

## Caribbean Handbook on Risk Information Management



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# CHaRIM Project

## Dominica National Flood Hazard Map Methodology and Validation Report

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**DRAFT 1.1**



**DRAFT VERSION**

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## Contents

1	National flood hazard map Dominica.....	4
1.1	Caribbean flash floods.....	4
1.2	The national flood hazard map .....	5
1.3	Return periods.....	6
1.4	The 2015 Draft version of the national flood map.....	6
1.5	Calibration and verification .....	7
2	Methodology .....	7
2.1	Requirements for the flood model.....	7
2.2	National scale hazard assessment methodology .....	8
3	Model software – LISEM .....	8
4	Rainfall data analysis, return periods and design storms .....	12
4.1	Recurrence intervals.....	12
4.2	Design storms .....	15
5	Spatial database .....	17
5.1	DEM and derivatives.....	19
	Soil depth.....	19
	Rivers network and river dimensions.....	20
5.2	Soil map and derivatives .....	22
5.3	Land use and infrastructure .....	27
	Land cover map and hydrological parameters.....	27
	Building density map .....	27
	Roads, bridges, dikes .....	28
6	Model output and Hazard maps .....	28
	Hydrological response .....	28
6.1	Summary flood hazard statistics .....	29
6.2	Stakeholder evaluation of Draft Flood hazard map .....	30
6.3	Evaluation against existing flood hazard assessments.....	30
6.4	Hurricane Erika .....	33
6.5	Recommendations to improve the flood hazard map .....	35
	References.....	37
	ANNEX: Dominica National Flood Hazard map .....	39

# 1 National flood hazard map Dominica

## 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<sup>2</sup> 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 Dominica, 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. Also the fact that some roads are elevated and may act as temporary barriers is not included. 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 Grenada).

### 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  $0.8 \times 0.8 = 0.64$ . 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 Dominica. 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 draft flood hazard map was created using as input an earlier land cover map (2000, Carland project). This map was improved by Van Westen (this project) with additional information. And the new map used in the 2016 flood hazard map.
- 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 Grenada. The relation was not checked on Dominica 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.

Overall the bad quality of the DEM dominates the results (elaborated below) and the 2016 map did not give large changes in flood hazard (chapter 6).

## **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.

Unfortunately, Dominica does not have measurements of discharge in a structured way. There are some river water levels measured during storm events, resulting in channel water level. However, the calibration is missing to translate these to discharges (water velocity is unknown). Hence the flood water level shown, depict mostly the channel depth (bank full conditions). Since the river channel cross sections may change rapidly because of sedimentation and erosion, the water level cannot be used, even when the location is known. Calibration against known discharge was therefore not possible. It is strongly suggested to revive the gauging stations and establish calibration curves. There are a number of early warning systems active that monitor river water level, these could be used easily.

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.

## **2 Methodology**

### **2.1 Requirements for the flood model**

Based on the physiography and topography of Dominica, 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 an 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.

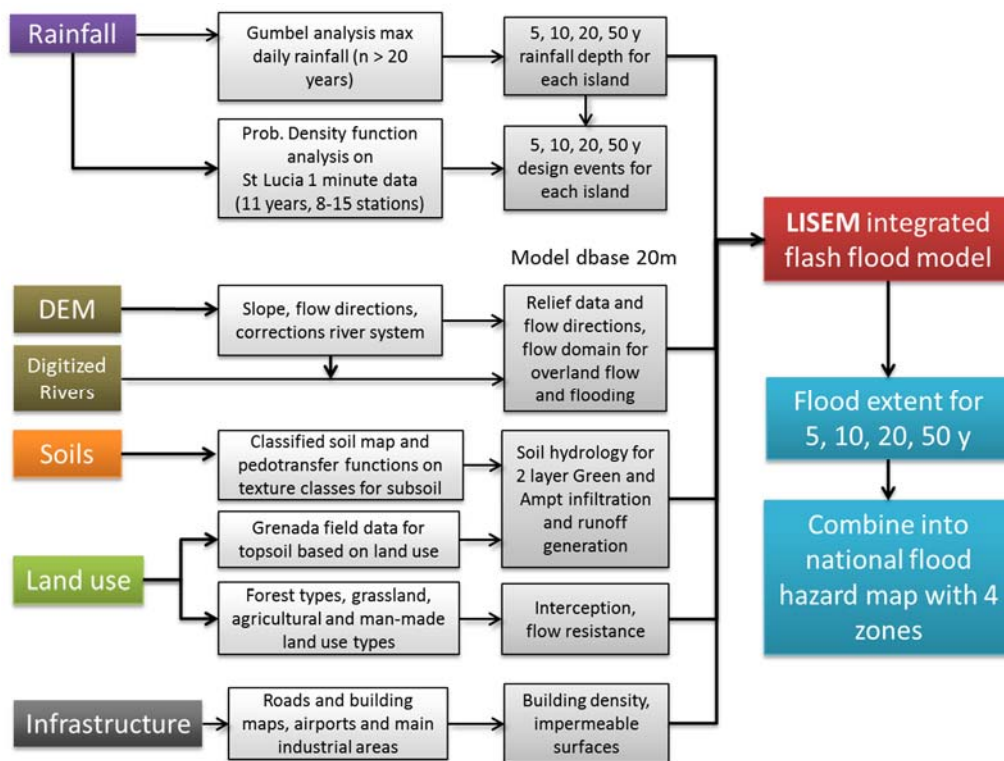
## 2.2 National scale hazard assessment methodology

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 from the tipping bucket stations, design curves were created using a Johnson Probability Density Function. These equations are used for Dominica but fitting them to match the daily totals belonging to the return periods of Dominica
- 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.

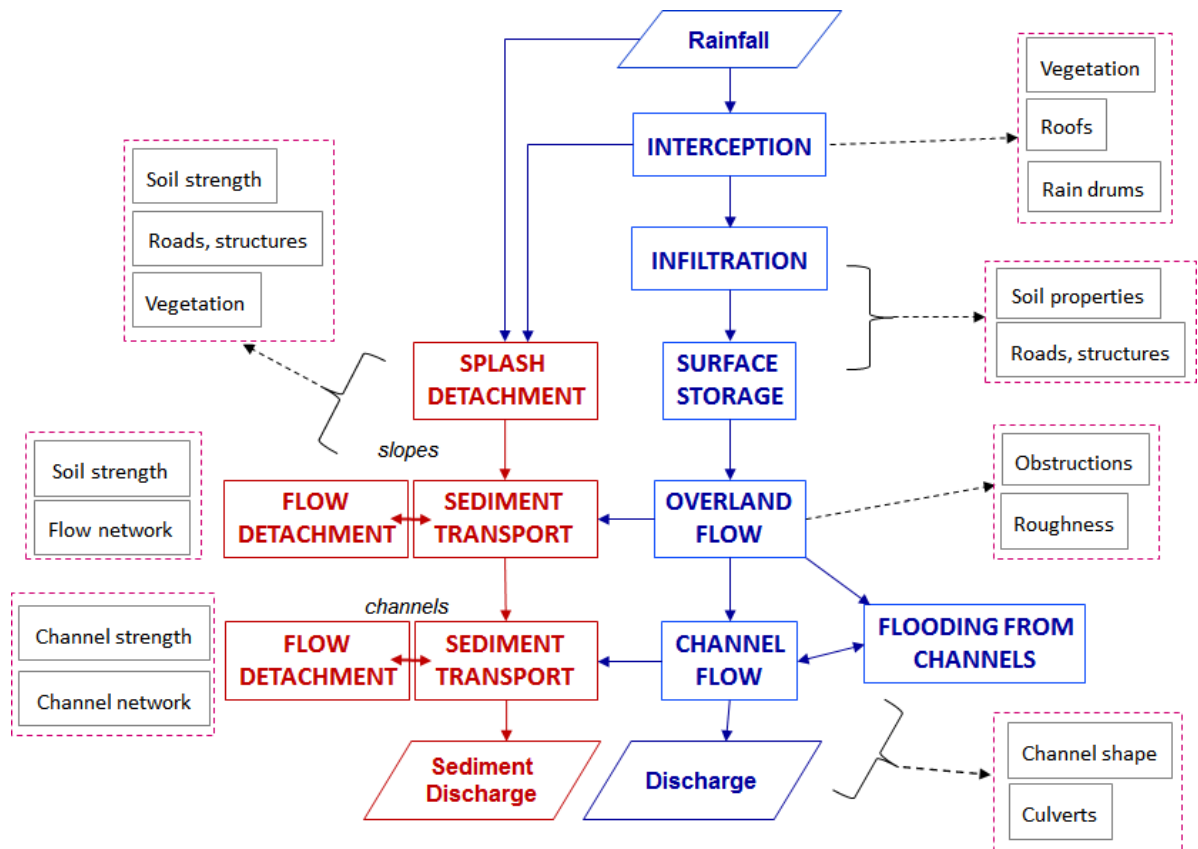


Figure 3.2. Flowchart of the water and sediment processes in LISEM. In dashed lines the main parameters are given. In CHARIM only the water processes are used (in blue).

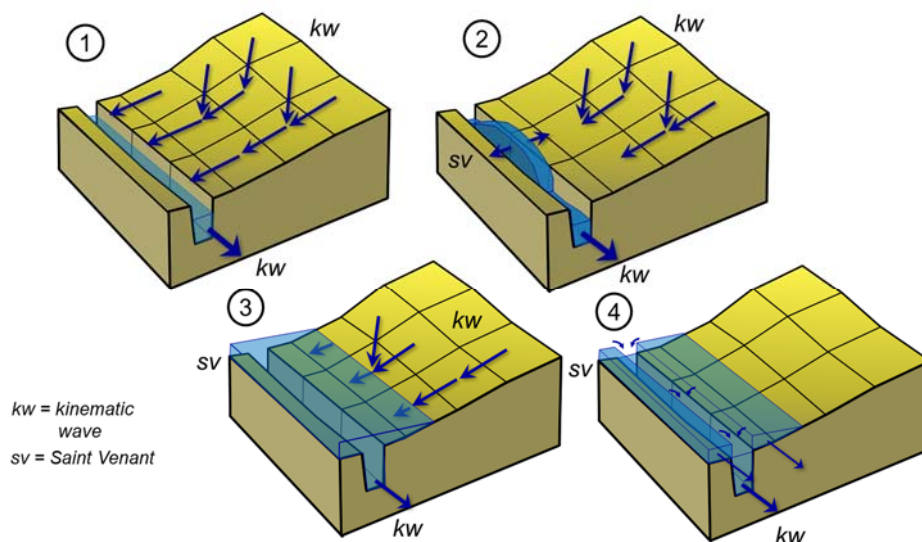
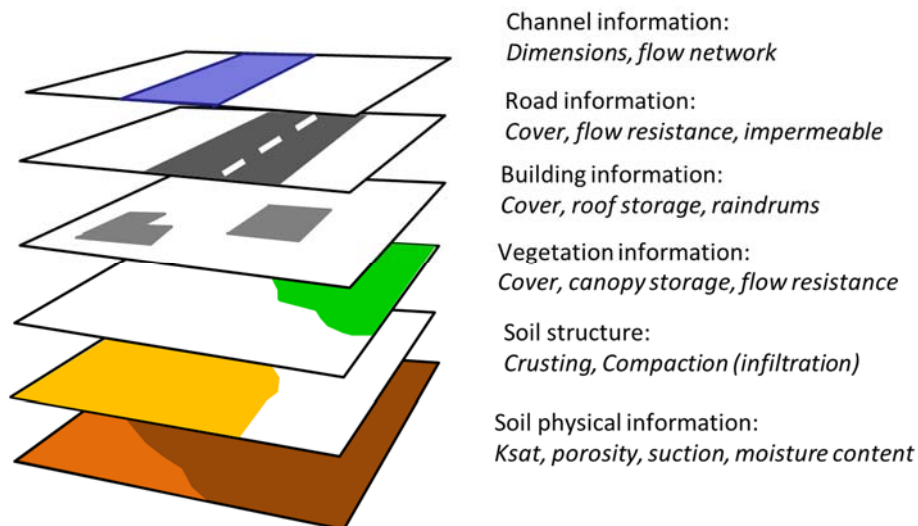


Figure 3.3. Schematic representation of flow processes from 1D kinematic wave runoff and channel flow (1), to overflow of channels (2), spreading out of water from the channels outward using 2D full Saint-Venant equations (3), and flowing back into the channel when water levels drop, most likely the 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](http://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, that 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 all stations. 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 Recurrence intervals

There are 2 stations on Dominica that have long records, Canefield airport on the south-east coast with 32 years since 1982, and Douglas Charles Airport at Melville Hall on the north-west coast with 39 years since 1976 (fig 4.1). Both records were checked for incomplete years and converted from inches to mm. 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.

