment of 2014 (after the December 2013 through), but this report was not found, and it is not clear if this is a damage study or a spatial flood hazard assessment. For Dominica and Grenada a flood hazard map was made by Opadeyi and Cooper in 2006, but no such study was found for St Vincent.

If this is the case the CHARIM flood hazard map is the first national scale flood hazard map constructed for St Vincent. In any case options for comparison and verification of this map are limited.

A draft flood map was produced in 2015, and evaluated by the stakeholder sin the CHARIM project. Most locations that are indicated as high flood hazard corresponded with the knowledge of the authorities. However one location, Campden Park, seemed to have a too high flood hazard in the 2015 draft map. In the 2016 map the simulations were done again, with two changes. The latest land cover map of the British Geological Survey was used, which affects the hydrology to some extent, and a new relation was found for channel width, as specified in chapter 5. The new flood hazard map does not have the same severity as the draft 2015 map, because the channels are generally wider and can convey more water before overflowing. The 50 year return period extent is still large, but this might never have been experienced in Campden Park so that the perception is of a lower flood hazard.

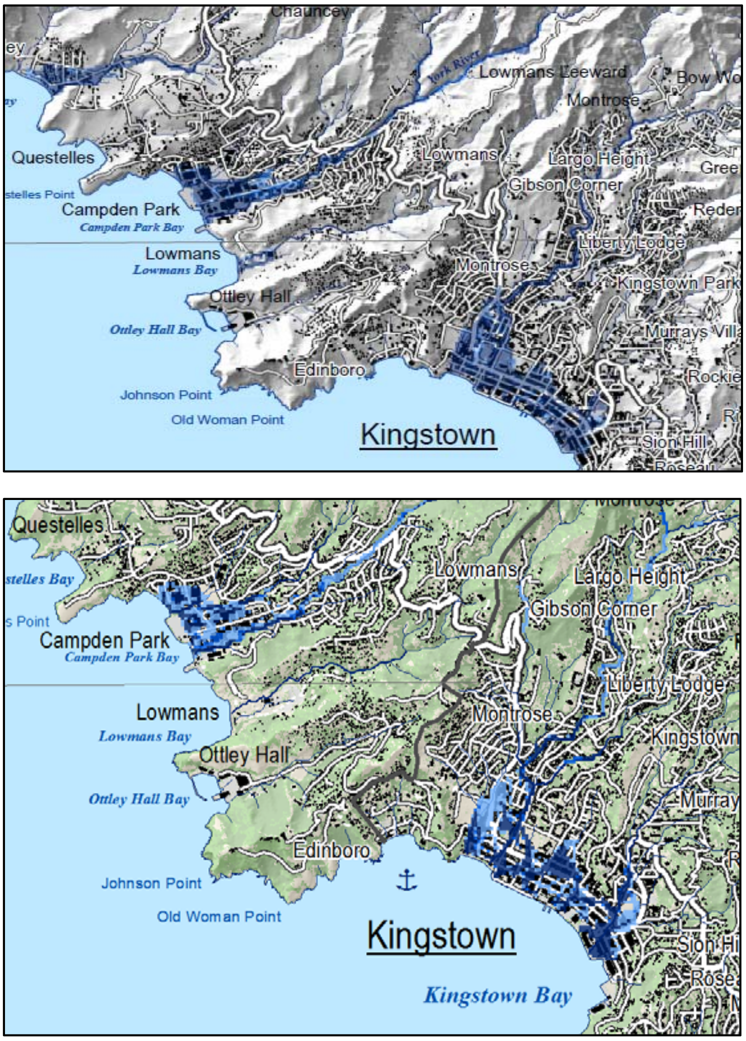


Figure 6.3. Top: 2015 draft flood hazard map, with areas that were considered too extensive in hazard. The bottom map shows the new flood hazard map and because the channels are deeper the hazard is not so extensive, only for the 50 year return period.

The old airport shows flood hazard for all return periods (see fig 6.4). In reality this depends on the small rivers bounding the runway to the north and south. The dimensions of these channels are not known and if sufficient water can be conveyed the real flood hazard might be less. The new airport has a potential small flood zone at the northern half of the runway, but in reality this is the taken care of by a series of culverts under the runway that can evacuate the flood water.

