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Preparing for Extreme And Rare events in coastaL regions

D3.5 Hurricane Irma Special Report

From Risk to Resilience: *A fact finding and needs assessment report in the aftermath of Hurricane Irma on Sint Maarten*

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Abstract (for dissemination, 100 words)	Hurricane Irma cause the disaster in September 6, 2017. As part of the extension on time some researchers/partners of project took the initiative to undertake a fact-finding mission on the impacts of Irma focusing on Sint Maarten. The research team went on three field missions to Sint Maarten between February and April 2018. This report describes Hurricane Irma and modelling outputs that simulate the hurricane, it addresses the fact-finding mission in relation to household surveys, risk root cause analysis, semi-structured interviews, stakeholder meetings, the needs and priorities of local humanitarian actors to humanitarian emergency and urban drainage system assessment. A special section to report vulnerability, hazard and risk assessment in Sint Maarten in the context of Hurricane Irma. The report also describe flood, surge, wave and tsunami models and forward recommendations that can be considered during the reconstruction phase.

Keywords	Hurricane Irma, Extreme events, Holistic risk assessment

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Disclaimer

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The deliverable D3.5 Hurricane Irma Special Report reflects only the authors' views and the European Union is not liable for any use that may be made of the information contained herein.

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Executive Summary

On 6 September 2017, Hurricane Irma, one of the most powerful Atlantic hurricanes, had a landfall on the island of Saint Martin as category 5 hurricane. Irma's landfall wind speed of about 287 km/h is the strongest that impacted the island. Irma killed people and caused enormous damages to livelihoods and assets in both the French and Dutch sides, Saint-Martin and Sint Maarten, respectively. About 90% of structures in the French side and 70% of the structures in the Dutch side were damaged by the destructive winds of Irma and associated high waves and storm surge. The total estimated damage in Sint Maarten is more than US$2 billion.

Following the aftermath of Hurricane Irma, the Sint Maarten Government requested the PEARL project team to incorporate this extreme event into the analysis of the project and provide advice for reconstruction and future development planning activities on the island. As the aim of PEARL is to advance knowledge and develop supporting tools that can be used to build resilience to extreme hydro-meteorological events in coastal regions, and Sint Maarten is one of the case studies of PEARL, researchers of the PEARL project has accepted the request and employed all available tools, models, data and resources to support the government and people of Sint Maarten.

The PEARL research team undertook a fact-finding and needs assessment mission on the impacts of Irma focusing mainly on the Dutch part, Sint Maarten. The team went on field missions to Sint Maarten between February and April 2018 and carried out workshops, stakeholder meetings, semi-structured interviews and household surveys regarding hurricane warnings, evacuations, people's awareness/perception of hurricane impacts, risk root cause analysis (RRCA), needs and priorities of local humanitarian actors and organisational responses after a hurricane. The team also collected drainage system and weather data that are used in flood, wave and wind storm modelling and risk assessment.

The household survey analysis shows that there was a major shift in construction of houses after the 1995 Hurricane Luis, the most devastating hurricane in Sint Maarten before Hurricane Irma. Most people built stronger concrete houses than wooden ones. However, risk sharing schemes such as insurance to natural disasters are not popular in the island, in which close to 50% do not have insurance and struggle to rebuild after Irma. Most people in Sint Maarten have moderate to great awareness of hurricanes and warning information, but close to 70% did not evacuate during Irma. From the evacuated ones, only 3% went to public shelters while the majority sought shelter at friends' or relatives' houses.

The RRCA identified that historic root cause drivers such as small island status, economic development and colonial marginalisation influencing the lack of capacities and regulations have manifestation in high population density, unplanned urbanisation and increased risk exposure in both Sint Maarten and Saint-Martin. Nevertheless, the damages caused by Irma fell disproportionately on Saint-Martin rather than Sint Maarten, and the recovery into reconstruction phase has been experienced more slowly. In Sint Maarten, better construction practices despite the absence of an appropriate code, to some extent minimised the relative damage to structures. The lesser impact of Hurricane Luis on the French side also had the paradoxical effect that the French experienced more damages to their infrastructure under Irma as core infrastructure was not buried underground, unlike in Sint Maarten.

The needs and priorities assessment to local community based organisations (CBOs) emphasised on four priority areas as central to community resilience in Sint Maarten - vulnerability and social

protection, livelihoods support, coordination (and communication) for the response and psychosocial support/trauma. As first responders to humanitarian emergency, the CBOs identified gaps and challenges affecting responses after Irma. The main gaps include elderly and poorer (migrants) communities struggle for basic needs such as food and reconstruction of dwellings, undocumented migrants won't speak out or register for aid for fear of being deported, unemployment (especially for women) across Sint Maarten is high as the tourism industry has been particularly hit, CBOs unclear how to support response due to poor information-sharing culture, aid not reaching survivors and social fabric damaged due to looting. The main challenges affecting responses include support from the Sint Maarten Government was not timely or adequate, CBOs physical infrastructure damaged by the Irma, low trust in government, no social welfare safety net, traditionally male dominated jobs as the post-Irma focus is on reconstruction, and cultural sensitivities to admitting to mental health issues.

The PEARL research team also carried out hazard, vulnerability and risk assessments. From a hurricane simulation, Hurricane Irma wind field and storm surge are computed using a hydrodynamic model. Existing inland flood model is updated using drainage system data collected during field mission. A coupled inland and coastal flood model is performed to identify flooded areas such as Cul de Sac, Lower prince's Quarter, Little Bay and Madam's Estate, Philipsburg, Cay Bay, Simpson Bay and Maho. A wave and preliminary tsunami simulations were also carried out to investigate their effect on the island. The PEARL Vulnerability Index method was applied to assess the susceptibility, lack of coping capacities, lack of adaptation capacities and the overall vulnerabilities. The assessment showed that the most vulnerable neighbourhoods in Sint Maarten are Dutch Quarter, Over the Bank, Over the Pond, Mount William and Bishop Hill.

Finally, a wide range of recommendations that needs to be considered during the reconstruction period and beyond are given. The recommendations include Sint Maarten has to address underlying issues of land use and building regulation through comprehensive plans and policies; recognising the need for stronger monitoring and enforcement through strengthened capacities and political support, whilst protecting the most marginalised populations from expropriation and forced investment (asset loss) from enforced regulation; improve the capacity, transparency and accountability of the Sint Maarten Government; control the quality of construction materials used during reconstruction; improve the insurance culture and promote better insurance coverage; improve security after hurricanes; build strong category 5 hurricane resistant shelters by investing on the schools and community centres used as public shelters; and improve the warning and evacuation using less technical information, by relating to previous similar events and in multiple languages. To reduce the inland flooding, the government has to consider implementing a combination of green infrastructure with open detention basins and improve drainage systems. Sea dikes and seawalls are recommended as coastal flood protection measures for Sint Maarten.

1 Introduction

1.1 Background

The island of *Saint Martin* is located in the Leeward Islands of northeast Caribbean Sea. The island is divided into two parts: the northern part called *Saint-Martin* is an overseas collectivite of France and the southern part called *Sint Maarten* is one of the constituent countries of the Kingdom of the Netherlands (see Figure 1.1). The total area of Saint Martin is 87 km^2 in which the Dutch part makes up approximately 34 km^2 and the French part makes up approximately 53 km^2. The populations of the two sides of the island are 40535 (in 2017)[1] and 35684 (in 2015)[2] in Sint Maarten and Saint-Martin, respectively. Hence, Sint Maarten is more densely populated than Saint-Martin. The volcanic island has hilly terrains where elevation ranges from near sea level at the coasts to about 420 m above mean sea level at the pics bordering the French and Dutch sides (see Figure 1.1). The lowlands are highly urbanized with predominantly residential buildings in the valleys and businesses located mainly along the coast.

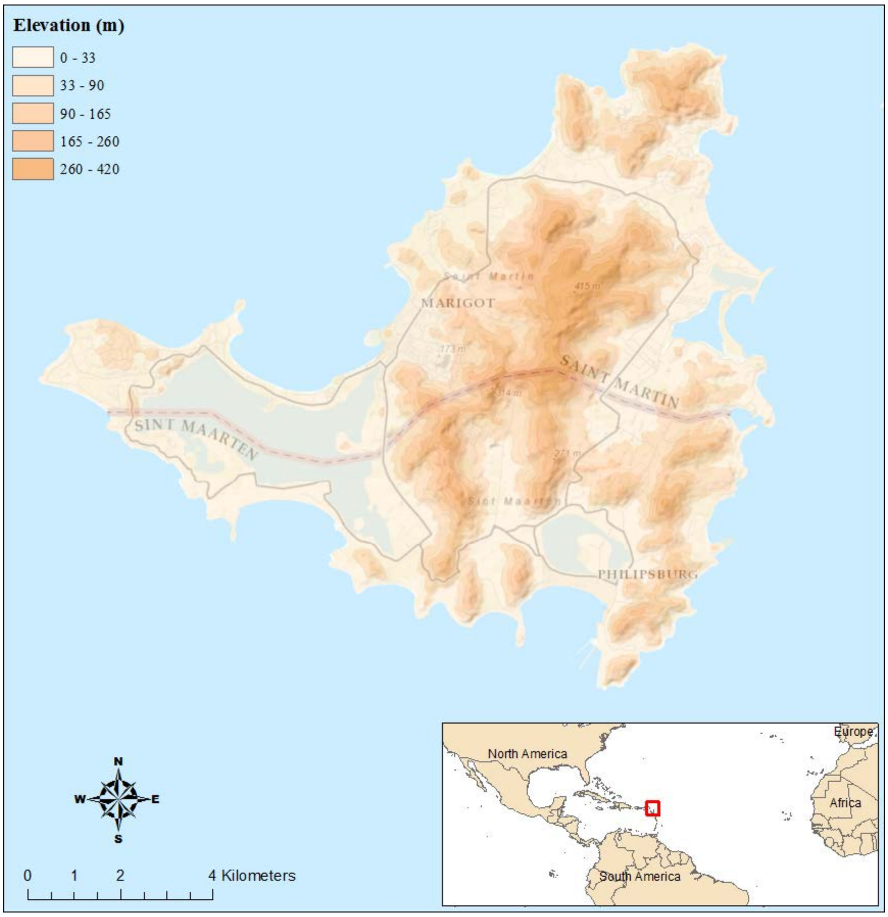


Figure 1.1. A map of Saint Martin showing the northern French side (i.e., Saint-Martin) and the southern Dutch side (i.e., Sint Maarten). The map also shows the elevation ranges of the whole island. (Source: the base map is an ESRI Topographic Map).