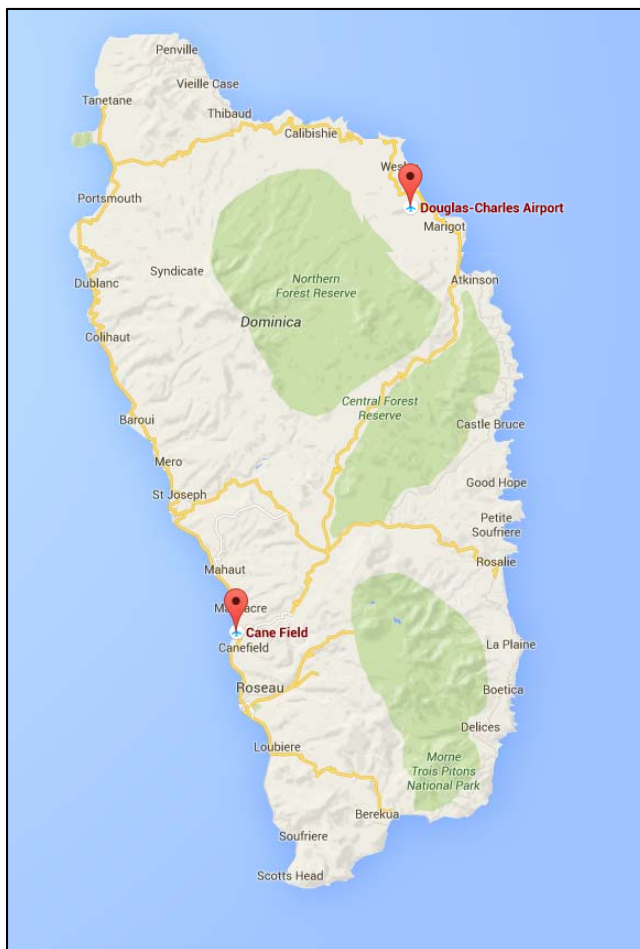


Figure 4.1. Location of the two stations with long records for the Gumbel analysis (Douglas-Charles airport is at Melville hall).



Gumbel distributions were fitted to each station. A Gumbel distribution is a special case of Generalized Extreme Value distributions, suitable for right hand skewed datasets (such as rainfall, that 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 two stations with good linear fits between the log-log values of the return periods and the maximum daily rainfall.

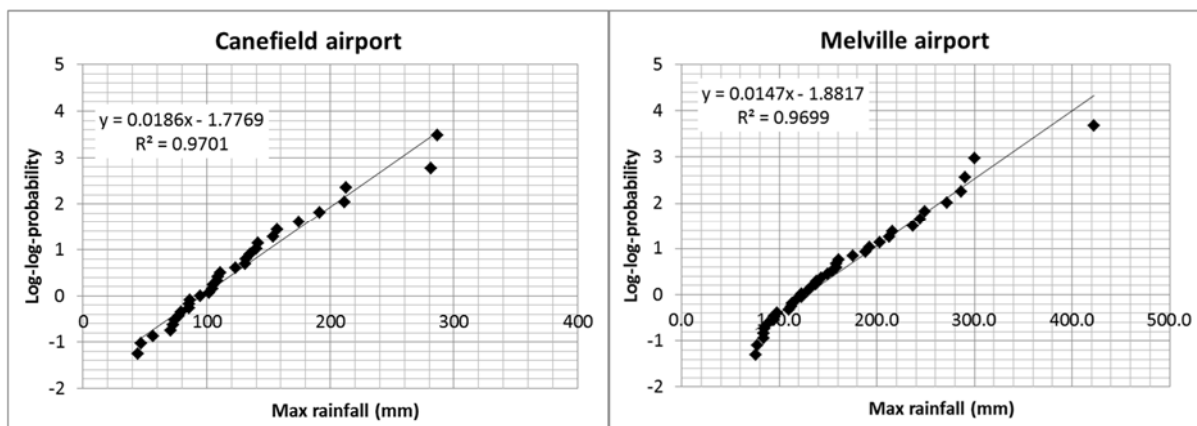


Figure 4.2. Gumbel analysis of maximum daily values of Canefield airport station (1982-2013) and Melville Hall station (1976-2013).

The stations have different return periods for a given daily maximum rainfall. For instance, a 200 mm daily rainfall has an average return period of 7.5 years at Melville Hall and 15 years at Canefield. 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 4.4.

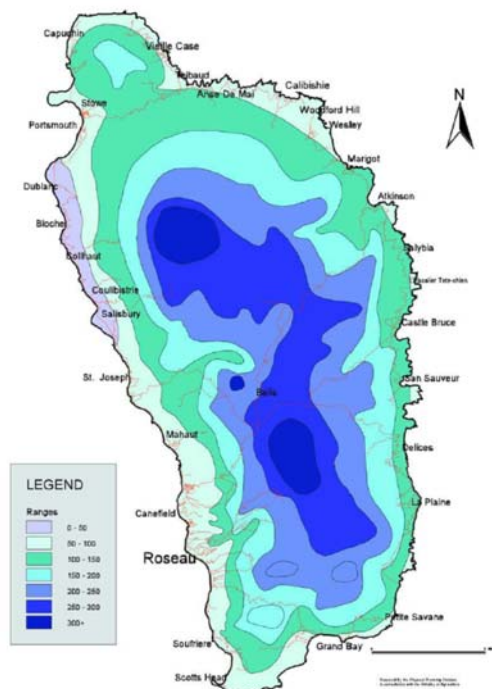
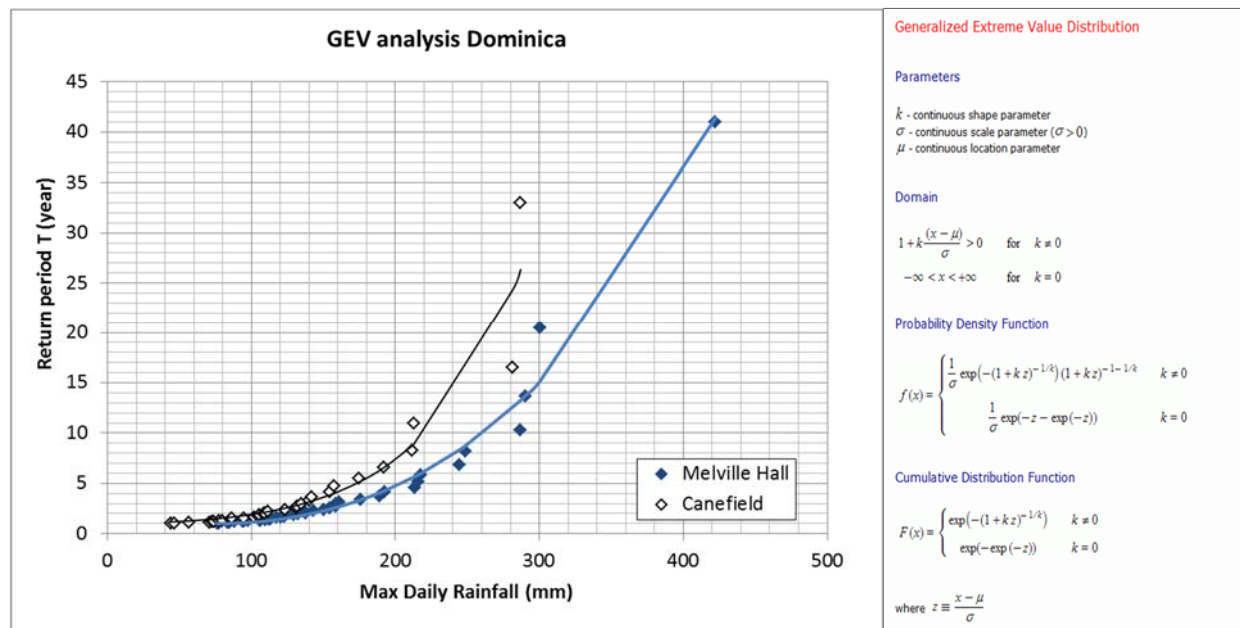


Figure 4.3. Long term average annual rainfall, units are inches per year.

It is not known if this is representative for the west coast and east coast of the island, although possibly the exposure to hurricanes from 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. Figure 4.3 shows the average annual rainfall in inches. This image suggests more rainfall information is available but not in the CHARIM project. Like the other islands there is an increasing rainfall towards the interior with the orographic effect of the central mountains.

However, it is not clear if such a gradient with elevation also exists for individual rainfall events. The return periods of different zones on the islands may be more complicated than can be captured by two stations.



	mu	sigma	k
Melville Hall	126.317	39.616	0.342
Canefield	81.832	58.914	0.042
Average	104.074	49.265	0.192

T	Canefield	Melville Hall	Combined
5	176.2	230.0	196.8
10	216.5	281.1	251.4
20	255.2	330.1	306.1
50	305.3	393.4	378.4

Figure 4.4. Left: GEV analysis of the two stations and resulting daily total values, from the average of the fitting parameters.

Looking at the return period analysis of the other islands in CHARIM (Grenada, St Vincent and the Grenadines, and Dominica), a north south gradient can be clearly seen in the design storm depth based on the analysis of daily maxima (fig 4.5). 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.

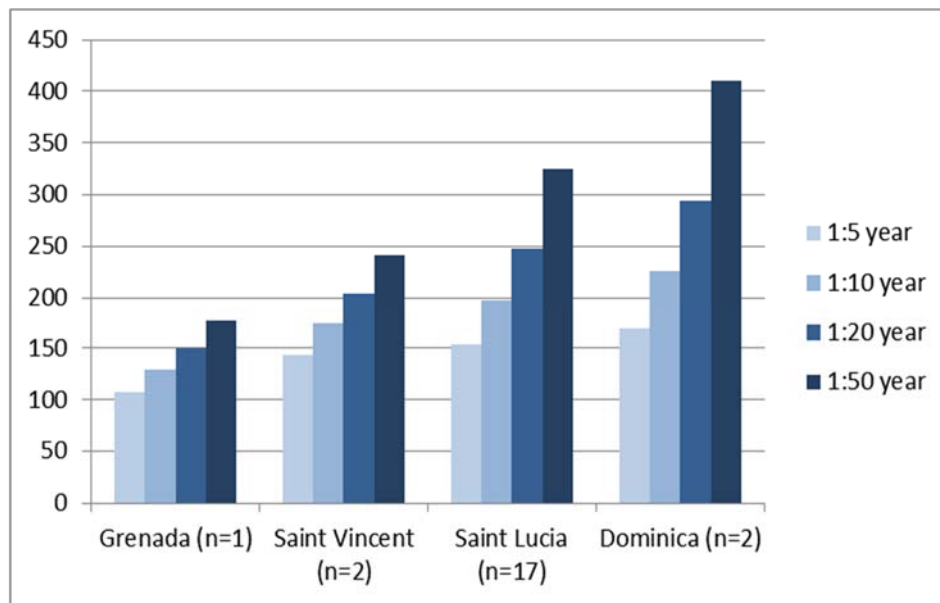


Figure 4.5. Return periods and daily maxima from GEV analyses of rainfall stations at the 4 islands in CHARIM.

## 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 4.8). 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 Dominica.