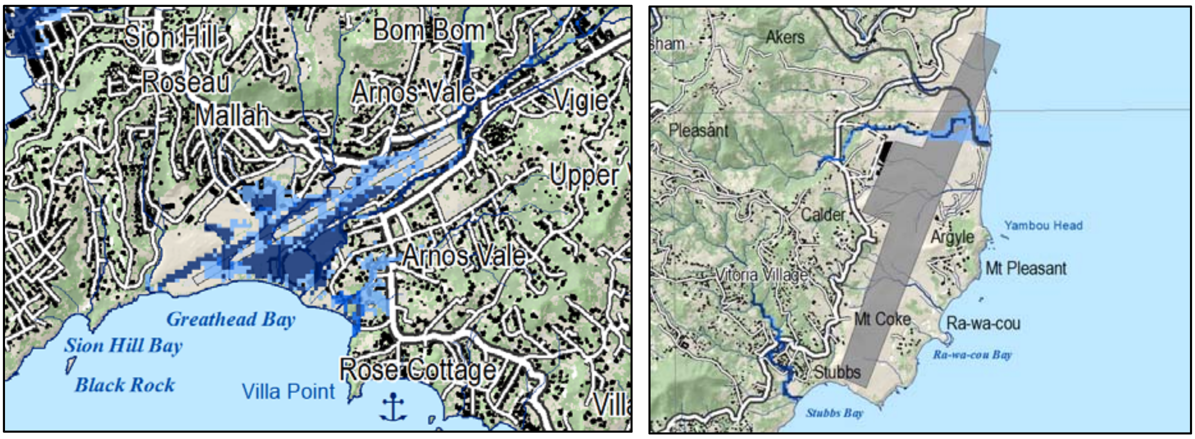


Figure 6.4. Flood hazard situation at the current ET Joshua airport (left) and the new airport (right). The flood hazard situation at the old airport seems severe but this depends on the exact dimensions of the bounding channels. The potential flood hazard at the new airport is not there in reality because of a series of culverts that let water under the runway.

6.3 Recommendations to improve the flood hazard map

Rainfall data

There are no detailed rainfall data, only daily data and only from one station, which might be biased because it is located on the southern part of the island (if spatial variation exists). An investment should be made to improve the rain gauge network on St Vincent. Without this data hazard modelling cannot be done, nor can any other estimate of drought or floods or hydrological modelling be done properly. This is independent of the model used. Since there might be a trend in rainfall form the southern to the northern islands, using rainfall from one location may be wrong, both in this study as well as in in those from other consultants. Island specific rainfall data is absolutely necessary.

Discharge data

One of the most important improvements is measuring river discharge in a few selected catchments. This has the following advantages:

- The flood model LISEM for national and watershed scale works well with the current dataset composition but is essentially uncalibrated. The first priority must be to collect data to calibrate and validate the model.
- All consultants until now just make an assumption on discharge conditions during a flood, without any backup data. They all use their own principles and assumptions, so that reports and results are not intercomparable.
- People may have a false sense of security from the FEW systems, because they operate on mere assumptions.

Continuous monitoring of streamflow is needed to calibrate any flood or discharge model. Several islands have Early Warning Systems that are currently not used for discharge measurements, they only serve to issue a warning to disaster management operators. It is not known if St Vincent has EWS as well. The following steps are advised:

- A continuous time series of water level will help to understand the water balance, as the baseflow data is related to groundwater activity and peak flow data is related to storm runoff form the slopes. So store and collect the water level at all locations where a FEW system is installed to start with.
- Check these readings with a level staff that is constructed on the side of the channel, possibly at a bridge. Note: baseflow levels are generally very low and uninformative, so a weekly visit to a river is not very useful, as all variations in water level are missed. A continuous short time interval series should be captured, preferably at a 10 min interval.
- On these locations the water velocity and channel cross section must be measured, to be able to convert the water level to a discharge (create a stage-discharge relationship).
- Establish a database for these catchments.

Hydrological data

- Channel dimensions: measuring channel dimensions is a simple task in the context of hydrological modelling at the watershed scale. This doesn't have to be done with a full elevation level equipment. Average width and depth is on every 100 m along the channel is sufficient. This should be done for the main rivers that are known to be flooded.
- Estimate/measure other elements that interfere with surface flow: elevated roads, bridges, culverts etc.
- Soil data: based on the soil and land use map, a series of simple soil tests should be done for a few selected catchments. In each catchment about 20-50 samples should be taken in different classes of land use and soils. Gradually this will lead to a database of pedotransfer functions that can be used on the entire island. These measurements will also benefit other projects for instance related to drought.