[1] http://stat.gov.sx/downloads/YearBook/Statistical_Yearbook_2017.pdf

[2] https://www.insee.fr/fr/statistiques/3545753?sommaire=3292701

The tropical marine climate of Saint Martin is characterized by a wet season from July to November bringing occasional heavy rainfalls and a dry season from January to April, where May, June and December are transition months. The average temperature of the island is 27 °C. The normal annual rainfall is about 1170 mm spreading over 145 rain days a year on average (Met Office, 2018). The island is located within the Atlantic hurricane belt, and hence, subject to frequent hurricanes (see Figure 1.2). The Atlantic hurricane season runs from 1 June to 30 November. However, most hurricanes that passed within a 150 km radius from Sint Maarten occur in the months of August, September and October (see Figure 1.3).

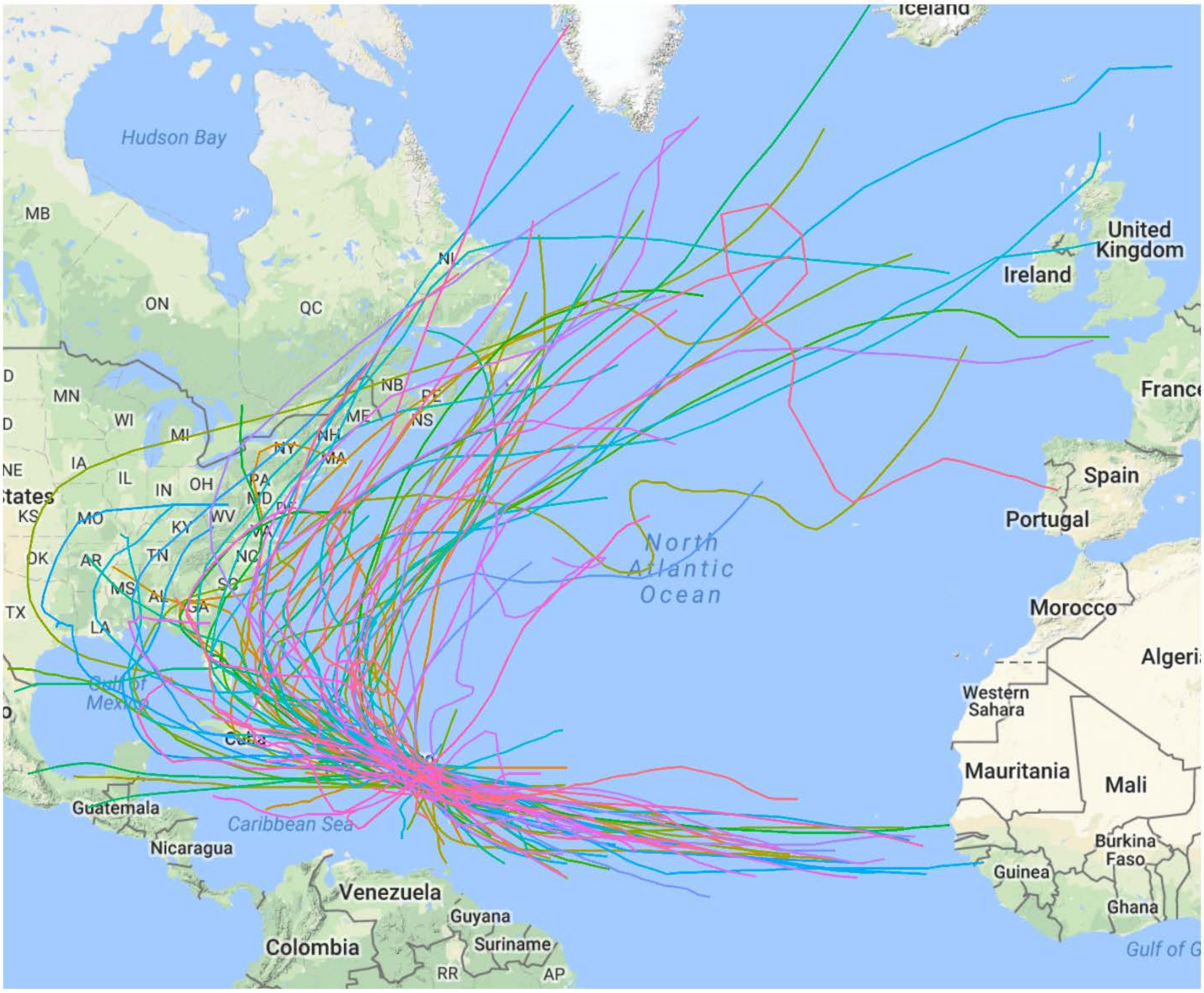


Figure 1.2. Hurricanes that passed within about 150 km from Saint Martin (1852 – 2017). The 150 km distance is from the eye of the hurricanes to the center of Saint Martin. Source: Historical hurricane track data (1851 – 2016) was acquired from the International Best Track Archive for Climate Stewardship of the National Oceanic and Atmospheric Administration's (NOAA) National Centers for Environmental Information[3]. 2017 track data was acquired from the UNISYS Weather Archive[4]. Background map is a Google 2018 terrain map.

[3] https://www.ncdc.noaa.gov/ibtracs/index.php?name=ibtracs-data-access

[4] http://weather.unisys.com/hurricane/atlantic/2017/index.php

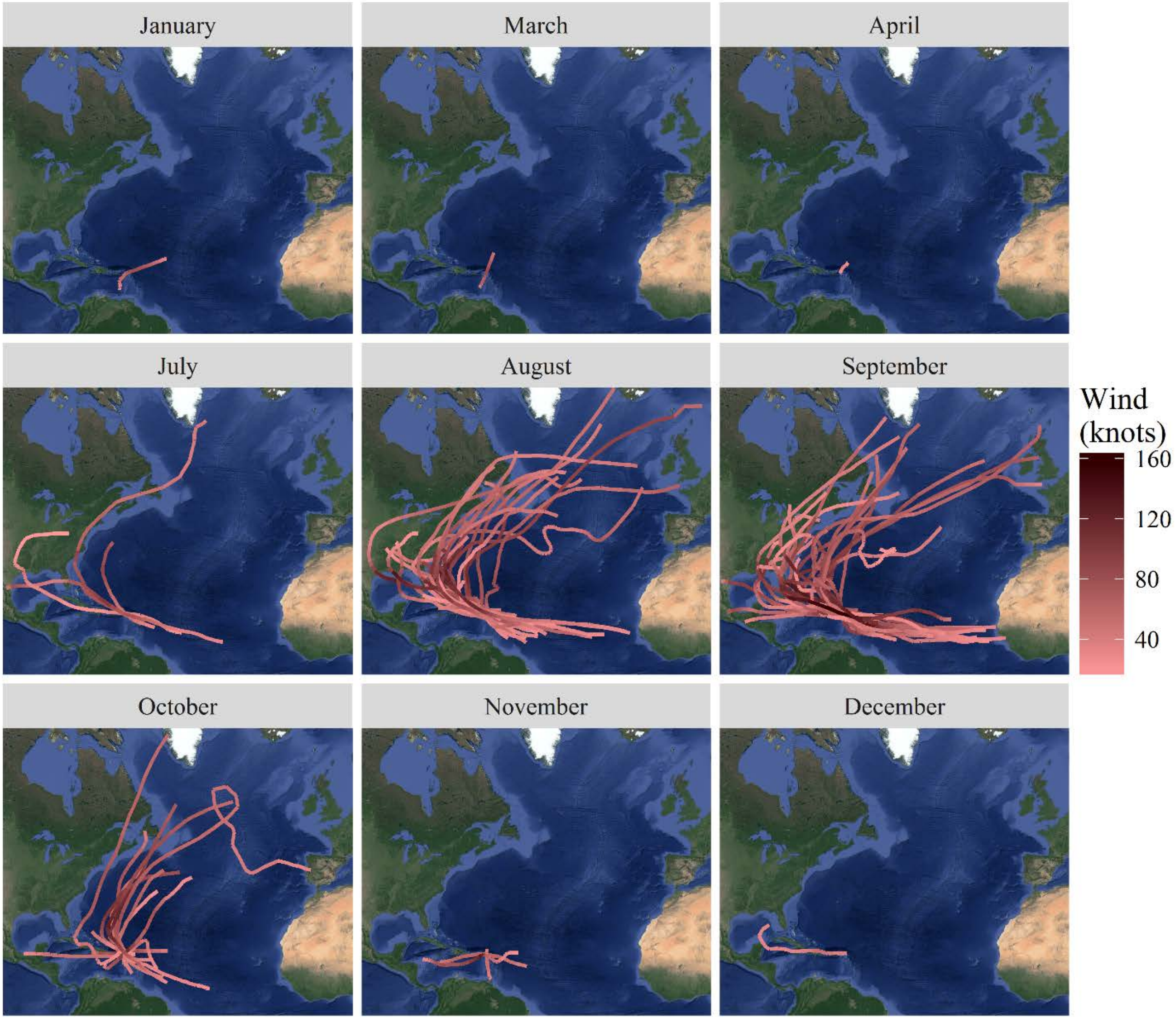


Figure 1.3. Hurricanes (shown in **Figure 1.2**) categorized by month. The months correspond to the time when the hurricanes passed within a 150 km radius of Saint Martin. Source: Background map is a Google satellite map.