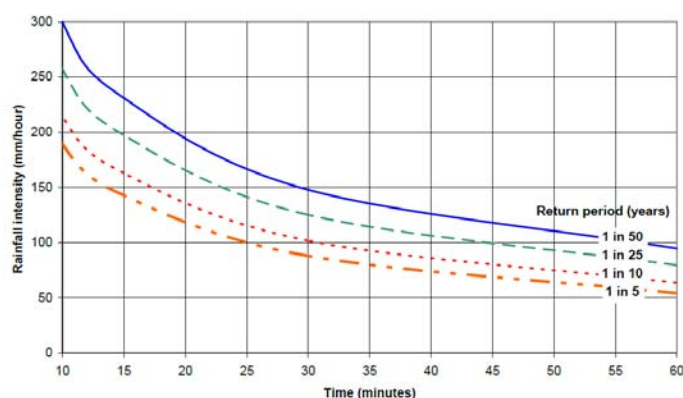
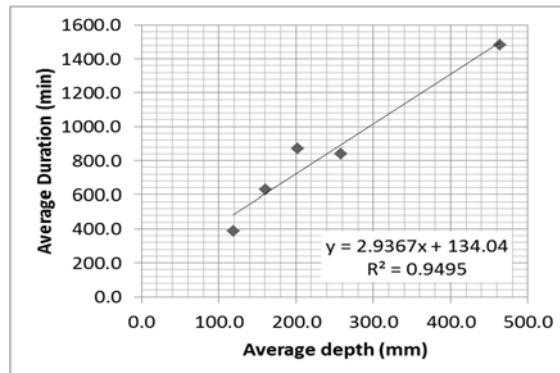


Figure 4.6. IDF curves for the Bahamas (Lumbroso et al., 2011).

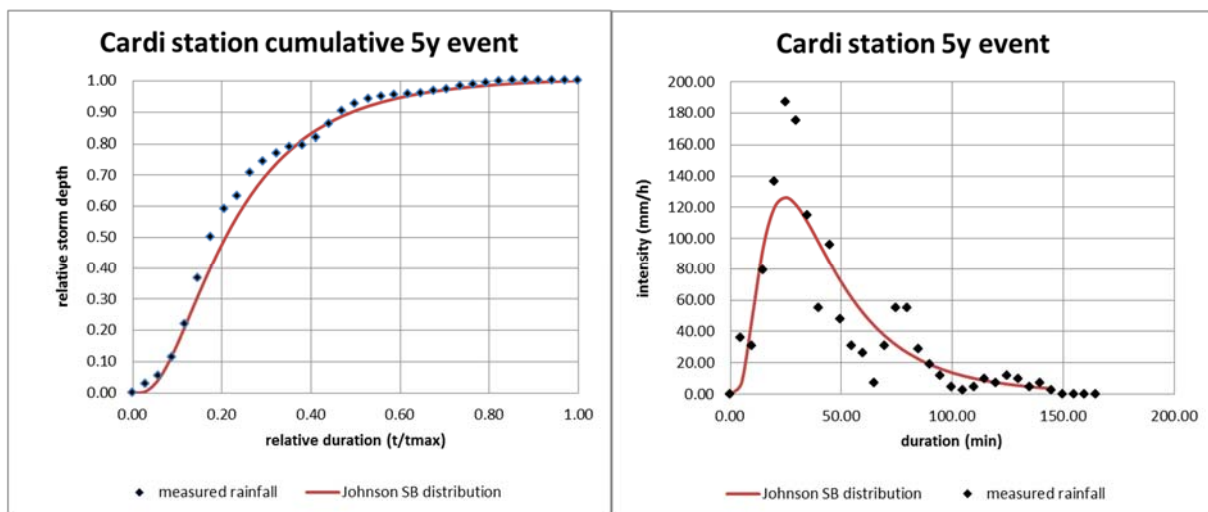
Analyzing the detailed rainfall data on st Lucia, there were in total 35 rainfall events of 90 mm and larger, based on the 1-minute intensity data of 15 stations over a period of 3 to 11 years (depending on the station). These events were grouped according to total depths. Of course the larger events only have a few realizations, a summary is given in Figure 4.11. 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 4.7. 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.**

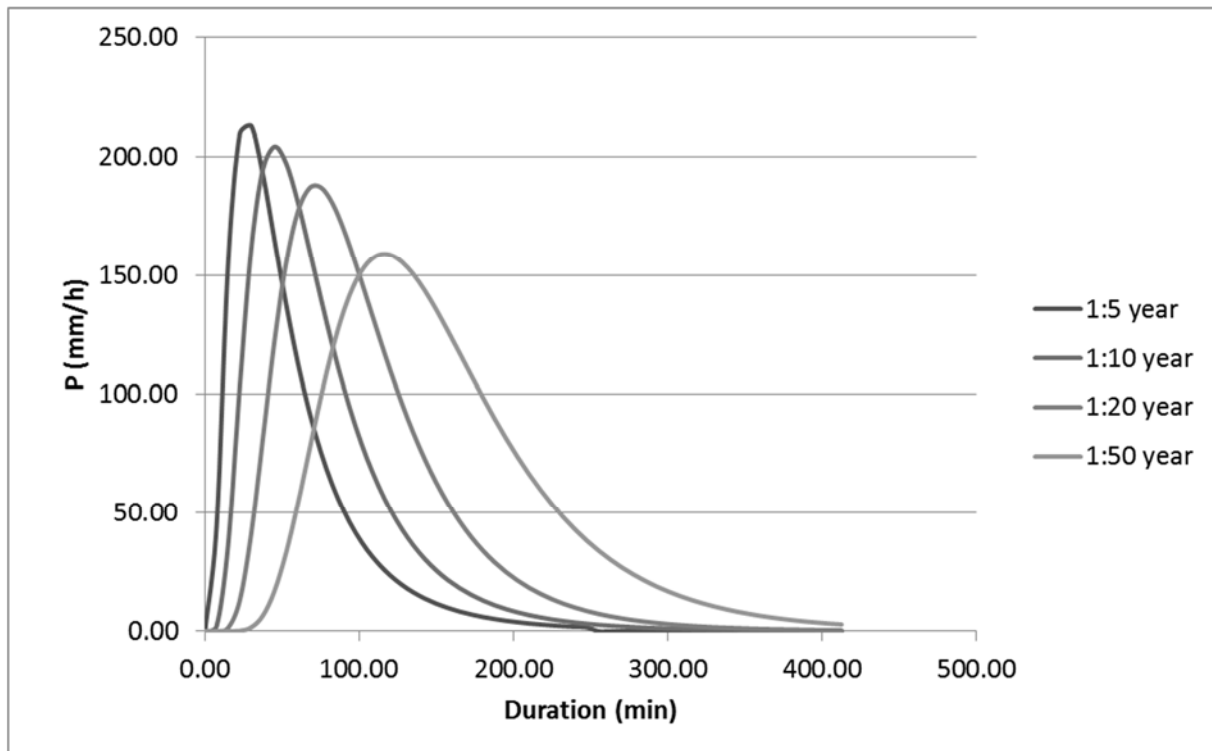
Within each class the events were fitted with a probability density function, for which a Johnson SB distribution was used. To do this events were from all stations in each class and converted to relative cumulative data (relative rainfall depth versus relative duration). This allows all events to be 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 4.8 shows an example from Cardi station on St Lucia.



**Figure 4.8. 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 4.9. 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 4.7,

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.



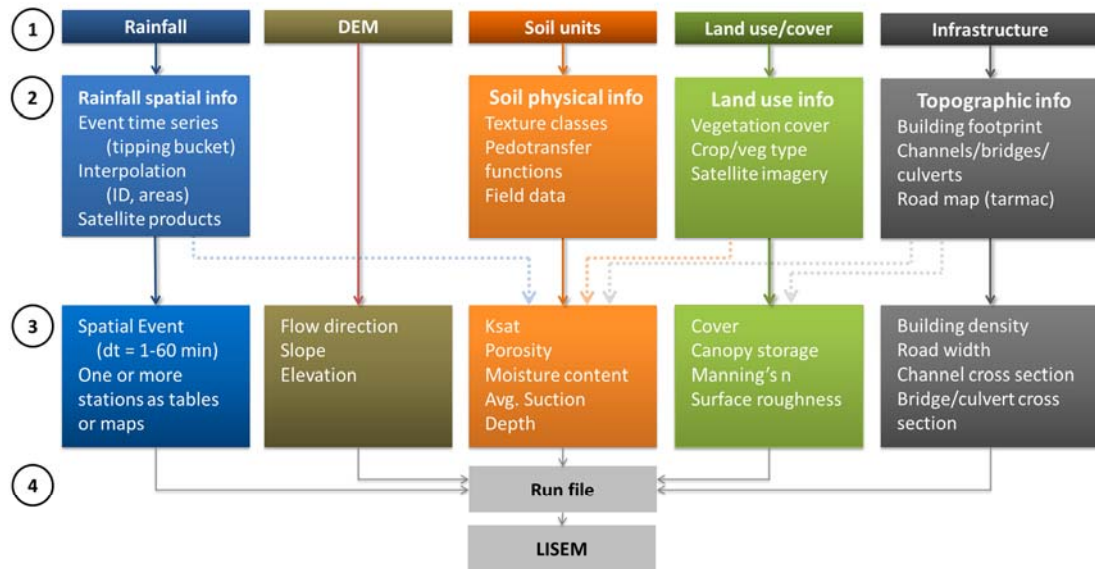
	1:5 year	1:10 year	1:20 year	1:50 year
Depth (mm)	220.3	270.0	317.6	379.3
Max Intensity (mm/h)	213.0	204.4	187.4	158.9
Duration (min)	195	265	330	400

Figure 4.9. Design storms for Dominica for 4 return periods, based on a Johnson SB distribution fit to representative rainfall events in the classes shown in fig 4.7.

## 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.



1. Basic maps needed, raster format, minimum resolution defined by user (min resolution wider than channel, no max area size)
2. Additional area information on rainfall distribution, soil and land use parameters, and infrastructure parameters. Derived from imagery, available maps, literature, field work, other models etc.
3. LISEM input database, generated automatically in PCRaster GIS (macro language script, combining base maps and knowledge to create maps for all input variables)
4. Define a run file for the job, specifying all options and map names for this run.

**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**

Basic data	Created from	Method
<b>DEM</b>	A 5m resolution raster DEM is available.	No further corrections, resample to 20m.
<b>Soil Map</b>	Digitized soil map (org. 1:40000) by the Soil Survey and Research Department of the University of the West Indies (Lang, 1967). Emphasis on clay minerals and weathering.	Soil types have a texture class indication which are converted to soil physical parameters with pedotransfer functions by Saxton and Rawls (1986).
<b>Land cover map</b>	Based on Landsat and SPOT images acquired between 1996 and 1999 (USGS, USAID project).	Has 18 classes for land cover information, interpreted directly to hydrological parameters.
<b>Road map</b>	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
<b>Building map</b>	Only Rousseau has a building footprint, outside Rousseau buildings are indicated as points	A size of 100 m <sup>2</sup> is assumed for the buildings outside Rousseau, based on the average of the existing footprint.
<b>River map</b>	main rivers are digitized, but the rivers do not coincide at all with the DEM, sometimes are situated outside the river valley.	A artificial river network was used based on the a the DEM. All outlets were hand corrected based on high resolution images in Google Earth.

**Table 5.1. Main data layers for Dominica, their origin and operations for the derivation of the hydrological database.**



## 5.1 DEM and derivatives

The island of Dominica is very steep with deeply incised rivers, and a few minor floodplains and sedimentary fans. These are cone like structures built up over time near the sea, on which many of the villages can be found.

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. The DEM of Dominica is available at a 5m resolution and was resampled to 20m, using the average of 2x2 cells. The resampling did not significantly change the level of detail. However, the 5m DEM seems to be very smooth with few details in the floodplains and along the coast where the major towns and airports are situated. The quality of the DEM is such, that the rivers that are digitized from the high res images do not follow the deepest areas of the terrain model, in fact in some places the rivers cut across hills and depressions. This can be clearly seen in the example of fig 5.2. This poses a major problem in flood simulation: the dynamics of the flood water and depth of the flood depend on the DEM and a low quality DEM directly translates itself to wrong flood information. In the national flood hazard map only the flood extent is used, which in the case of Dominica is justified.