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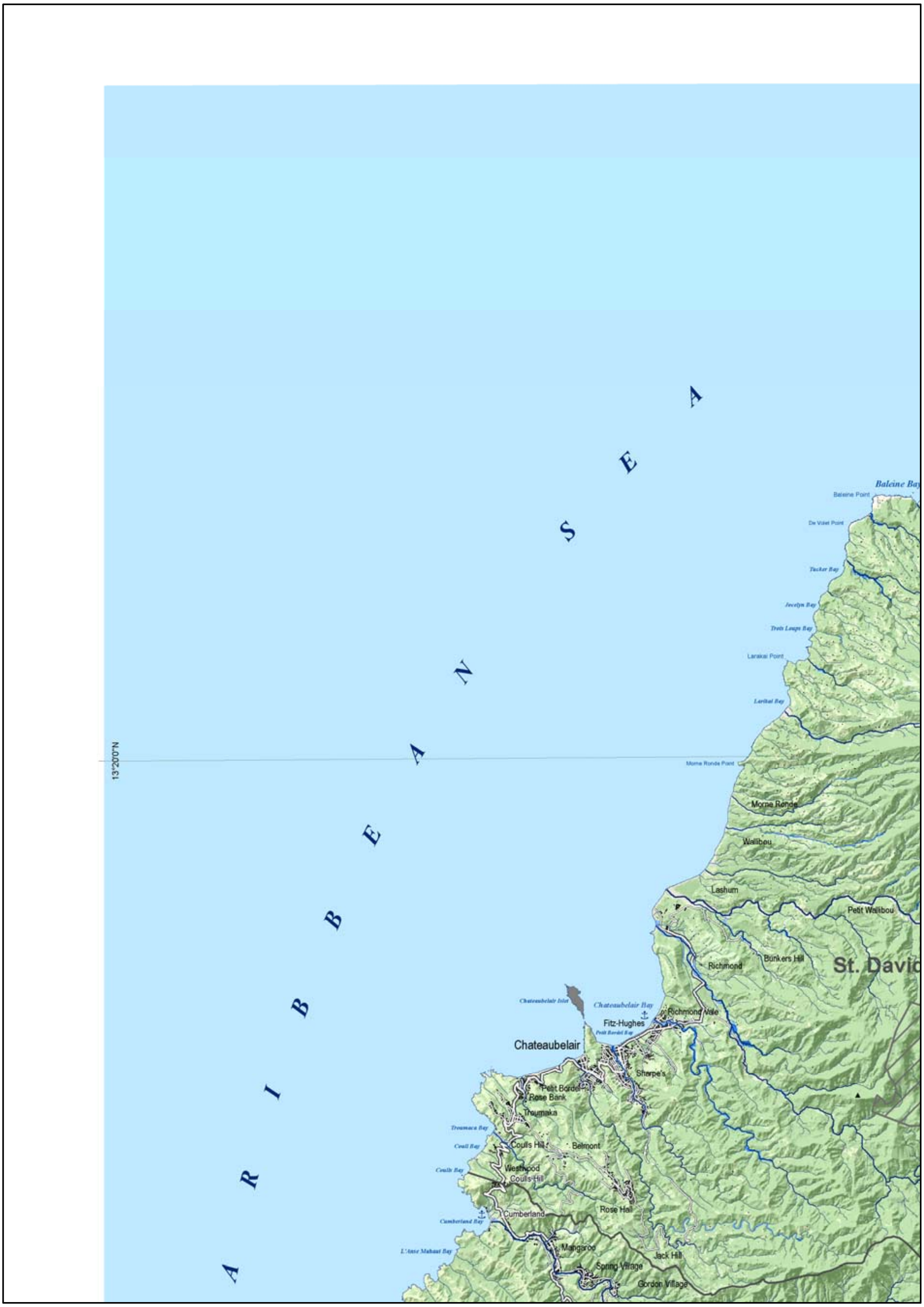