Notable *major hurricanes*[5] that affected the island include Hurricane Luis in 1995 and Hurricane Lenny in 1999 (see a list of historical major hurricanes that passed within a 150 km radius from Saint Martin in Figure 1.4). These hurricanes brought an enormous amount of damage to the people of Saint Martin both economically and socially, including loss of life (see more in MDC, 2015). The damages due to hurricanes are associated with one or a combination of strong wind, storm surge, pluvial flooding and mudslides. For example, Hurricane Luis, the most famous hurricane in Sint Maarten before 2017, is well remembered for its strong wind. The maximum wind speed registered

[5] Major hurricane is a hurricane that is classified as Category 3 or higher (≥ 178 km/h) in the Saffir-Simpson Hurricane Wind Scale (Source: https://www.nhc.noaa.gov/aboutgloss.shtml)

for Luis at the Princess Juliana Airport meteorological station in Sint Maarten was 183.5 km/h[6]. The rainfall from Luis amounted to 165.8 mm on 5 September 1995. The hurricane killed nine persons in Saint Martin and an estimated 60% physical damage on the island that amounted to an estimated US$1.8 billion (Lawrence et al., 1998). On the other hand, the primary impact of Hurricane Lenny is due to heavy rainfall and the resulting flooding. The rainfall recorded at Princess Juliana Airport over 36 hours was 696 mm[7]. Lenny killed three in Sint Maarten and caused mudslides and flooding. It also caused an estimated sea wave between 3 m and 5 m.

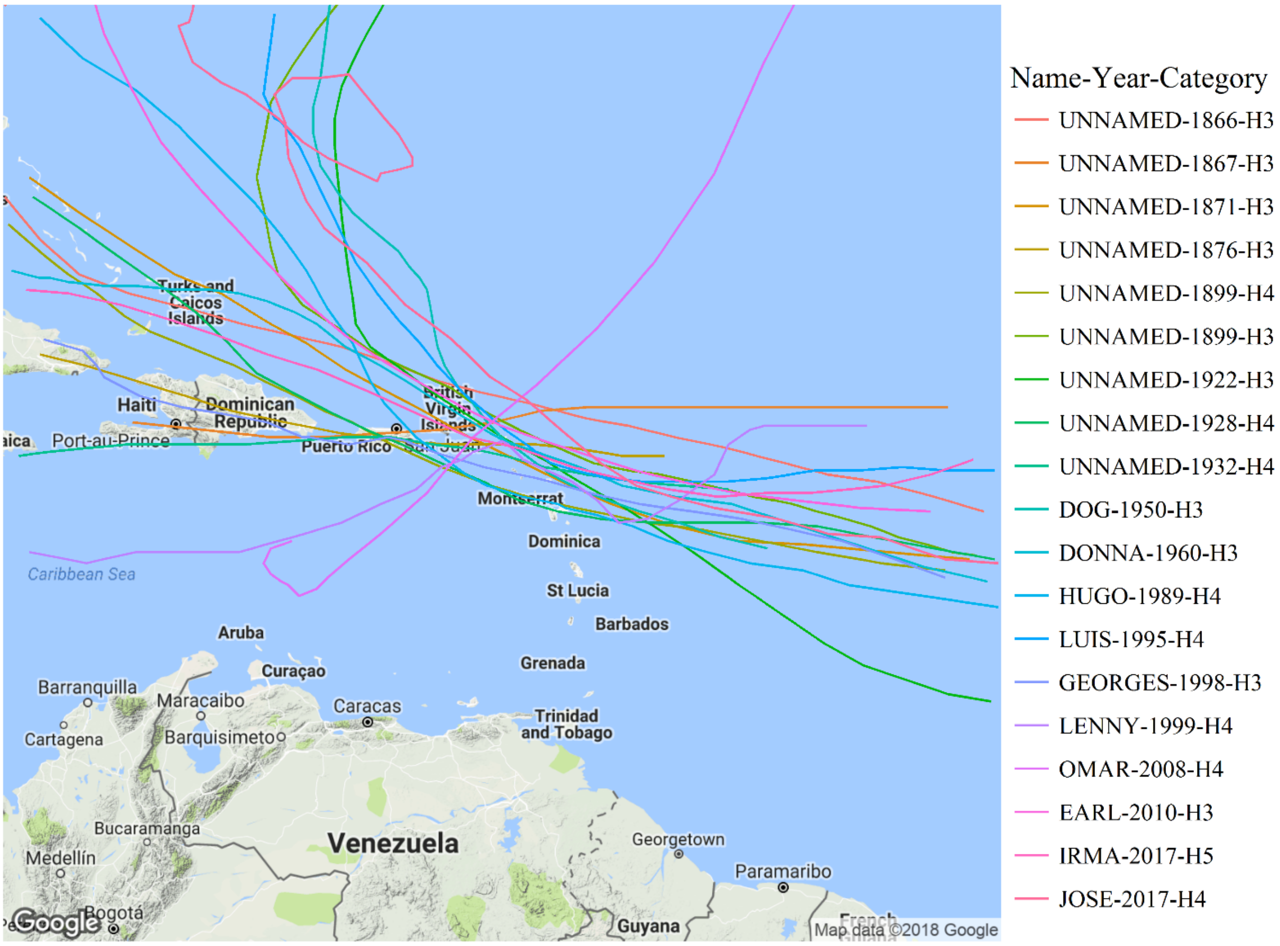


Figure 1.4. Major hurricanes that passed within about 150km from Saint Martin (1852 – 2017).

The tourism-led economy of the island also suffers from the impacts of hurricanes. For example, the storm surge created by Hurricane Luis eroded beaches, capsized and sank boats and damaged the main port (ECLAC, 2017). The airports on both the French and Dutch sides were damaged and closed to commercial traffic[8]. Hurricane Lenny also caused damages to the harbour and airports. Luis and Lenny caused major destructions to the hospitality industry including significant impacts on resorts, hotels, restaurants, cruise lines, car rentals and other related businesses. For example, in Sint Maarten alone, the number of cruise and stay-over tourists reduced by more than 100,000 in

[6] The maximum wind reported by the National Hurricane Center of NOAA is higher – 212 km/h (Lawrence et al., 1998)
[7] http://www.meteo.cw/Data_www/pdf/pub/HurricanesTropicalStorms_DC.pdf
[8] https://www.nytimes.com/1995/09/08/world/st-maarten-is-left-smashed-and-looted-after-luis.html

each case (see Figure 1.5), which amounted to a loss of revenue more than US$100 million. In the subsequent years, although the cruise tourism picked up faster, the stay-over tourism recovered very slowly, perhaps, due to the lag in the reconstruction of the island's hospitality sector.

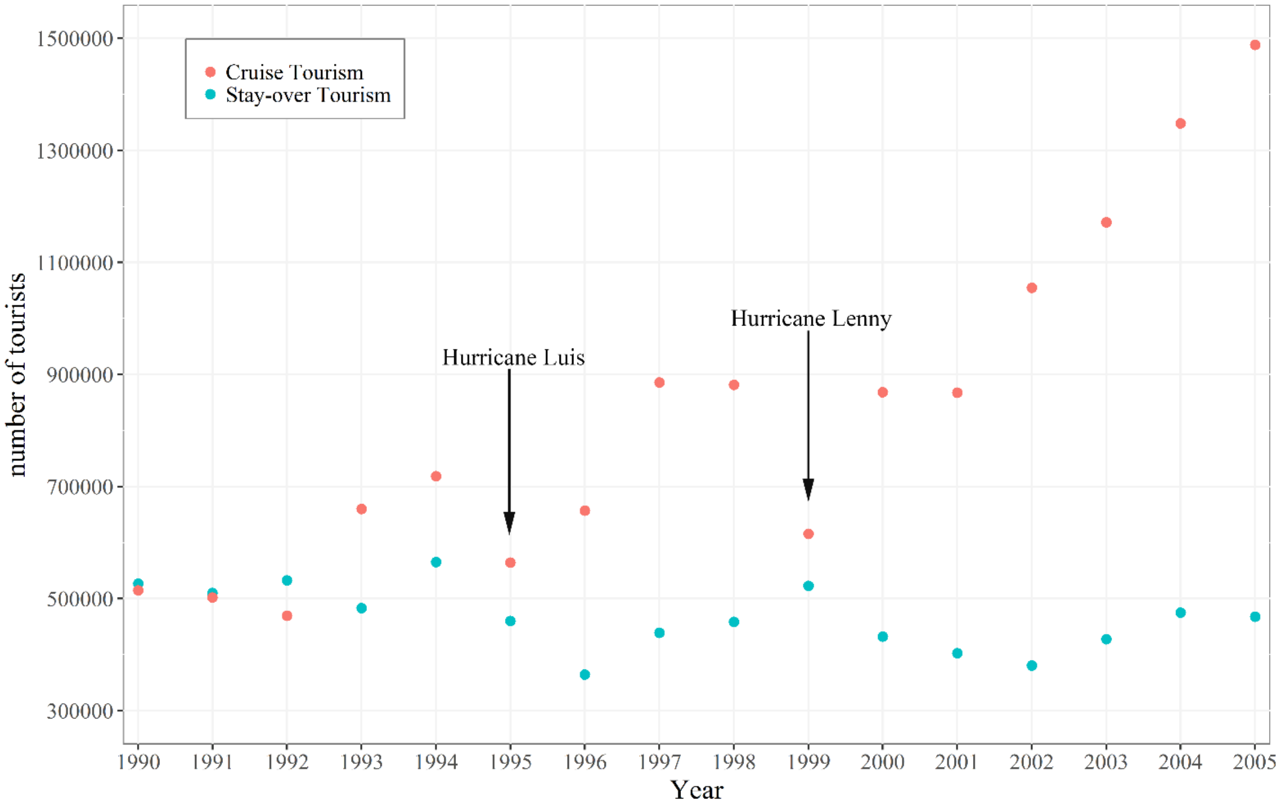


Figure 1.5. Impact of Hurricanes Luis and Lenny in the stay-over and cruise tourism on Sint Maarten. Source: data regarding the number of tourists in Sint Maarten is acquired from the Statistical Yearbook Netherlands Antilles 1993 – 2006 of the Digital Library of the Central Bureau of Statistics Curacao[9].