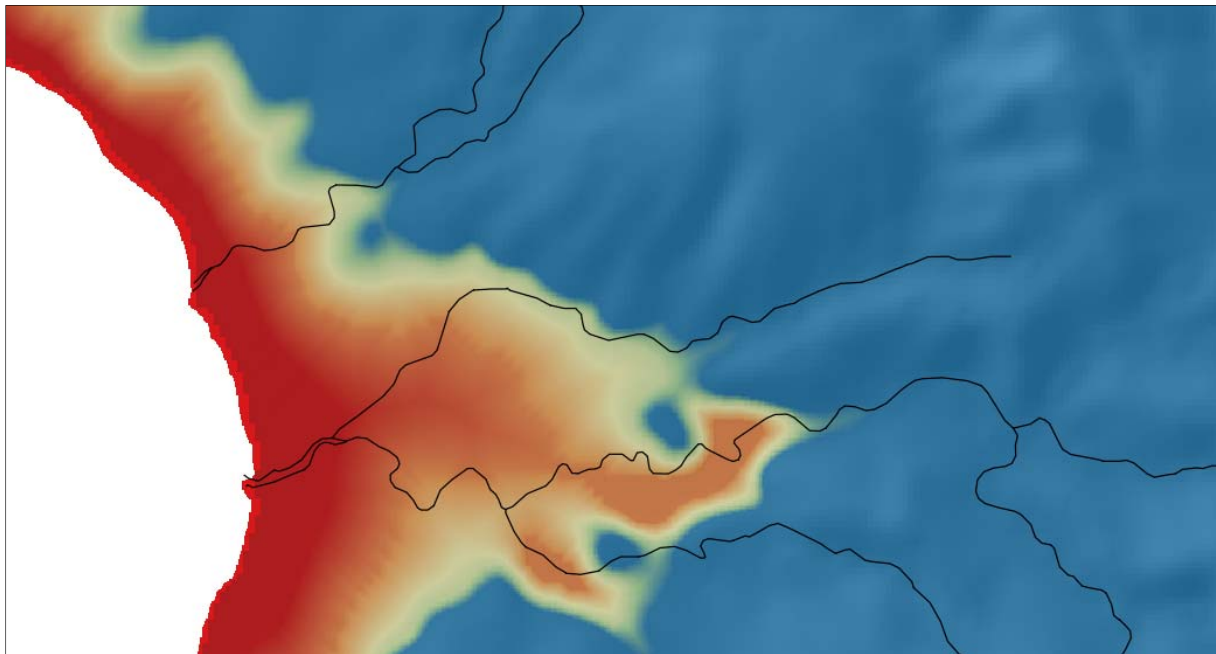


Figure 5.2. DEM in 5m resolution (left) and digitized river system. It can be seen that the DEM lacks detail and the rivers (black) do not follow the lowest areas in the DEM. Colours range from 5 m (red) to 30 m (blue) to emphasize the lower areas. The area shown is approximately 2 km by 1 km.

### 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 this research, the following GIS operation was used to create a soil depth map (in m):

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

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 Dominica, but on the islands of St Lucia and Grenada have been done, although limited to observations of river depth (surface to bedrock) and road cuts. Fig 5.3 shows the soil depth for the areas shown above. The river depth is simply the soil depth in the channel pixels.

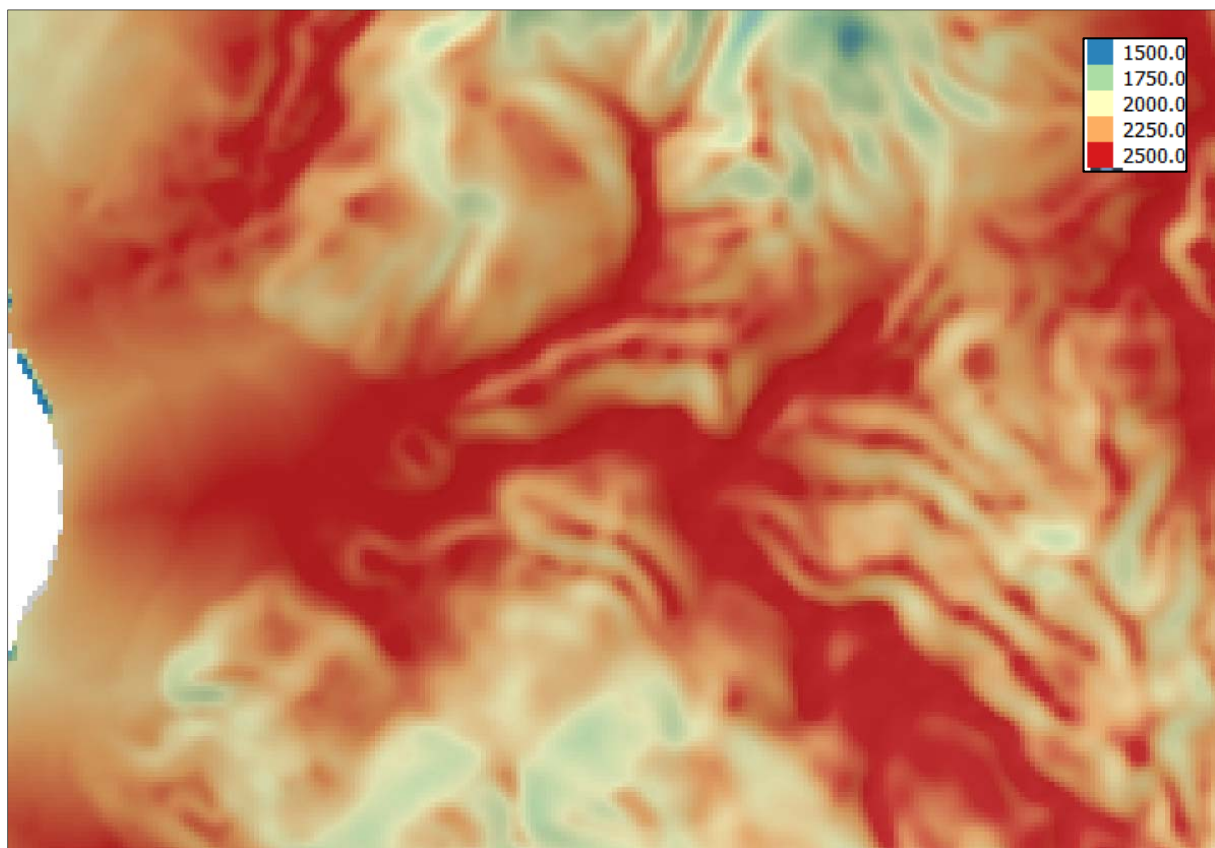


Figure 5.3. Example of soil depth (in mm) generated from the DEM, river system and proximity to the sea. Steeper slopes have shallower soils, valley floors accumulate material and have deeper soils.

#### ***Rivers network and river dimensions***

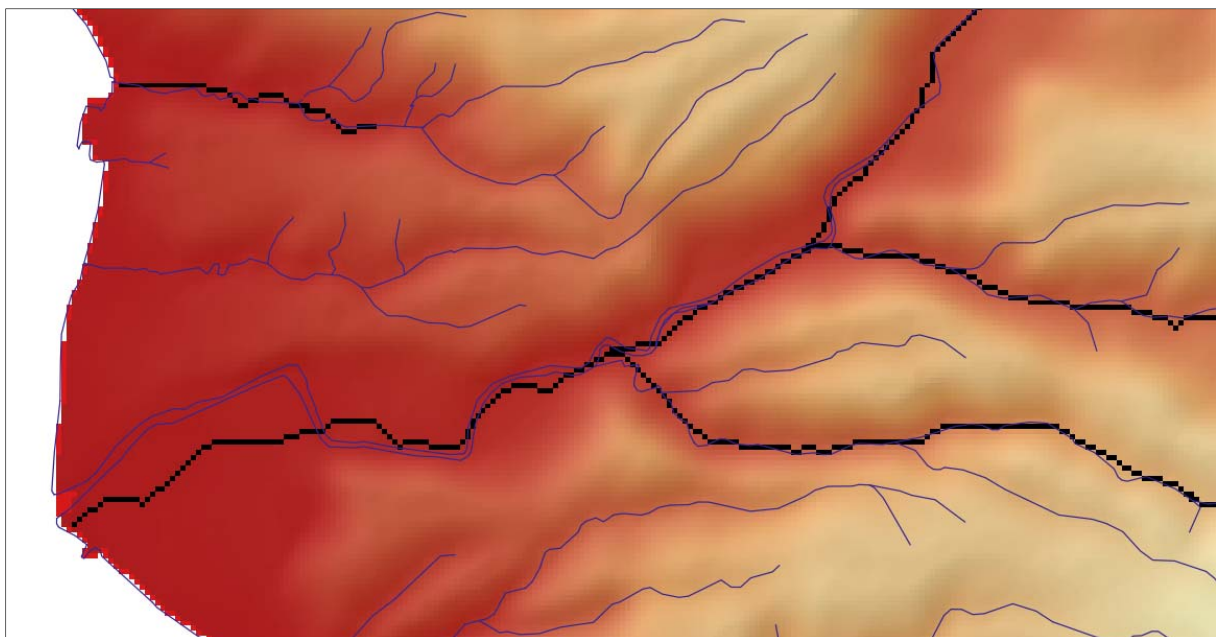
Two shape files with the rivers exists in the Dominica database, one with only the main rivers that can be seen on images, the other with every drainage line depicted as a river channel. It is not known if the latter is an automatically generated river system form the DEM, or if it represents all actual rivers. The two do coincide so the digitized river information is included in both. On the other hand under forest vegetation the rivers are very difficult to trace or not visible at all so the many branches of the river system are almost certainly not all digitized from images. Since LISEM generates floods by overflowing channels, accurate channel maps are important. Manmade channels are not included, but they would not be used in the national flood hazard map anyway.



Unfortunately, the low quality of the DEM shows that the river systems do not coincide with the DEM, rivers cut across slopes, or traverse low elevated hills in the floodplain. Hydrologically this gives very wrong results. Water flowing out of a channel that is not in the lowest point will fill up a valley until the level of the riverbed, and the water will not flow back. Water stagnates in places where rivers cut across bumps and slopes. In general the flood volume and extent was too high when using the “true” digitized river network. In order to have a flood model results there was no other option than to use a generated river network from the DEM, with rivers following the deepest part of the DEM. Figure 5.4 shows an example of the DEM, the generated network and the digitized river network.

**Important:** until a new and better DEM is generated that coincides with the visible digitized river channels, the simulated flood extent will not be of a good quality everywhere. This is independent of the model used, as all flood simulation software depends on a good quality DEM.

It is impossible to use this network directly in the model (or any model) as flood water that overflows will flow into the deepest points of the valley and cannot drain from there. The simulated flood hazard would be more severe than it is in reality.



**Figure 5.4.** Stream network example with the black raster cells showing the DEM generated stream network based on the deepest drainage lines of the DEM, and blue lines showing the digitized stream network.

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 sea. 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 river 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. Fig 5.5 shows the effect for the Roseau river mouth.

Everywhere it is observed that the river has eroded until bedrock, apart from the last kilometer or so near the mouth, where sedimentation takes place and the river widens. This river depth was estimated by using the soil depth as river depth. The soil depth is generated from the DEM as explained below.

**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 website provides visual references: <http://www.camnl.wr.usgs.gov/sws/fieldmethods/Indirects/nvalues/>. Generally the riverbeds are either filled with sediment (near the outlet) or rocky with boulders, which gives a Manning's  $n$  of 0.03-0.04, and generally 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 of Dominica (1:40000) dates from 1967 and is made by the Soil Survey and Research Department of the University of the West Indies (Lang, 1967). It does not use the same classification system as the other 3 islands in the CHARIM project, but is organized more on the chemical properties of the volcanic soils and the degree of weathering and leaching of minerals, which causes the dominance of different types of clay minerals (see fig 5.5). There are Protosols with little to no chemical alteration (skeletal soils, beach sands), Allophanoid soils, that are yellow-brown and are partly weathered, with good water storage properties, Smectoid soils which are less advanced in chemical weathering of the volcanic parent material and have clays with swelling and shrinking properties and Kandoid soils with high amounts of iron oxide. Gibbsite is formed in highly weathered soils resulting in an abundance of aluminum oxide. Apart from those there are some podzols and waterlogged soils in swamps.

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 "Canefield". Each of these units have a texture description which was linked to 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 ( $K_{sat}$  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. This results in the values in table 5.3.