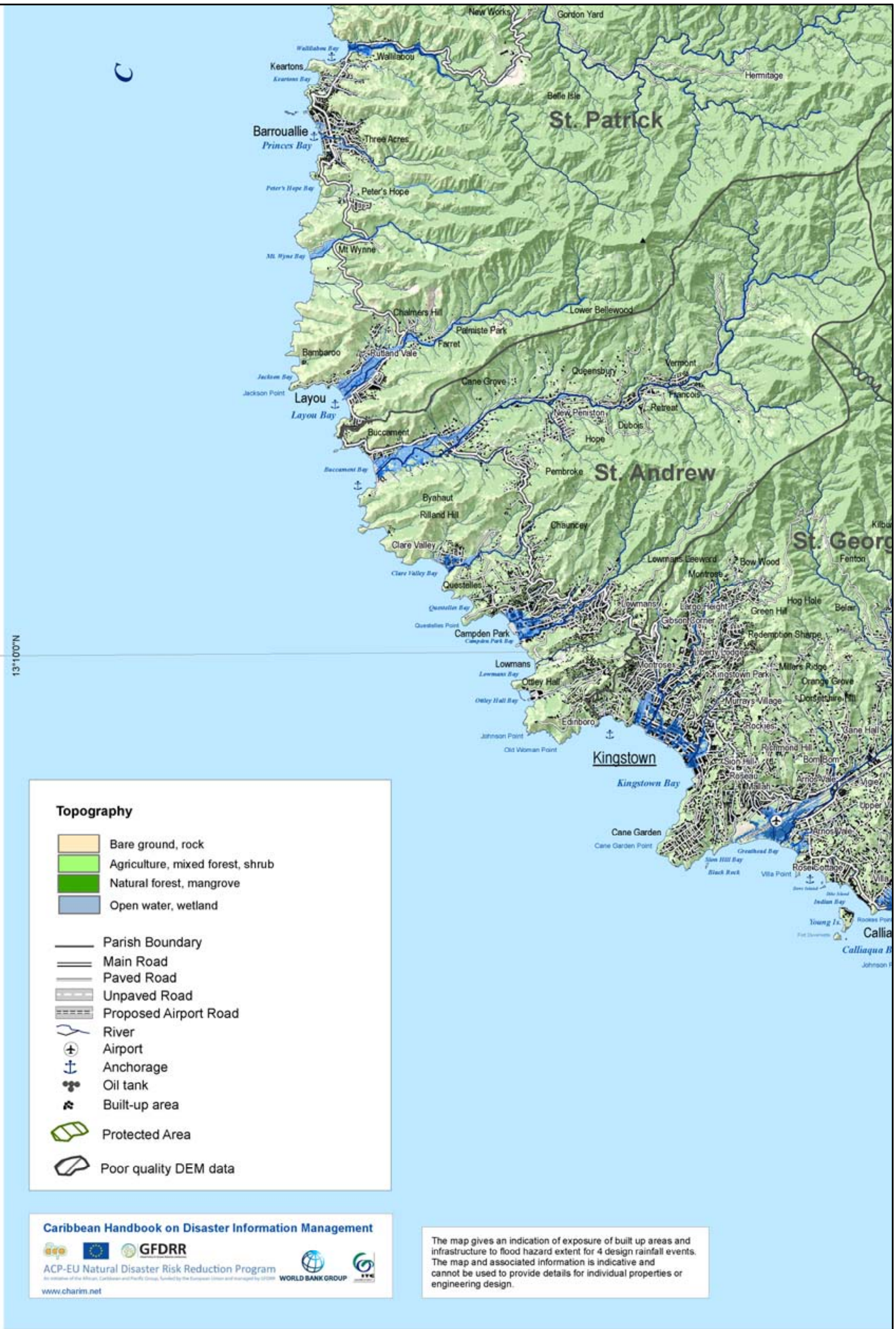
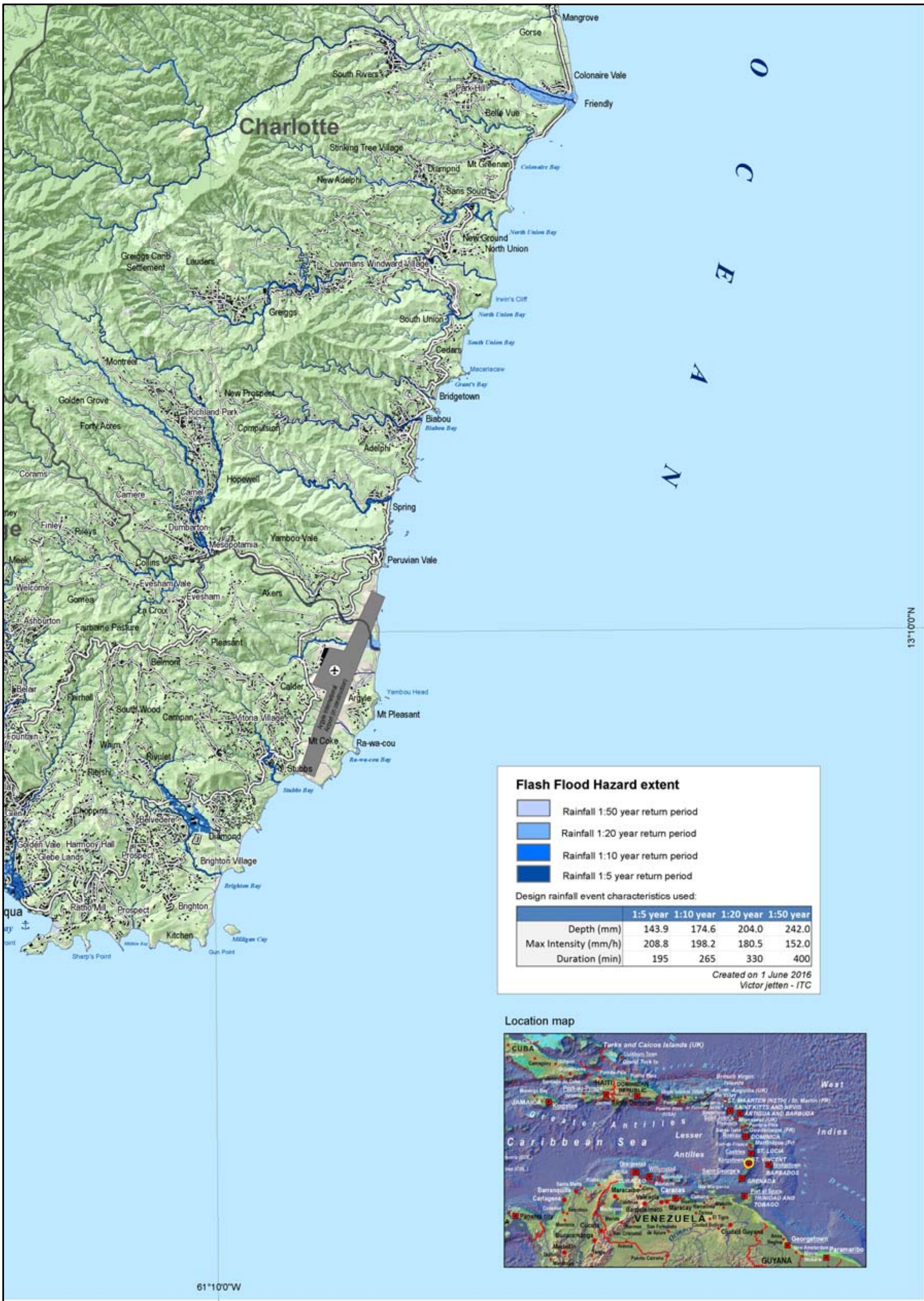
Annex: the national flood hazard map