More recently, Hurricane Irma, which is one of the most powerful Atlantic hurricanes, had a landfall on Saint Martin as category 5 hurricane on 6 September 2017. Irma's landfall wind speed of about 287 km/h (Cangialosi et al., 2018) is the strongest that impacted the island. Irma killed at least 15 people (11 in Saint-Martin[10] and four in Sint Maarten) and caused enormous damages to livelihoods and assets. About 90% of structures in the French side and 70% of the structures in the Dutch side were damaged by the destructive winds of Irma.

Hence, researchers/partners of the PEARL project (see Section 1.2 about the project) took the initiative to undertake a fact-finding mission on the impacts of Irma focusing mainly on the Dutch part, Sint Maarten. The research team went on field missions to Sint Maarten between February and April 2018 and carried out workshops, interviews and household surveys regarding hurricane warnings, evacuations, people's awareness/perception of hurricane impacts and organisational responses after a hurricane. The team also collected drainage system and weather data that are used in flood risk assessment. In this special deliverable, we report our findings, analysis and recommendations for future hurricane preparations and the reconstruction work.

[9] http://digitallibrary.cbs.cw/CBS0000005/00039/allvolumes

[10] This number includes 1 death in Saint Barthelemy.

1.2 PEARL project

Preparing for Extreme And Rare events in coastaL regions (PEARL) is a European Union's Seventh Framework Programme for Research, Technological Development and Demonstration (EU-FP7) funded project that focuses on tsunamis and climate-related coastal risks[11].

Coastal floods are regarded as one of the most dangerous and harmful of all natural disasters. Rapid urbanisation in coastal areas combined with climate change and poor governance can lead to a significant increase in the risk of local pluvial flooding coinciding with high water levels in rivers and high tide or storm surges from the sea, posing a greater risk of devastation in coastal communities.

There is a need to improve forecasting, prediction and early warning capabilities using state of the art science and technology to help policy makers and emergency services to develop robust risk reduction strategies. However, forecasting and prediction is only part of the answer. Of equal importance is the ability to effectively warn the population in areas that will be affected, and that warning systems for the general public are integrated into broader management strategies and supported by appropriate institutional and organisational arrangements. Preparing for effective response to extreme events not only involves technology but also significantly social, economic, organisational and political considerations. The PEARL project seeks to fill in the lack of interaction between social aspects and technical measures – appearing to be a major hindrance for solving some of the greatest problems associated with floods and flood-related disasters.

Based on the belief that problems are best solved by attempting to correct or eliminate root causes, as opposed to merely addressing the immediately obvious symptoms, the PEARL project aims at developing adaptive risk management strategies for coastal communities focusing on extreme hydro-meteorological events, with a multidisciplinary approach integrating social, environmental and technical research and innovation. PEARL considers all fundamentals in the risk governance cycle, focusing on the enhancement of forecasting, prediction and early warning capabilities and the building of resilience and reduction of risk through learning from experience and the avoidance of past mistakes.

Disasters that are triggered by hydro-meteorological events are interconnected and interrelated with both human activities and natural processes. They therefore require holistic approaches to help us understand their complexity in order to design and develop adaptive risk management approaches that minimize social and economic losses and environmental impacts and increase resilience to such event.

A particularly important part of the management of complex problems such as disasters due to extreme hydro-meteorological events, is improving forecasting, prediction and early warning capabilities (especially over a range of spatial and temporal scales) using state of the art science and technology to help policy makers and emergency services to develop robust prevention, mitigation and preparedness strategies. Important as it may be, it is however only one part of the answer. Equally important is that these systems are integrated into broader management strategies (structural and non-structural, engineering and natural) and are supported by appropriate institutional and organisational arrangements.

[11] http://www.pearl-fp7.eu/

PEARL contains several case study sites and Sint Maarten is one of them. The project team has developed useful tools and models that can be used for simulations of hurricanes, inland flooding, emergency evacuation and assessment of widespread impacts. In addition, the team has collected data on critical infrastructure in Sint Maarten.

As a result, following the aftermath of Hurricane Irma, the Sint Maarten Government requested the project team to incorporate this extreme event into the analysis of PEARL and provide advice for reconstruction and future development planning activities on the island. The team has accepted the request and employed all available tools, models, data and resources to support the government and people of Sint Maarten.

1.3 This report

This special deliverable addresses two main objectives: fact-finding mission and reconstruction inputs. The analysis related to the fact-finding mission is based on the impacts of Hurricane Irma while the part of the report that addresses the reconstruction also considers impacts of selected hydro-meteorological and geophysical hazards (i.e., isolated rainfall events, hurricanes, earthquakes and tsunamis).

In Section 2, we describe Hurricane Irma and modelling outputs that simulate the hurricane. In Section 3, we address the fact-finding mission in relation to household surveys, risk root cause analysis, semi-structured interviews, stakeholder meetings, the needs and priorities of local humanitarian actors to humanitarian emergency and urban drainage system assessment. In Section 4, we report vulnerability and hazard assessment in Sint Maarten in the context of Hurricane Irma. In Section 5, we describe flood, storm surge, wave and tsunami models, and assess the hazard, vulnerability and risk and forward recommendations that can be considered during the reconstruction phase. Finally, we give conclusions in Section 6.

2 Hurricane Irma

2.1 Evolution of Hurricane Irma

Hurricane Irma was the ninth named hurricane of the 2017 Atlantic hurricane season (Cangialosi et al., 2018). Irma originated in the west coast of Africa around Cabo Verde on 27 August. It started growing and became more concentrated on 28 and 29 August. The disturbance was already sufficiently organized and become a tropical depression at around 0000 UTC 30 August, located at around 220 km from Cabo Verde Island. Irma became a hurricane on 31 August around 0600 UTC. It continued to rapidly strengthen and reached major hurricane status by 0000 UTC 1 September. The hurricane reached its maximum intensity of 295 km/h around 1800 UTC 5 September when it was located about 240 km east-southeast of Barbuda. As a category 5 hurricane, Irma made landfall on Barbuda on 6 September around 0545 UTC with maximum recorded winds of 295 km/h and a minimum pressure of 914 mb. Irma continued to exhibit an impressive satellite appearance (Figure 2.1 and Figure 2.2) and made its second landfall on Saint Martin at 1115 UTC (i.e., 07:15 local time) on 6 September with the same wind speed and pressure as for its Barbuda landfall.

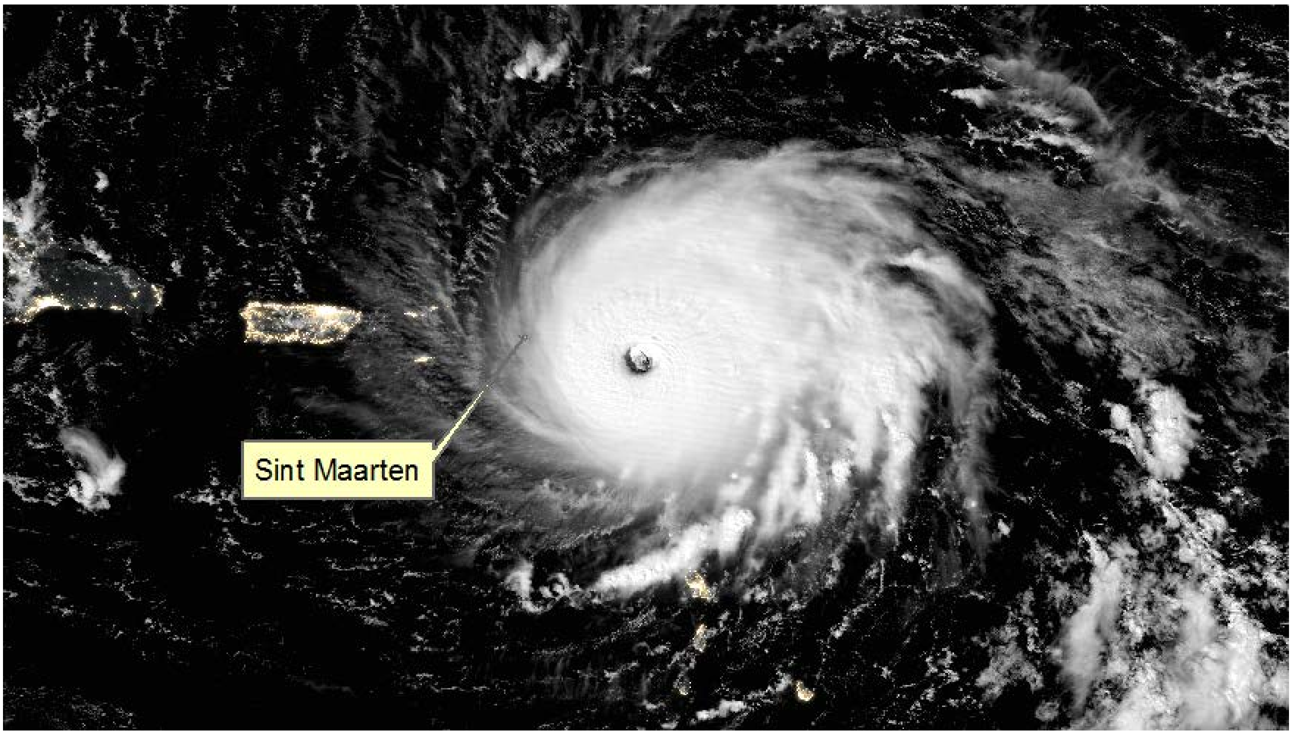


Figure 2.1. Satellite Image of Hurricane Irma – 0535 UTC September 6. Source: NASA[12]

On the same day at 1630 UTC, Irma made its third landfall on the island of Virgin Gorda in the British Virgin Islands still as a category 5 hurricane. Later that day, as Irma moved away from the Virgin Islands, a double eye structure was formed indicating that the major hurricane had weakened slightly. Even though Irma was no longer at its peak intensity, it remained a category 5 hurricane.