## LANG'S (1967) CLASSIFICATION OF SOILS IN DOMINICA

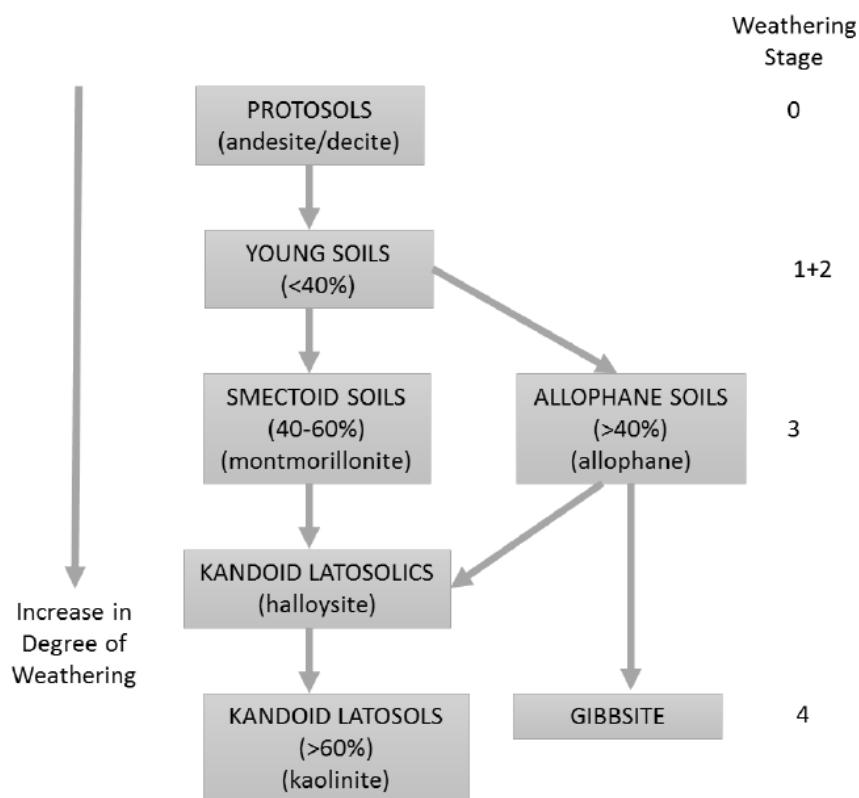


Figure 5.5. Soil types of Dominica organized by degree of weathering and (clay) mineral composition.

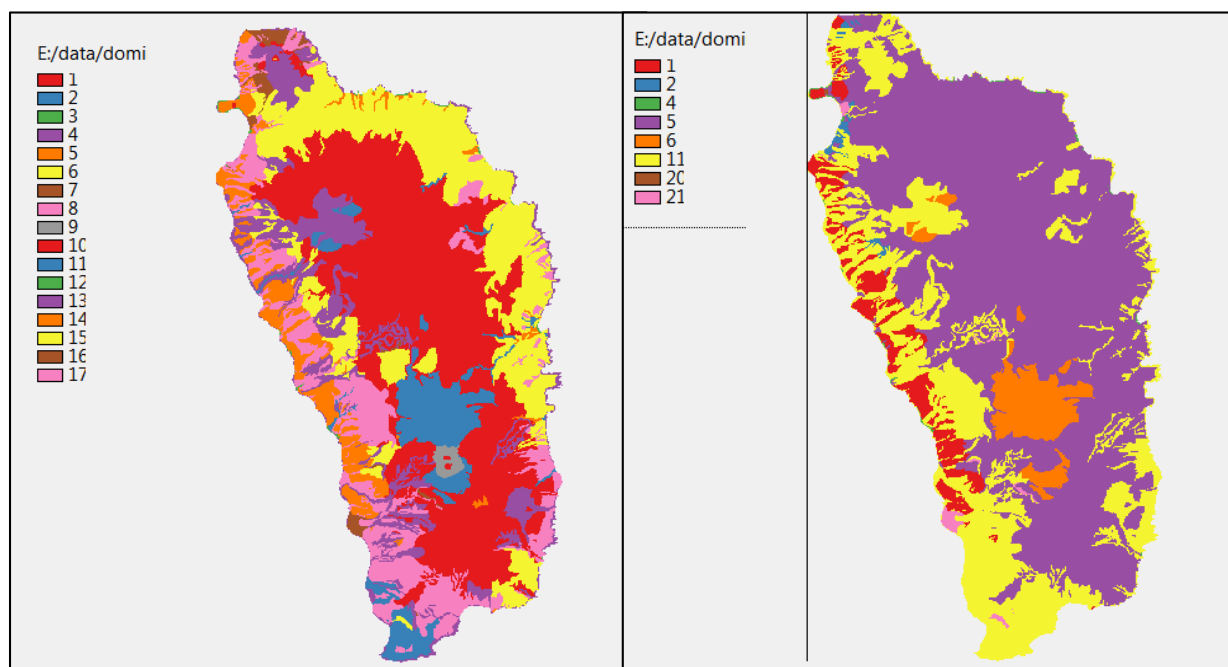


Figure 5.6. Soil types of Dominica (left) and the translation into texture classes that serve as hydrological units (right). The class numbers are shown in table 5.3.

Figure 5.6 shows the 17 main classes in the Dominica soil map, and the derived 8 classes of the texture class map, that are used as hydrological units.

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):

$$K_{sat_{eff}} = K_{sat} * (1 - stone) / (1 - 0.85 * stone)$$

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

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 top 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.

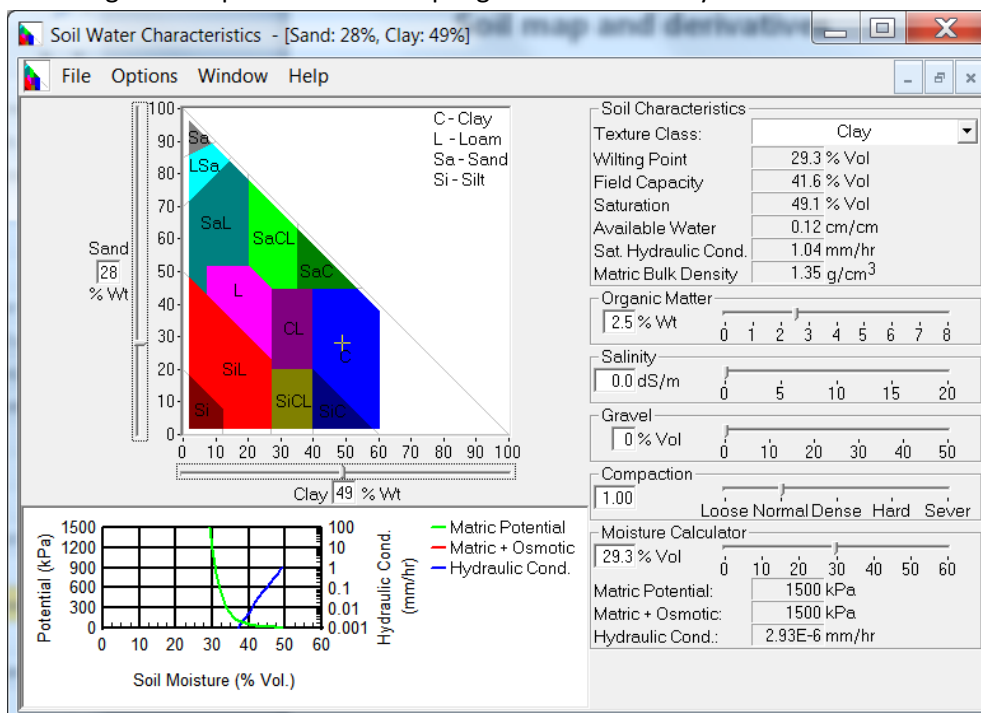


Figure 5.7. Pedotransfer functions by Saxton and Rawls (1986) used in SPAW model software.

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 5.7 and table 5.2, that the ksat 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.

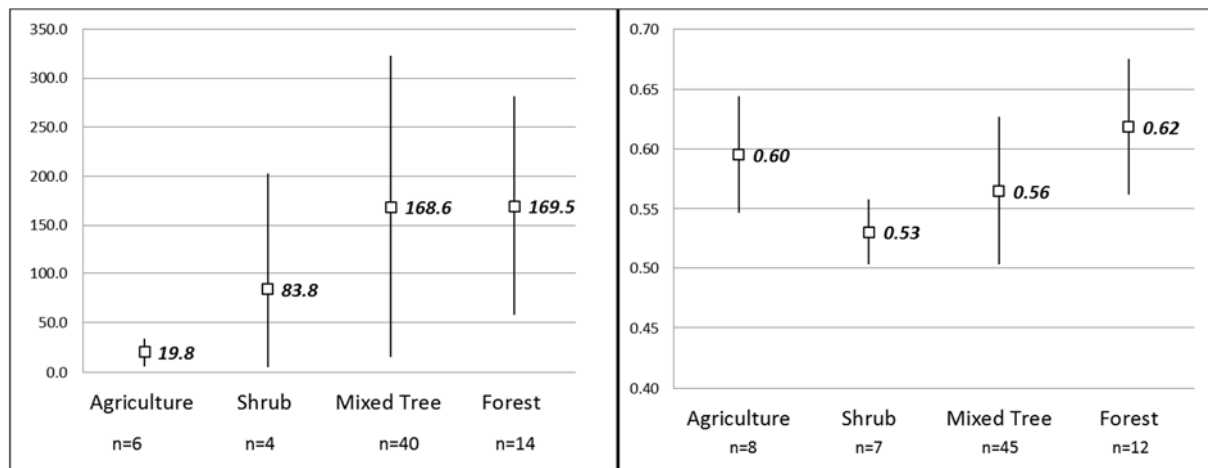


Figure 5.8. Left: saturated hydraulic conductivity (mm/h) and right: porosity (-) organized per main land cover type. The measurements are from Grenada, taken in the Gouyave and St John watersheds (Pratomo, 2015). The values in bold are the average, the lines show one standard deviation around the mean.

	Ksat (mm/h)				Porosity (cm <sup>3</sup> /cm <sup>3</sup> )			
	Agriculture	Shrub	Mixed Tree	Forest	Agriculture	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
<b>avg</b>	<b>19.8</b>	<b>83.8</b>	<b>168.6</b>	<b>169.5</b>	<b>0.60</b>	<b>0.53</b>	<b>0.56</b>	<b>0.62</b>
+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).

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).

The advantage of this approach is that the forested areas have a larger buffering effect than would be evident from 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.

Main soil type	Texture class	nr.	Ksat (mm/h)	Pore (-)	Field Cap. (-)	Wilt Point (-)
Smectoid Clay Soils	C	1	9	0.56	0.4	0.25
Other Clay Latosolics	CL	2	16	0.54	0.35	0.2
n.a.	L	3	74	0.48	0.25	0.1
Beach Sand and Shingle	S	4	161	0.45	0.11	0.06
Latosolics and Latosols (Allophanoid, Kandoid)	SaCL	5	31	0.43	0.28	0.15
Allophanoid podzolics	SaL	6	102	0.45	0.18	0.06
n.a.	Si	7	73	0.46	0.3	0.06
n.a.	SiC	8	15	0.56	0.41	0.24
n.a.	SiCL	9	22	0.5	0.38	0.18
n.a.	SIL	10	48	0.48	0.3	0.09
Young Soils, Protosols, Skeletal	LS	11	95	0.45	0.25	0.1
Pond	Water (W)	20	1	0.12	0.11	0.1
unclassified, Soufriere	Urban (A)	21	15	0.2	0.3	0.06
n.a.	Salt pans (m)	22	1	0.4	0.3	0.06
n.a.	Rock/outcrops (R)	23	1	0.3	0.11	0.06

**Table 5.3.** Main classes derived from the Dominica soil map, translated to texture classes and assumed saturated hydraulic conductivity (Ksat in mm/h), Porosity, field capacity and wilting point (cm<sup>3</sup>/cm<sup>3</sup>), after Saxton and Rawls (1986). The table shows all classes on the 4 CHARIM islands, n.a. indicates the texture class does not occur on Dominica

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 ( $\theta_i$ ) of 0.75 of the porosity ( $\theta_s$ ), which is approximately at field capacity ( $\theta_{fc}$ ) 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):