Saint Vincent
Flood Hazard
Scale 1:50,000
0 0.5 1 2 3 4 5 Kilometers
1 cm = 0,5 Km.
61°10'0"W
13°20'0"N
A T L A N T I C
Fancy
Owia
Owia Bay
Point Village
Old Sandy Bay
Sion Hill
New sandy Bay Village
London
Overland Village
Orange Hill
Waterloo
langley Park
Chapmans
Georgetown
Caratal Village
Byera Hill
Byera


St. Patrick
St. Andrew
St. Georg
Kingstown
Kingstown Bay
Barrouallie
Princes Bay
Layou
Layou Bay
Keartons
Wallilabou
New Works
Gordon Yard
Hermitage
Belle Isle
Three Acres
Peter's Hope
Mt Wynne
Chalmers Hill
Palmiste Park
Farret
Bambaroo
Rutland Vale
Cane Grove
Queensbury
Vermont
Francois
Retreat
New Peniston
Dubois
Hope
Lower Bellewood
Buccament
Pembroke
Jackson Point
Byahaut
Rilland Hill
Chauncey
Clare Valley
Questelles
Lowmans Leeward
Bow Wood
Montrose
Lowmans
Campden Park
Largo Height
Gibson Corner
Green Hill
Hog Hole
Redemption Sharpe
Liberty Lodge
Kingstown Park
Millers Ridge
Orange Grove
Ottley Hall
Murrays Village
Edinboro
Johnson Point
Old Woman Point
Cane Garden
Cane Garden Point
Villa Point
Young Is.
Calliaqua B
Fenton
13°10'0"N
Topography
Bare ground, rock
Agriculture, mixed forest, shrub
Natural forest, mangrove
Open water, wetland
Parish Boundary
Main Road
Paved Road
Unpaved Road
Proposed Airport Road
River
Airport
Anchorage
Oil tank
Built-up area
Protected Area
Poor quality DEM data
Caribbean Handbook on Disaster Information Management
GFDRR
ACP-EU Natural Disaster Risk Reduction Program
WORLD BANK GROUP
www.charim.net
The map gives an indication of exposure of built up areas and infrastructure to flood hazard extent for 4 design rainfall events. The map and associated information is indicative and cannot be used to provide details for individual properties or engineering design.



	1:5 year	1:10 year	1:20 year	1:50 year
Depth (mm)	143.9	174.6	204.0	242.0
Max Intensity (mm/h)	208.8	198.2	180.5	152.0
Duration (min)	195	265	330	400