[12] https://earthobservatory.nasa.gov/NaturalHazards/view.php?id=90912

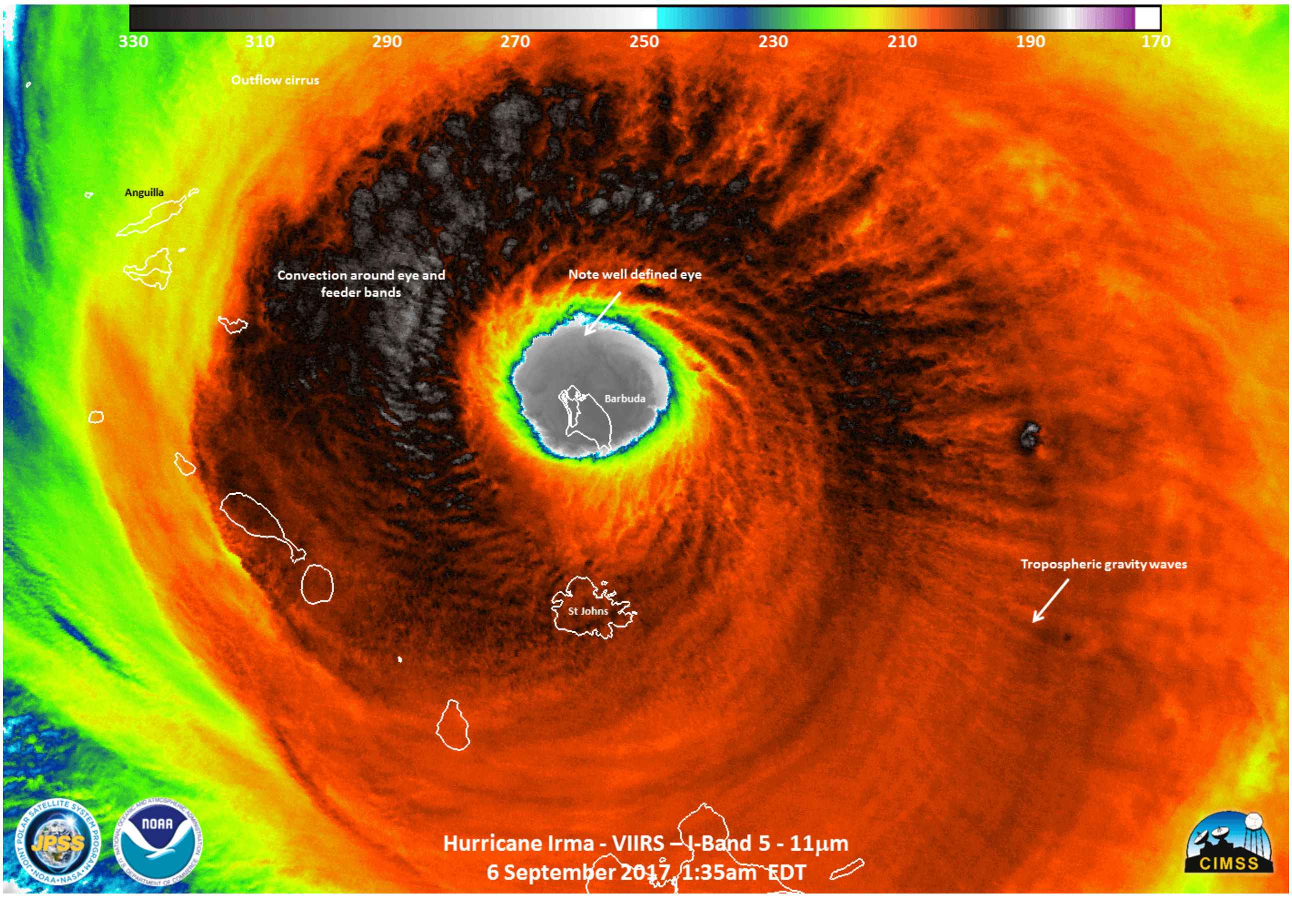


Figure 2.2. Infrared Image – VIIRS – NOAA/NASA Suomi NPP satellite – 0535 UTC September 6. Source: NOAA/JPSS[13]

From 1800 UTC 6 September to 1800 UTC 7 September, the eye of Irma was located about 90 km to the north of the northern shore of Puerto Rico and the Dominican Republic, with the strongest winds to the north of the center. The eye of Irma passed just south of the Turks and Caicos Islands around 0000 UTC 8 September, and it made landfall on Little Inagua Island in the Bahamas at 0500 UTC that day at category 4 intensity with estimated maximum winds of 155 km/h and a minimum pressure of 924 mb. Irma then turned slightly to the left, due to a building subtropical ridge, and moved toward the northern coast of Cuba. Irma strengthened to a category 5 hurricane once again on 8 September around 1800 UTC, only 18 hours after weakening below that threshold.

Irma then intensified a little more and made its fifth landfall near Cayo Romano, Cuba, on 9 September around 0300 UTC with estimated maximum winds of 167 km/h. Hurricane Irma is the first category 5 hurricane landfall in Cuba since 1932. The passing of Irma through the land of Cuba caused it to weaken the hurricane significantly, first to a category 4 storm a few hours after landfall in the Cuban Keys and then down to a category 2 hurricane by 9 September around 1800 UTC. Shortly after that time, the forward speed of Irma slowed, and it began to make a turn to the northwest, which caused the core of the hurricane to move over the Florida Straits early on 10 September.

[13] http://www.jpss.noaa.gov/weather_gallery.html#gallery-1

When Irma moved over the warm waters of the Florida Straits, the hurricane re-intensified once again. Irma became a category 4 hurricane again on 10 September by 0600 UTC when it was centred about 100 km south-southeast of Key West, Florida. As category 4 hurricane, Irma made yet another landfall near Cudjoe Key in the lower Florida Keys around 1300 UTC that day with maximum winds of 132 km/h and a minimum pressure of 931 mb.

Irma weakened to a category 3 hurricane around 1800 UTC 10 September 10. Irma made its final landfall near Marco Island, Florida, the same day at around 1930 UTC with estimated maximum winds of 115 km/h and a minimum pressure of 936 mb. Once inland over southwestern Florida, Irma weakened quickly, due to the influences of land and strong wind shear. As a category 2 hurricane, Irma passed just east of Naples and Ft Myers in Florida by 0000 UTC 11 September and as a category 1 hurricane between Tampa and Orlando by 0600 UTC that day.

Irma became a tropical storm by 1200 UTC 11 September when it passed west of Gainesville. The center of Irma moved over southern Georgia just west of Valdosta around 1800 UTC that day with maximum winds of 52 km/h, and the system became a remnant low with 30 km/h winds once it crossed into Alabama by 0600 UTC 12 September. The remnant low continued northwestward while weakening and dissipated shortly after 1200 UTC 13 September over southeastern Missouri.

Irma was a Category 5 hurricane for 60 hours, which is the second longest duration on record (behind the 1932 Cuba Hurricane). This made Irma the strongest hurricane ever observed in the open Atlantic Ocean, and one of only 5 hurricanes with measured winds of 295 km/h or higher in the entire Atlantic Basin. The best track of the hurricane is shown in Figure 2.3 using NOAA's National Hurricane Center (NHC) data.

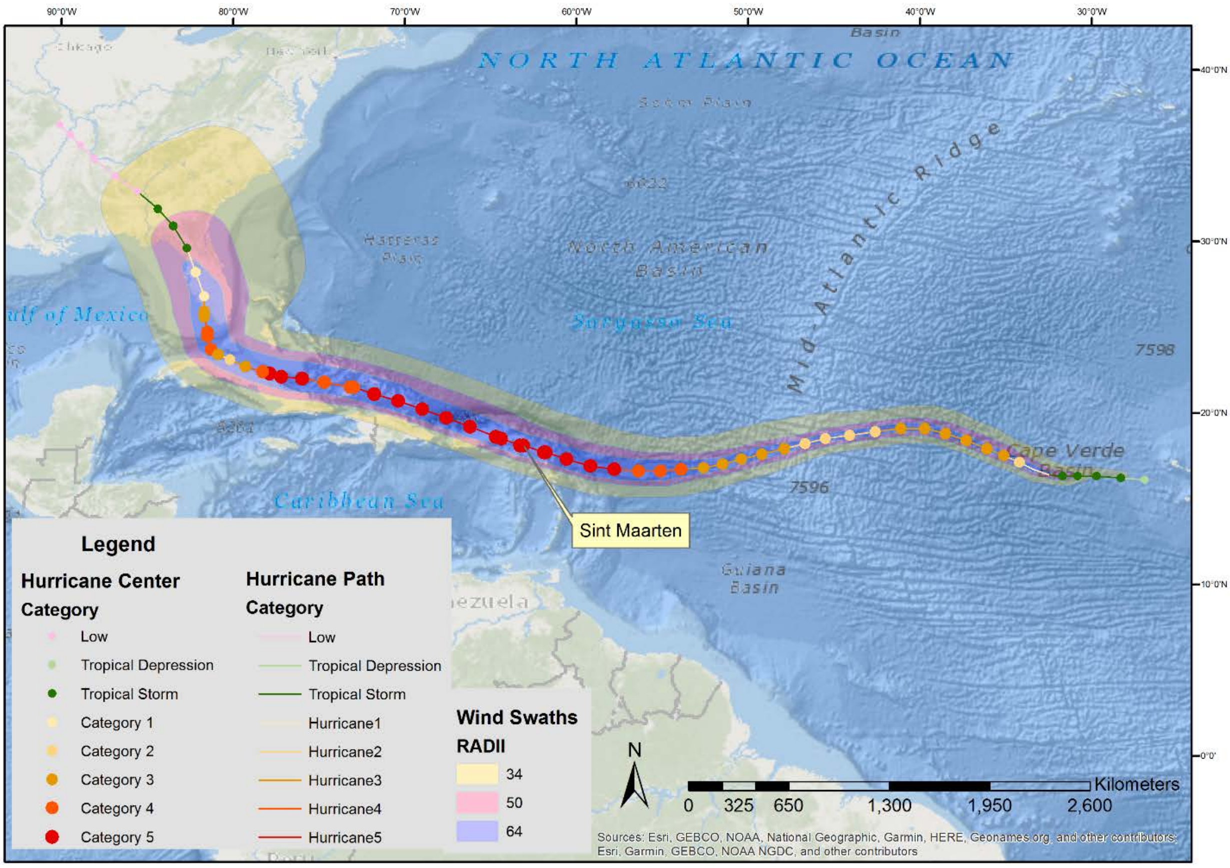


Figure 2.3. Best track positions for Hurricane Irma, from 30 August to 12 September 2017. Source: NHC

2.2 Hurricane Irma in Sint Maarten

The Meteorological Department of Sint Maarten – most commonly referred to as the Met Office – is the scientific organization responsible for issuing the early warnings in the event of any severe weather, seismic issues or climatic events. In the case of hurricanes, the main source of information came from the NHC in Miami. Met office gather this information and combines it with other meteorological services to analyse the possible threat to the island of Sint Maarten.