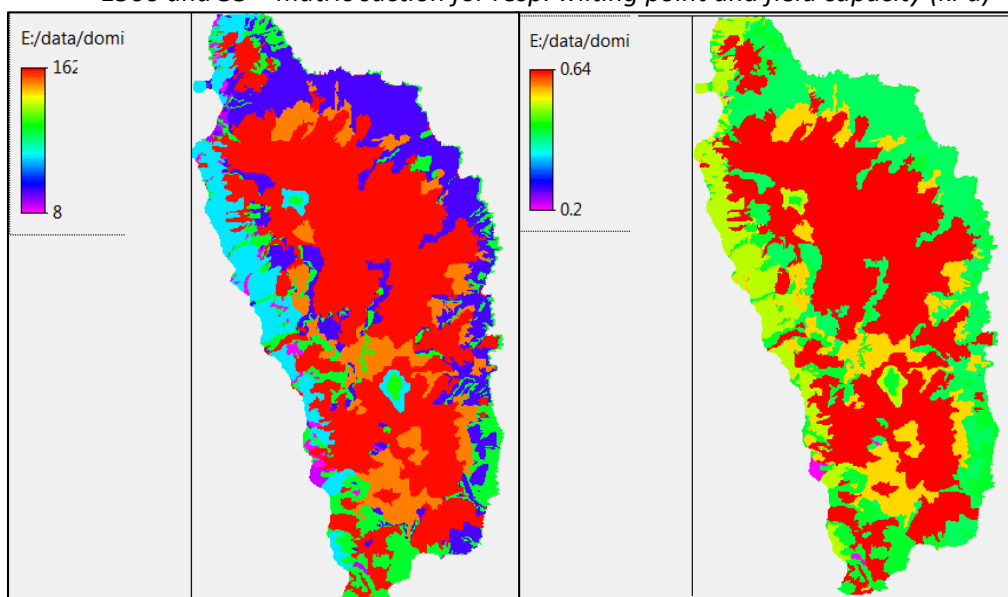
$$\psi = a \theta_i^{-b}$$

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)



**Figure 5.9.** Main hydrological parameters of the top soil. Left: ksat (mm/h), right: Porosity (cm<sup>3</sup>/cm<sup>3</sup>).



## 5.3 Land use and infrastructure

### *Land cover map and hydrological parameters*

The original land cover map from 2000 produced in CarLand project (Caribbean Land Cover project) was improved using additional data and resampled in CHARIM. In the original map, Landsat and SPOT images acquired between 1996 and 1999 were the source data for this forest and land cover map (USGS, 2006). The land cover types are reclassified according to their hydrological characteristics. For event based surface hydrology only the major land cover types are important. The land cover types have therefore similar values if they are hydrologically similar (such as Evergreen forest and Semi-deciduous evergreen forest). The parameter values used in LISEM are shown in table 5.3.

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 mm (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" (cm<sup>3</sup>/cm<sup>3</sup>) 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<sup>2</sup>. 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 5.10.** Top: Building footprint of Roseau and elsewhere on the island. Bottom: 20m resolution building map used in LISEM, only Roseau shows variation in building cover per gridcell, outside Roseau no building size information is available and an average building size of 70m<sup>2</sup> is used. 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).

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.

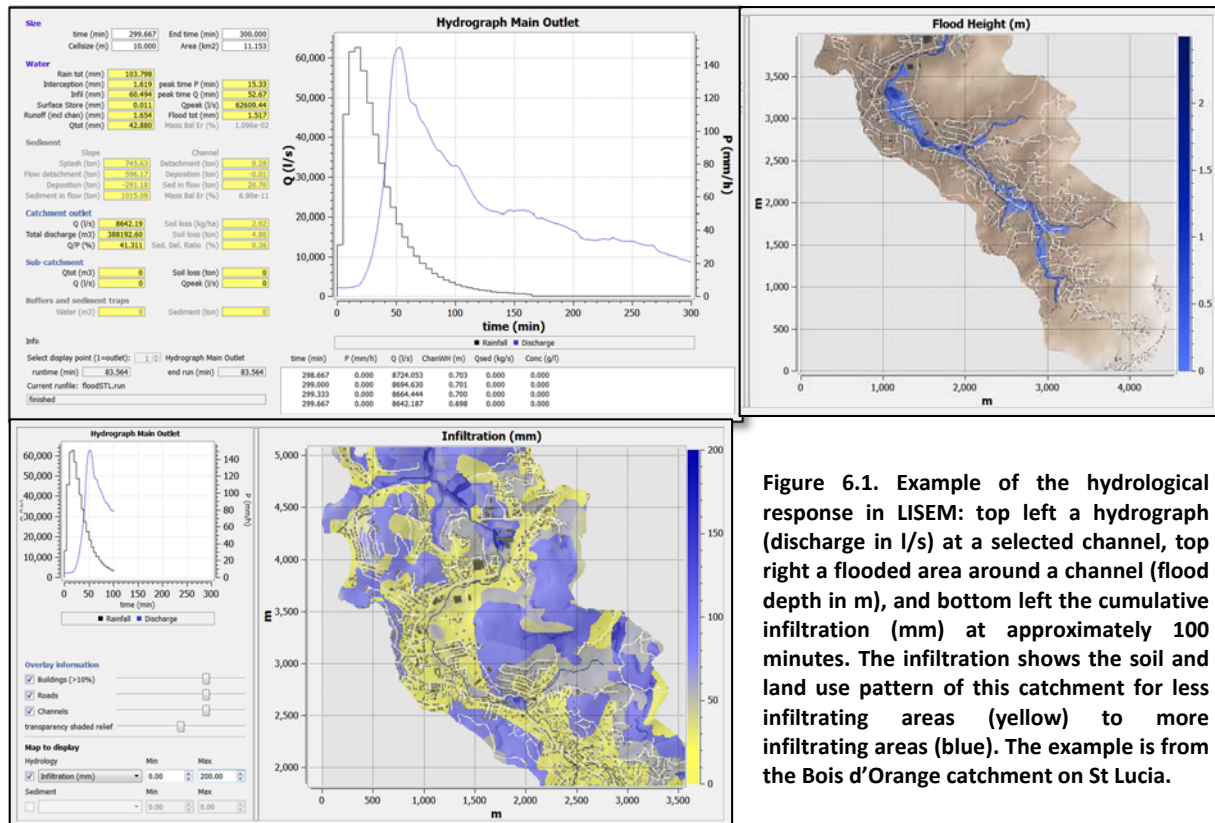


Figure 6.1. Example of the hydrological response in LISEM: top left a hydrograph (discharge in l/s) at a selected channel, top right a flooded area around a channel (flood depth in m), and bottom left the cumulative infiltration (mm) at approximately 100 minutes. The infiltration shows the soil and land use pattern of this catchment for less infiltrating areas (yellow) to more infiltrating areas (blue). The example is from the 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 four return periods. In total the area flooded increases from 30.7 to 59.4 km<sup>2</sup>, while the flood volume increases from 9.5 to 26.0 million m<sup>3</sup>. Note however that the quality of the DEM plays an important role in these values so they should be used with care.

Note that for these statistics, areas inundated by less than 5 cm were not flooded. The level of accuracy of the modeling system and the database were not considered sufficient for that level of detail. The flooded area is the "flood extent" on which the national flood hazard map is based.

The average building size in the national flood database is approximately 75 m<sup>2</sup>, 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 flooded is 5352 for 1:5 years and rises to 6465 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 3 meters. In other words the no of buildings affected *cannot* be used as a damage estimate.

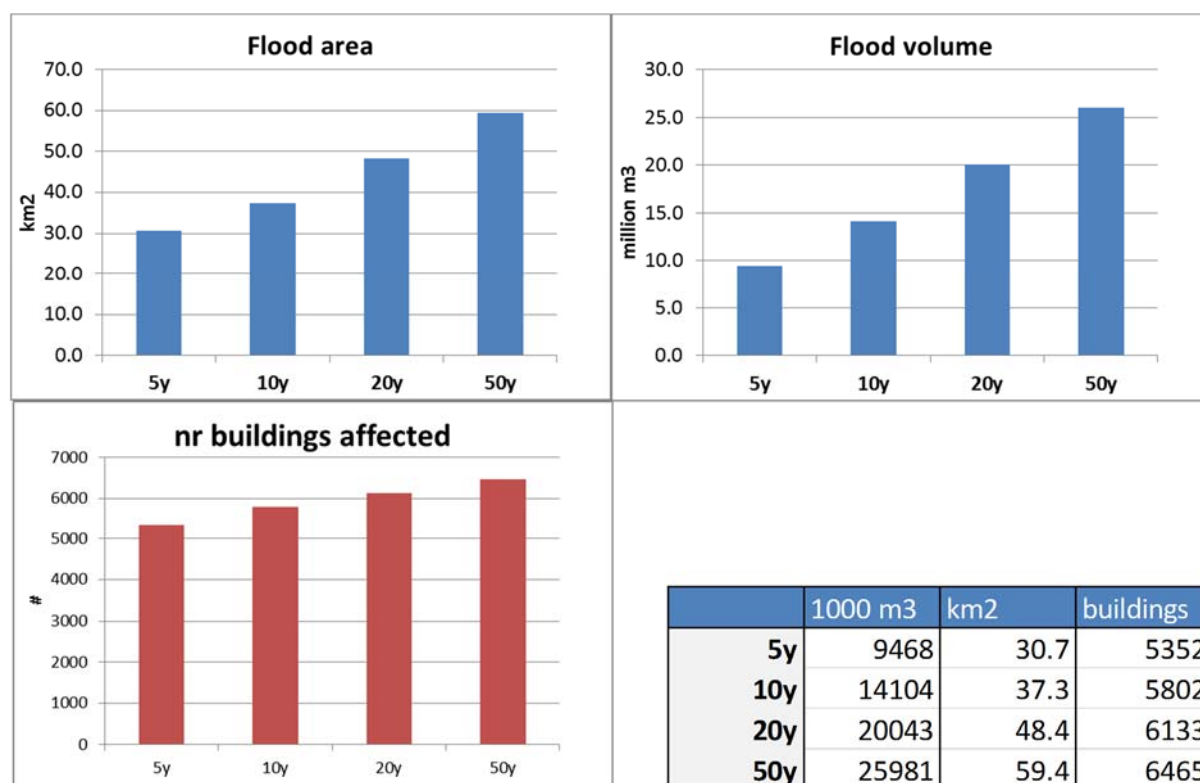


Figure 6.2. Summary statistics of the national flood hazard map of Dominica for the 4 return periods. Note that the building nr affected is an approximate number based on an average building size of 75 m<sup>2</sup>.

## 6.2 Stakeholder evaluation of Draft Flood hazard map

The 2015 draft flood hazard map was discussed with Barbados counterparts. In this section the evaluations and differences between the 2015 draft and the final 2016 flood hazard maps are discussed. The main difference is the improvement of the river width and depth, which gives some differences in flooding, although not very much. The low quality DEM and the uncertainty about the location of the river network still dominates the results. The following locations were remarked as not correct, according to experience (see fig 6.3).

## 6.3 Evaluation against existing flood hazard assessments

A flood hazard study was done for Dominica, by Opadeyi and Cooper (2006), referred to in the multi-hazard assessment by CIPA (2006). The method calculates a runoff probability based on the USDA Curve Number method, the probability of occurrence of an average rainfall (~ 2 year return period) and a slope class to differentiate between runoff contributing and flooded areas (based on the flood hazard mapping on Grenada). Although it is called a flood hazard map the link to hazard probability is not very clear, and hence it is more like a flood susceptibility map. It has three classes: low, medium and high flood hazard. According to this map, most of the island experiences low hazard, the eastern and western slopes bordering the ocean experience medium hazard and narrow areas along the rivers experience a high flood hazard. Upon interpretation it seems that the medium hazard class consists in fact not of flooded areas but of runoff contributing areas, while the low hazard class is non-flooded area. Only the high hazard class corresponds to overflowing river channels. If this interpretation is correct, there is some similarity between that map and the 2016 CHARIM flood

hazard map. The north west (fig 6.4) shows similar patterns but the new flood hazard map has more extensive flooding, especially in Portsmouth, and also in the north east. This may be due to many factors: the older may have used a different river pattern map, it may or may not have used land use and soil information etc.