In the specific case of Hurricane Irma, the information was gathered, processed and analysed using NHC bulletins in combination with a Canadian weather service and WeatherOnline Meteorological Services[14]. Met Office was in charge of public forecast and special bulletins when Irma was a threat to the island. Bulletins and special reports were issued every 6 hours during the first days of the hurricane and later when the hurricane become a real threat to Sint Maarten the bulletins were released every 3 hours. With regards to Hurricane Irma, a total of 10 bulletins[15] and 14 special bulletins[16] were released by the Met Office. We highlighted the main aspects of the bulletins in Table 2.1.

The bulletins were posted on the Met Office's web page[17] and official Facebook page[18]. In addition, the bulletins were also sent directly to airlines, airport management, harbour/ marine, the Government (Prime Minister, Ministers and Emergency Support Function (ESF) coordinators[19]), radio stations, Government Information Service (also known as the Department of Communication - DCOMM), hoteliers, disaster management group/ fire department, health department and private individuals who asked to be included in the list.

Table 2.1. Excerpts of Weather Bulletins issued by the Sint Maarten Met Office during Hurricane Irma. Unless updated, columns have the same information as the column above.

Bulletin number	Date (dd/mm/yyyy)	Time (UTC-4)	Issues
Regular Bulletins			
1	30/08/2017	10:00 hrs	Satellite images indicate that low-pressure area a couple of hundred miles west of Cabo Verde Islands has become better organized overnight. Advisories will likely be initiated at 11 am on a tropical cyclone.
2	31/08/2017	06:00 hrs	At 5:00 am the center of Tropical Storm Irma was located about 1759 miles (2831 km) east of Sint Maarten. The system is moving towards the west near 12 mph (19 km/h). Irma is likely to become a hurricane later today. There is no immediate threat to land; however, members of the public are advised to monitor this system.

[14] https://www.weatheronline.co.uk/
[15] Found through the official Facebook page of the Sint Maarten Met Office
[16] Collected directly from the Met office during the field mission
[17] http://www.meteosxm.com/about-us/
[18] https://www.facebook.com/sxmweather/
[19] ESF is the emergency support group in Sint Maarten disaster management. https://www.sxmemergency.org/en/updates/relief/emergency-support-group/

Bulletin number	Date (dd/mm/yyyy)	Time (UTC-4)	Issues
3	31/08/2017	12:00 hrs	At 11:00 am Tropical Storm Irma was upgraded to a category 2 hurricane. At that time, the center of Hurricane Irma was located about 1705 miles (2744 km) east of Sint Maarten. Maximum sustained winds have increased to near 155 km/h with higher gusts. Irma is forecasted to become a major hurricane by tonight and is expected to be an extremely dangerous hurricane for the next several days.
4	31/08/2017	18:00 hrs	Irma becomes category 3 hurricane. At 5:00 pm, it was located about 1617 miles (2602 km) east of Sint Maarten and is moving at speed near 19 km/h.
5	01/09/2017	06:00 hrs	Irma holding steady as a category 3 hurricane. At 5:00 am, Hurricane Irma was located about 1745 miles east of Sint Maarten. Maximum sustained winds are 185 km/h with higher gusts.
6	01/09/2017	18:00 hrs	Irma turns westward. At 5:00 pm, Hurricane Irma was located about 1570 miles (2527 km) moving at 20 km/h. Maximum sustained winds are 195 km/h with higher gusts. This puts Irma as a category 3 hurricane.
7	02/09/2017	12:00 hrs	Irma is moving westward across the Atlantic as a small hurricane. Irma is about 1300 miles (2092 km) east of Sint Maarten. Sustained winds are about 175 km/h. Met Office will continue to monitor the progress of Irma and advice all necessary preparations should be made in the event Irma does make landfall.
8	02/09/2017	17:00 hrs	At 05:00 pm, the eye of Hurricane Irma was located about 1213 miles (1952 km) east of Sint Maarten moving a little south of due west at 24 km/h and this general motion is expected to continue for the next couple of days. Maximum sustained winds are 175 km/h with higher gusts. Some strengthening is forecasted during the next 48 hours. Irma is currently a small hurricane. However, it is expected to grow in size during the next couple of hours and to be a major hurricane when it moves closer to the Lesser Antilles early next week.
9	03/09/2017	06:00 hrs	Irma is back to category 3. At 05:00 am, it was located about 1024 miles (1648 km) east of Sint Maarten and is moving at 24 km/h. Some strengthening is forecasted through Monday night.
10	03/09/2017	11:00 hrs	Irma is back to category 3. At 11:00 am, the center of the hurricane is about 966 miles (1555 km) east of Sint Maarten moving at 22 km/h. Maximum sustained winds are near 185 km/h.

Bulletin number	Date (dd/mm/yyyy)	Time (UTC-4)	Issues
Special Bulletins			
1	03/09/2017	18:00 hrs	A **hurricane watch** is in effect for Sint Maarten. Hurricane watches issued for portions of the leeward islands. NOAA hurricane hunter aircraft en route to Irma. Irma is located about 875 miles (1408 km) east of Sint Maarten. Maximum sustained winds are 185 km/h. Irma is moving at 22 km/h. Hurricane conditions are possible in Sint Maarten by late Tuesday night; however, tropical storm force winds are expected by Tuesday evening. All citizens/residents should remain vigilant and make preparations to protect life and property and be ready to take the necessary action when called upon.
2	03/09/2017	20:15 hrs	A **hurricane watch** is in effect for Sint Maarten. Irma is expected to be near the northern Leeward Islands by late Tuesday. Irma is located about 843 miles (1357 km) east of Sint Maarten. Maximum sustained winds are 185 km/h.
3	04/09/2017	06:00 hrs	A **hurricane watch** is in effect for Sint Maarten. Irma is located about 715 miles (1151 km) east of Sint Maarten. Maximum sustained winds are 185 km/h. Very rough seas are expected with the approach of Hurricane Irma.
4	04/09/2017	08:00 hrs	A **hurricane watch** remains in effect for Sint Maarten. NOAA hurricane hunter aircraft finds Irma a little stronger. Irma is located about 697 miles (1122 km) east of Sint Maarten. Maximum sustained winds are 195 km/h. Sea swells generated by Irma will begin affecting the northern Leeward Islands today.
5	04/09/2017	11:30 hrs	A **hurricane warning** has been issued for Sint Maarten. Hurricane warnings issued for portions of the Leeward Islands. Irma is located about 650 miles (1046 km) east of Sint Maarten. Maximum sustained winds are near 195 km/h. Irma is expected to produce total rainfall accumulations of 3 to 6 inches (76.2 to 152.4 mm) with isolated maximum amounts of 10 inches (254 mm) across the Leeward Islands. Sea swells generated by Irma will begin affecting the local area later today and during the next few days. These swells are likely to cause life threatening surf and rip current conditions especially on the northern and eastern shores. Mariners are advised to stay in port in order to safeguard life and property. All residents/visitors are strongly advised to begin finalizing preparations to protect life and property.

Bulletin number	Date (dd/mm/yyyy)	Time (UTC-4)	Issues
6	04/09/2017	14:05 hrs	A **hurricane warning** is in effect for Sint Maarten. Irma is located about 620 miles (998 km) east of Sint Maarten. Maximum sustained winds are near 195 km/h.
7	04/09/2017	17:05 hrs	A **hurricane warning** is in effect for Sint Maarten. Irma strengthens as it heads towards the Leeward Islands. Preparations within the warning area should be rushed to completion. Irma is located about 580 miles (933 km) east of Sint Maarten. Maximum sustained winds are near 215 km/h. Irma is moving at 20 km/h. Sea swells generated by Irma will begin affecting the local area later today and during the next several days.
8	04/09/2017	20:10 hrs	A **hurricane warning** is in effect for Sint Maarten. Dangerous Hurricane Irma is heading towards the leeward islands. Irma is located about 540 miles (869 km) east of Sint Maarten. Maximum sustained winds are near 220 km/h. The combination of a dangerous storm surge and large breaking waves will raise water levels by as much as 6 to 9 feet (1.8 to 2.7 m) above normal tide levels along the coasts of Sint Maarten. Near the coast, the surge will be accompanied by large and destructive waves
9	05/09/2017	05:00 hrs	A **hurricane warning** is in effect for Sint Maarten. Irma is located about 414 miles (666 km) east of Sint Maarten. Maximum sustained winds are near 240 km/h. Irma is moving at 22 km/h. Irma is expected to produce total rainfall accumulations of 4 to 8 inches (101.6 to 203.2 mm) with isolated maximum amounts of 12 inches (304.8 mm) across the Leeward Islands.
10	05/09/2017	08:00 hrs	A **hurricane warning** is in effect for Sint Maarten. Irma becomes an extremely dangerous category 5 hurricane. Irma is located about 367 miles (591 km) east of Sint Maarten. Reports from a hurricane hunter aircraft indicated that Irma continues to strengthen and maximum sustained winds have increased to 280 km/h with higher gusts. The combination of a dangerous storm surge and large breaking waves will raise water levels by as much as 7 to 11 feet (2.1 to 3.4 m) above normal tide levels along the coasts of Sint Maarten. Irma is an extremely dangerous category 5 hurricane. Some fluctuations in intensity are likely during the next day or two, but Irma is forecast to remain a powerful category 4 or 5 hurricane.

Bulletin number	Date (dd/mm/yyyy)	Time (UTC-4)	Issues
			All residents/visitors are strongly advised that all preparations for the arrival of this extremely dangerous system should be rushed to completion and continue monitoring the progress of the hurricane.
11	05/09/2017	14:00 hrs	A **hurricane warning** is in effect for Sint Maarten. Potentially catastrophic Category 5 Hurricane Irma heading to the Leeward Islands. Irma is located about 274 miles (441 km) east of Sint Maarten. Maximum sustained winds are near 295 km/h. Irma is expected to produce total rainfall accumulations of 8 to 12 inches (203.2 to 304.8 mm) with isolated maximum amounts of 18 inches (457.2 mm) across the Leeward Islands.
12	05/09/2017	17:00 hrs	A **hurricane warning** is in effect for Sint Maarten. Irma is located about 225 miles (362 km) east of Sint Maarten. Maximum sustained winds are near 295 km/h. Irma is moving at 22 km/h.
13	05/09/2017	20:00 hrs	A **hurricane warning** is in effect for Sint Maarten. Irma is located about 180 miles (290 km) east of Sint Maarten. Maximum sustained winds are near 295 km/h.
14	05/09/2017	23:00 hrs	A **hurricane warning** is in effect for Sint Maarten. Irma is located about 138 miles (222 km) east of Sint Maarten. Maximum sustained winds are near 295 km/h. Hurricane conditions are expected in Sint Maarten by later tonight into tomorrow; however, tropical storm force winds are expected with the next few hours.

The weather bulletins posted on the Met Office Facebook page stopped on 5 September and were re-establish on 16 September reporting a potential Tropical Cyclone 15 and on 17 September reporting the outlook of Tropical Storm Maria. Hurricane Irma made landfall on Sint Maarten on 6 September at 07:15 am local time. The eye of Irma crossed through the whole Saint Martin Island. It took around two hours for the hurricane to cross the island and an estimated 45 minutes between the front and tail of Irma's eye according to information collected from residents in the field mission. Further, the tail of Irma caused the most destruction in the island.

As communication infrastructure was damaged in the island, only one radio station was almost entirely operational during and immediately after Irma passed[20]. The Met office had a continuous open line communication with this station to update the residents and the general public of the island on the location and potential remaining threat of Irma.

[20] It was reported that the radio station had a short interruption of about 1.5 hours.

2.3 NHC forecast of Hurricane Irma

Since the NHC bulletins are the main source of information for the Met Office of Sint Maarten, this section describes the official bulletins released by the centre that had a direct relationship with the island of Sint Maarten.

As officially reported by the NHC in its report of the Hurricane Irma (Cangialosi et al., 2018), Irma formed sooner than predicted by the models. Only 12 hours before the formation of Irma the NHC give the status of high chance for the formation of the hurricane. In a 78 hours analysis, the NHC predicted a low chance (< 40%) of the possible formation of a system and in the 36 to 48 hours genesis prediction, the NHC forecasted a medium chance of formation (40 to 60%). In general, other global models were also not accurate nor consistent in predicting the formation of Irma.

The track forecasts of Irma made by NHC were relatively accurate. NHC manage to predict Irma's track with a confidence level of 30 to 40% lower than the mean official error for the 5 years period for all forecast times. Statistically speaking the track of Irma suggest that this hurricane was more difficult to forecast than most hurricanes on record for a long period forecast. Figure 2.4 shows the NHC forecast against the best track line and the potential track area of the forecast.

The NHC forecast for the intensity of Hurricane Irma had errors larger than the reference 5 years mean at all forecast times, which indicates how extreme was this event in the region. The other two factors affecting the poor overall forecast of the intensity were:

1) The early stages of Irma's lifecycle were too low because the extended period of rapid intensification was under-forecast, and

2) The NHC forecasts did not expect Irma to interact with Cuba as much as it did, and consequently, Irma weakened more than expected when it was near that island.

Analysing the forecast track and cone made by the NHC prior Hurricane Irma made landfall in Sint Maarten, it is clear that none of the forecasts predicted the eye of Irma passing through the island. On 30 August, the forecasted track was showing a slight displacement of the storm to the south, pointing towards Guadalupe and Dominica islands. Forecast tracks for 31 August show a slight north movement of the prediction paths. At that point, some of the forecasted lines were pointing directly towards Sint Maarten, especially those at 5:00 PM AST and 11:00 PM AST[21]. Yet, no forecast cone over Sint Maarten on that date.

[21] AST is the Atlantic Standard Time, which is UTC-4

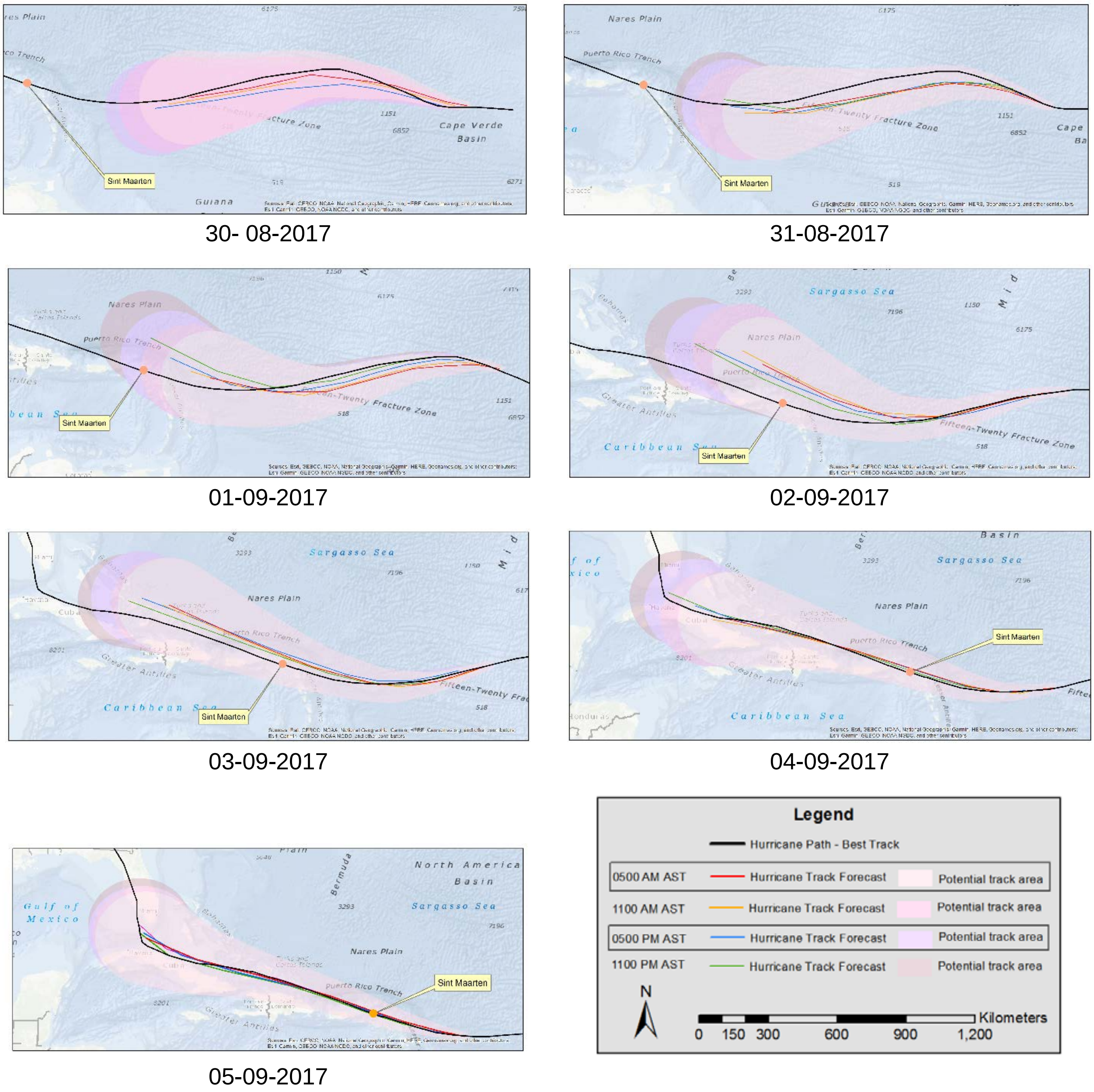
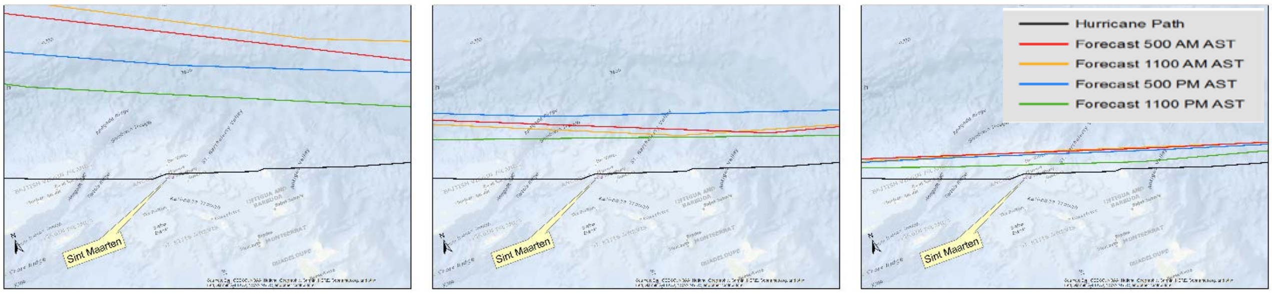


Figure 2.4. NHC forecast track path and forecast cone versus best track cone of Hurricane Irma

However, all the possible paths of the NHC forecast on 1 September were showing a tendency on the eye of the storm to move north of Sint Maarten. The predicted cones of Irma started to appear over the island in the forecast made at 1100 AM AST. Forecast made from 2 to 4 September continued to locate the centre of the hurricane north of the island but started displaying a slight move to the south again (Figure 2.4 and Figure 2.5). On 3 September, the closest track located the centre of Irma about 55 km north whereas on the 4th, the closest track to the island was located only about 22 km north. All the forecasted cones on those three days intersected Sint Maarten.