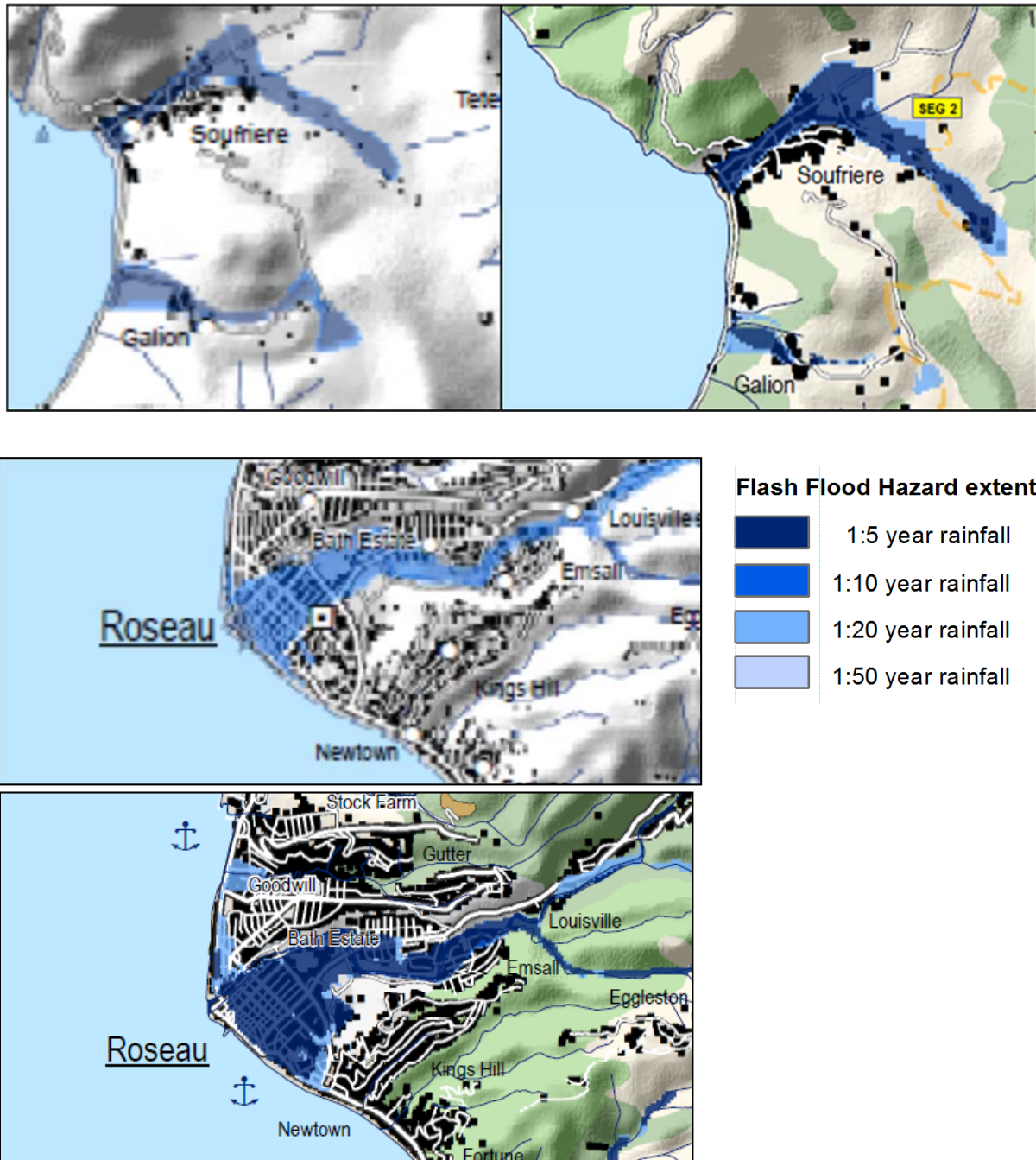


Figure 6.3. Two areas on the original draft flood map that were considered as overestimated in areal extent. The final map does not show much difference.



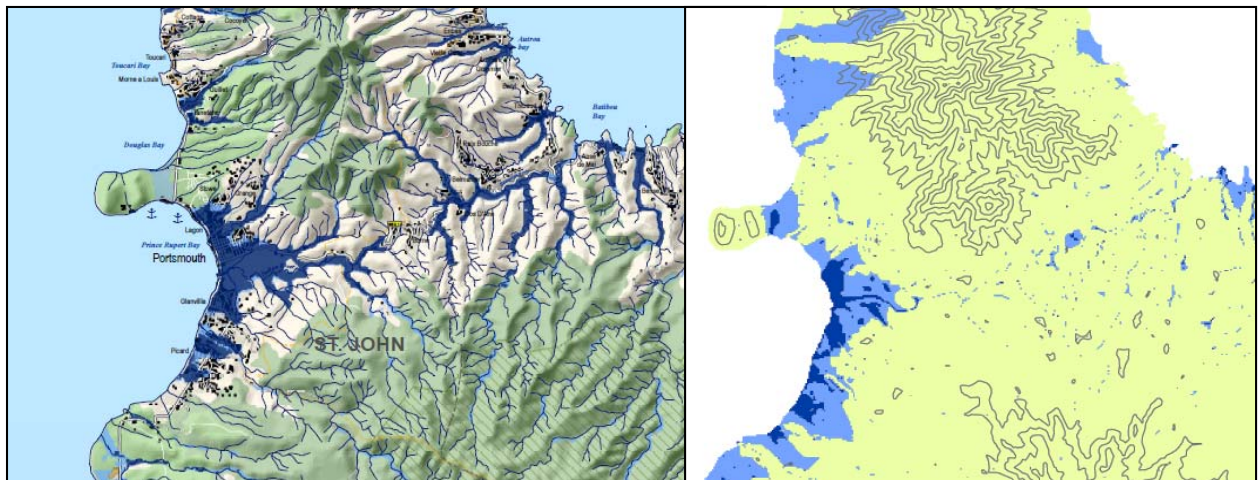


Figure 6.4. Comparison of the flood hazard map with an earlier flood susceptibility map (date and origin unknown), northern part of the island.

The south west is actually quite comparable (fig 6.5), the pattern in Roseau is very similar and also along the east coast, if we compare the high susceptibility class of the earlier map with the hazard extent classes of the new map.

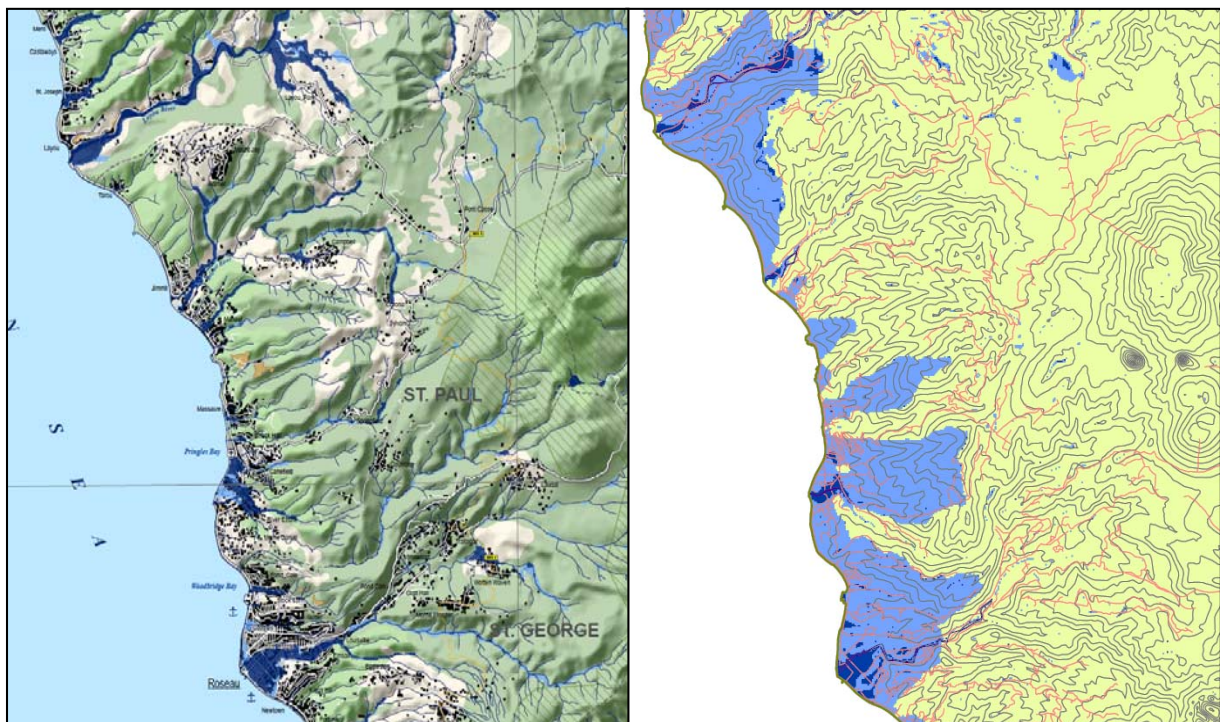


Figure 6.5. Comparison of the flood hazard map with an earlier flood susceptibility map (date and origin unknown), South western part of the island.

Finally the south east section is very different (fig 6.6), with almost no flooding on the older map and substantial flood hazard in the new map. In the next section we will look at the hurricane Erika, which had substantial damage in this area, so the older map does not seem to predict the flood susceptibility accurately.

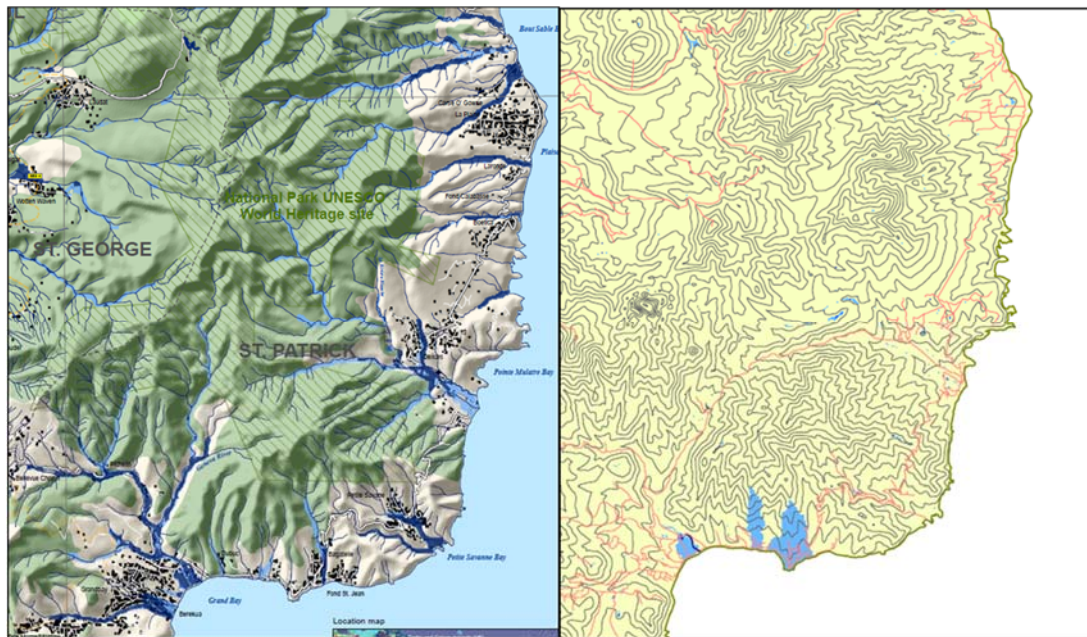


Figure 6.6. Comparison of the flood hazard map with an earlier flood susceptibility map (date and origin unknown), south eastern part of the island.

## 6.4 Hurricane Erika

On 25 August 2015, the hurricane Erika hit Dominica with full force. A rapid damage and impact assessment was done by GFDRR immediately after the event, and a technical assistance mission by BRGM focusing more on landslides. The first report resulted in many maps with housing damage and casualties, naming a number of communities that were severely affected. In this report there was also enough rainfall information (see fig 6.7) to simulate the effects of the storm with LISEM, using the Dominica flood hazard GIS dataset. In this section we simply compare the modeled flood depth with location that are known to have experienced damage, as a way to verify the validity of the model approach.

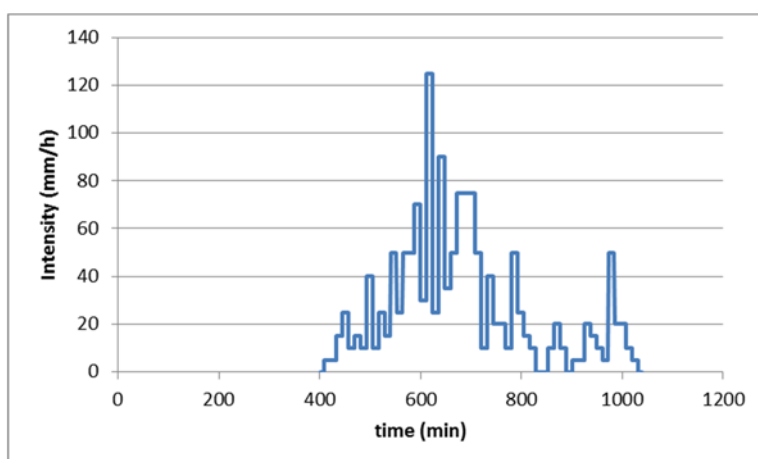


Figure 6.7. Reported rainfall intensities (GFDRR, 2015) for Canefield station, with a total of 203 mm. The rainfall may have been more intensive than this as reported in the BRGM (2015) report, but no actual measured values were obtained.



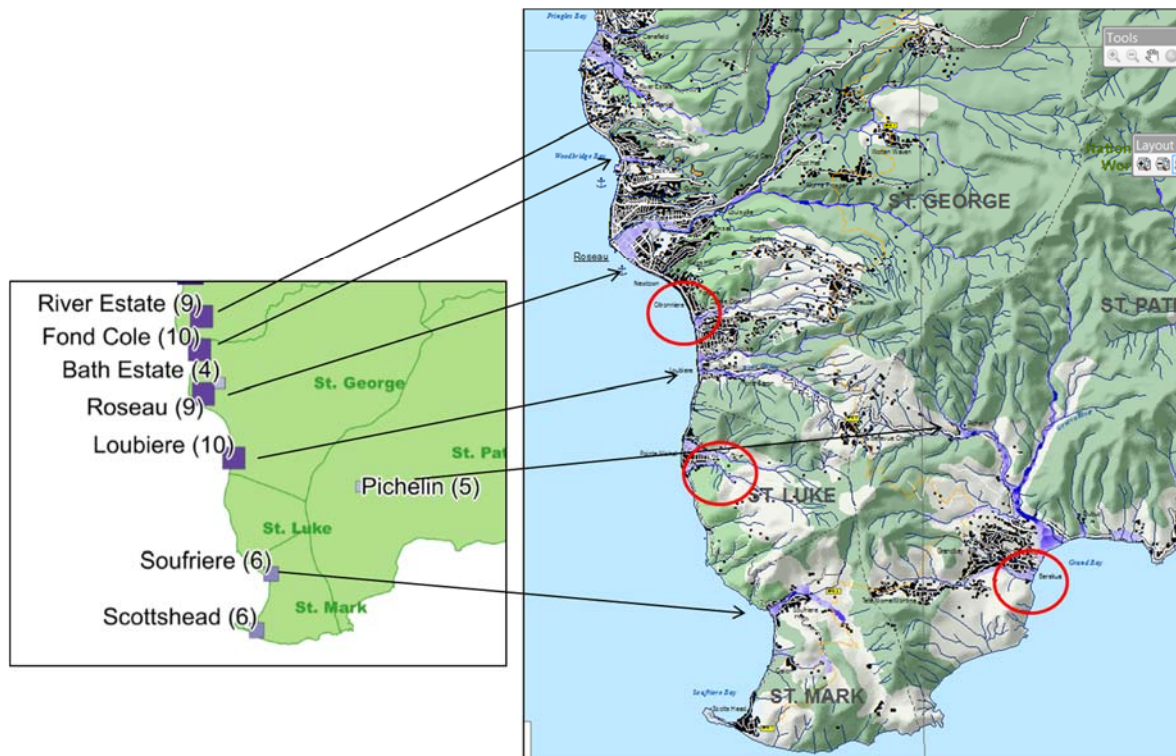


Figure 6.8. Total damage to houses along the south west coast (GFDRR, 2015) and simulation of Erika with LISEM. Arrows indicate correctly predicted flood extent, while red circles have a predicted flood but no reported damage.

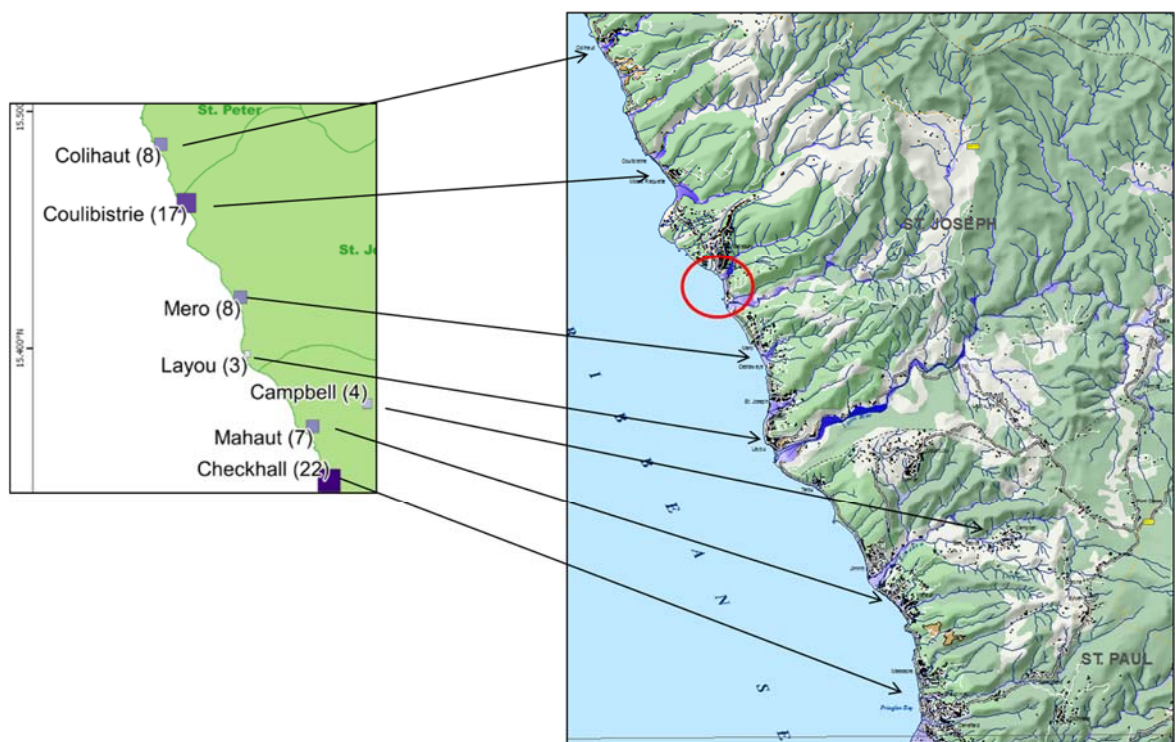


Figure 6.9. Total damage to houses along the west coast (GFDRR, 2015) and simulation of Erika with LISEM. Arrows indicate correctly predicted flood extent, while red circles have a predicted flood but no reported damage.

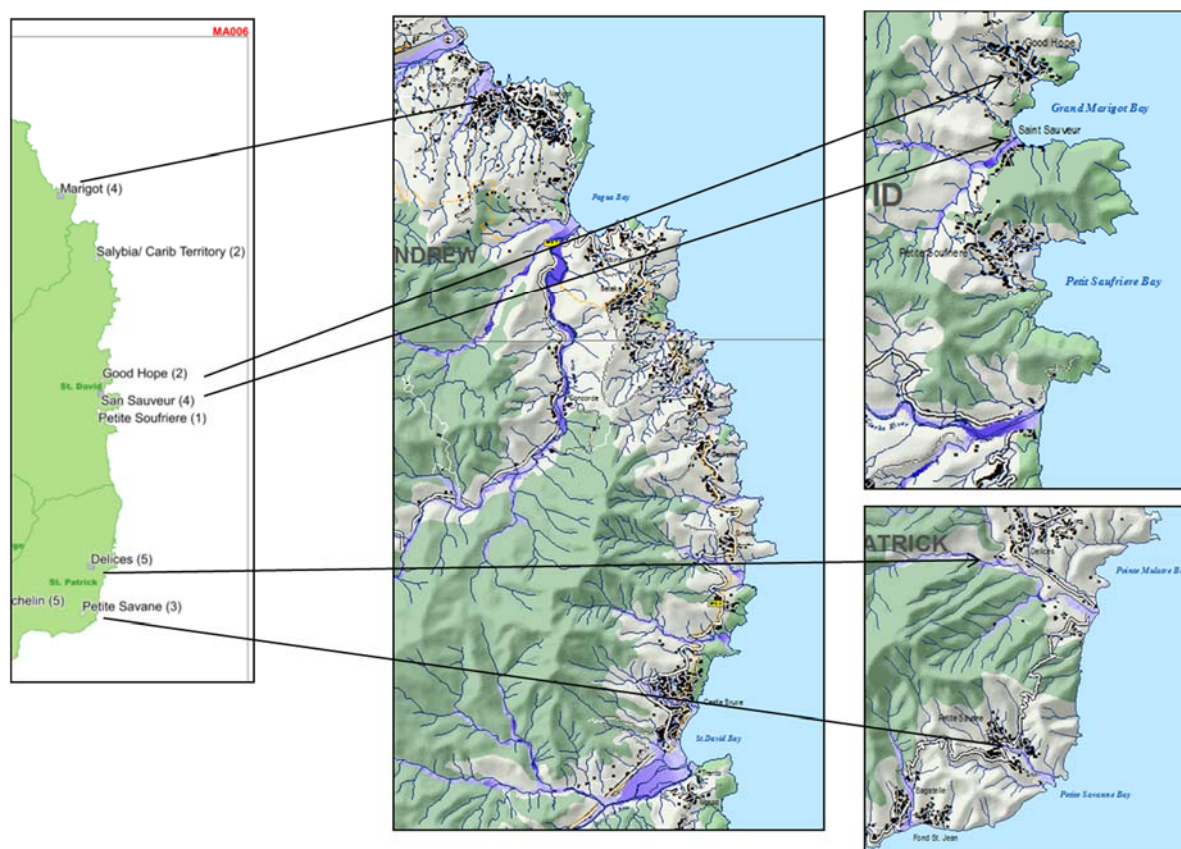


Figure 6.10. Total damage to houses along the east coast (GFDRR, 2015) and simulation of Erika with LISEM. Arrows indicate correctly predicted flood extent, while red circles have a predicted flood but no reported damage.

Comparison of the simulated flood extent with the location of the reported damage to houses show a good similarity. Certainly the model can be used for rapid damage assessment purposes, as a guidelines to where to go. The model shown more locations with flooding, but this is probably the result of the fact that the same rainfall is applied homogeneously across the island while in reality there is much more spatial variation. It may also be that the damage reporting is not complete because in such circumstances this is difficult to achieve.

## 6.5 Recommendations to improve the flood hazard map

### DEM

One of the most important improvements can come from a much better DEM (such as from LIDAR data) with matching river patterns. This will considerably alter the flood hazard.

### Discharge data

One of the most important improvements is measuring river discharge in a few selected catchments. If early warning systems exist on Dominica, they should be used for this. 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.

Select Locations: while island wide inventories are of course good to work on, they are also maybe a task too large to execute (taking too much manpower). Concentrating on catchments in which you have a flood early warning system installed (FEW system), and collect the following data from these catchments. In other words: establish three catchments per island on which you concentrate these efforts with the goal to test and validate any tool you want to use. Establish a database for these catchments.

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 from 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).

### **Rainfall data**

There is no detailed rainfall data, only daily data and only from a few stations. An investment should be made to improve the rain gauge network on Grenada, St Vincent and Dominica. Without this data flood modelling cannot be done. Since there seems to be a trend in rainfall from the southern to the northern islands, using rainfall from another location may be wrong, both in this study as well as in those from other consultants. Island specific rainfall data is absolutely necessary.

### **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 selected catchments. In each catchment about 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. Taking sample rings and processing them is not much work, about two weeks per catchment for 1 person.



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**ANNEX: Dominica National Flood Hazard map**