(a) (b) (c)

Figure 2.5. NHC forecasted tracks for Hurricane Irma on (a) 2 September, (b) 3 September and (c) 4 September

Based on the NHC forecasted track for 5 September, it was clear that the eye of Irma would pass very close if not directly over the island (Figure 2.4 and Figure 2.6).

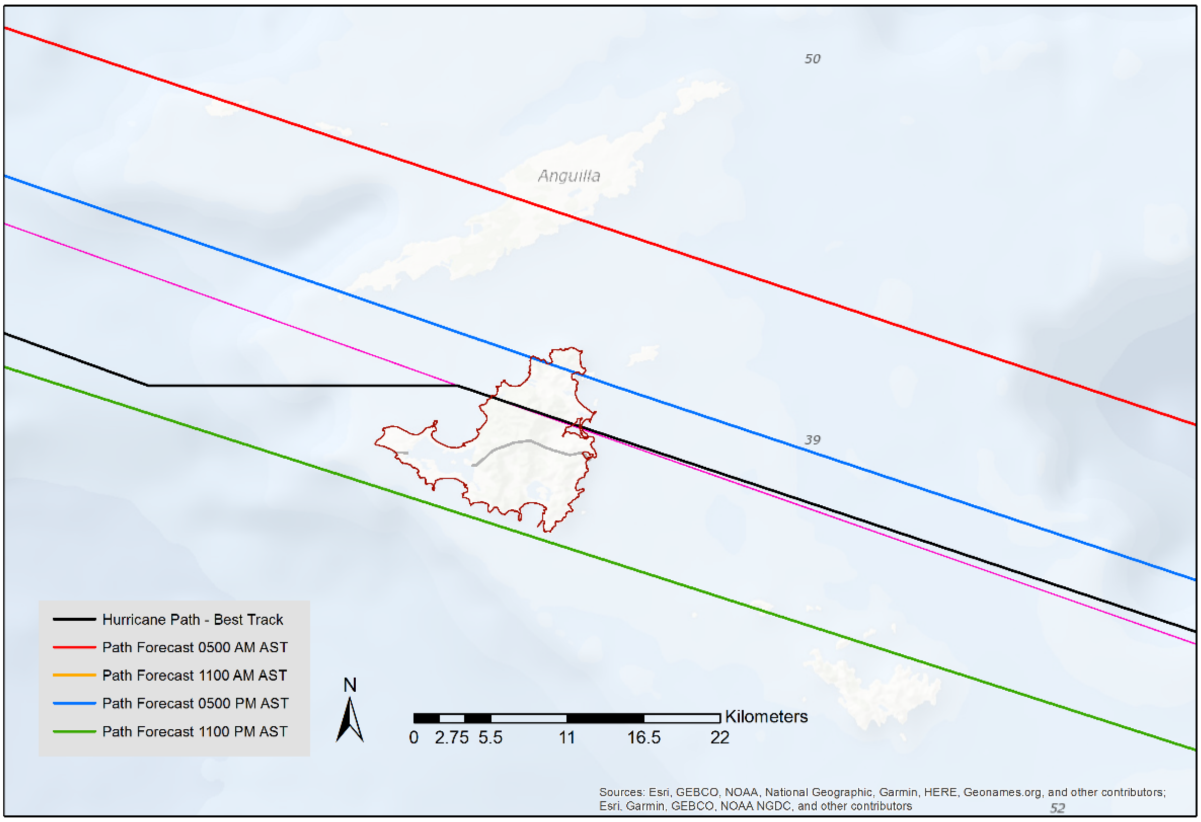


Figure 2.6. NHC forecasted tracks and Best Track of Hurricane Irma on 5 September 2017.

2.4 Statistics of Hurricane Irma

2.4.1 Landfalls and Maximums of Hurricane Irma

From the moment it originated on 27 August and during the 18 days that remain active until it dissipated on 13 September, Irma made a total of seven landfalls. Time and day as well as maximum sustained wind speed and the minimum pressure of those specific moments of the storm are shown in Table 2.2 and Figure 2.7.

Table 2.2. Landfalls of Hurricane Irma. Source: Adapted from (Cangialosi et al., 2018)

Landfall Number	Day – Time dd/mm/yyyy – HHHH (UTC)	Location	Wind Speed (Km/h)	Pressure (mb)
1	06/09/2017 – 0545	Barbuda	295	914
2	06/09/2017 – 1115	Saint Martin	295	914
3	06/09/2017 – 1630	Virgin Gorda - BVI	295	915
4	08/09/2017 – 0500	Little Inagua Island - Bahamas	250	924
5	09/09/2017 – 0300	Cayo Romano, Cuba	269	924
6	10/09/2017 – 1300	Cudjoe Key - lower Florida Keys	212	931
7	10/09/2017 – 1930	Marco Island - Florida	185	936

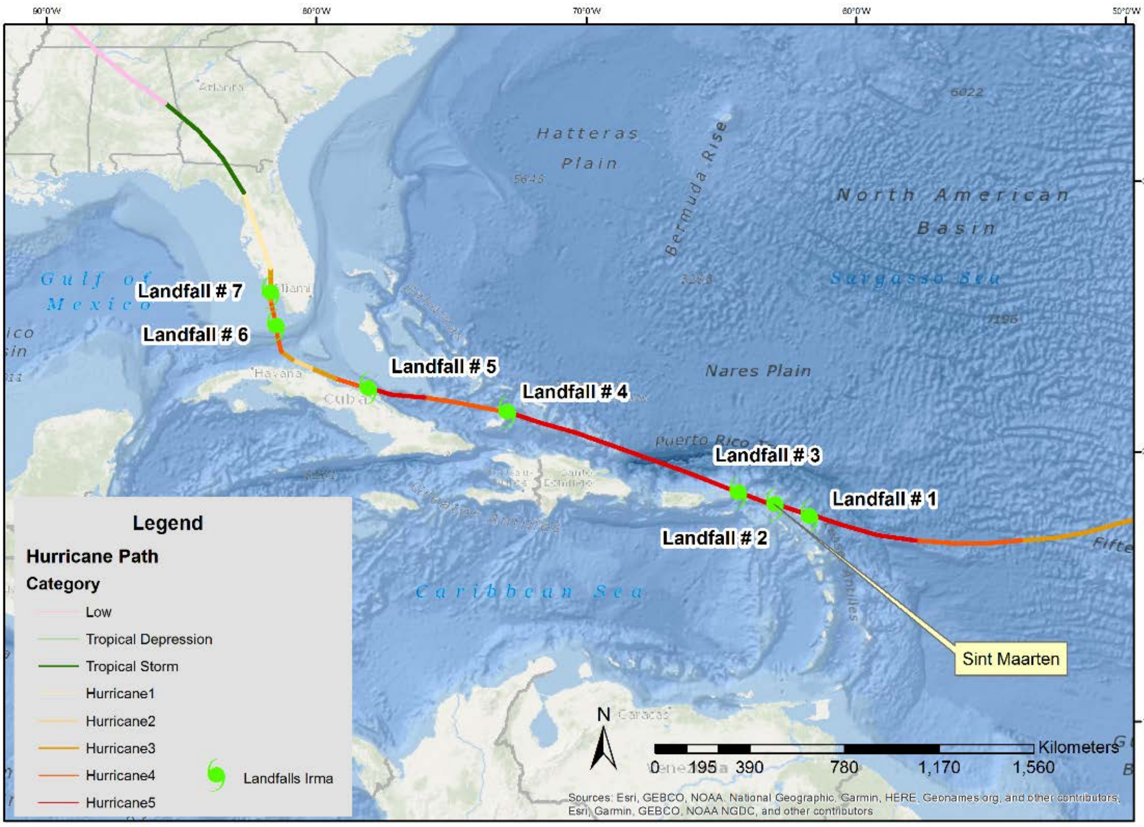


Figure 2.7. Hurricane Irma landfalls

2.4.2 Reported Fatalities, injuries and damages

During its path across the Caribbean and the southeastern part of United States, Hurricane Irma is reported to have caused at least 44 direct causalities by its strong winds, tornadoes, heavy rains and storm surges (Cangialosi et al., 2018). There is also a report of 85 causalities indirectly linked to the hurricane in countries along its track (see Table 2.3). The causes of the indirect deaths include

carbon monoxide poisoning due to generator failure, chainsaws accidents and electrocutions and heart attacks or other health issues.

Irma also caused major economic damages more than US$50 billion. Homes, schools, public buildings, businesses and infrastructure were destroyed by Irma. Due to its exceptionally destructive nature, the name Hurricane Irma is retired by the World Meteorological Organisation[22]. In the rotating list of hurricane names, Irma will be replaced by *Idalia*.

Table 2.3. Number of reported deaths and injuries associated with Hurricane Irma in selected islands/countries. Source: (Cangialosi et al., 2018)

Country	**Direct Deaths**	**Indirect Deaths**	**Injuries**†	**Damages (million USD)**‡
Anguilla	1	0	-	190
Barbados	1	0	-	120 to 305
Barbuda	3	0	-	150 to 300
British Virgin Islands	4	0	125	850 to 2300
Cuba	9	0	-	200
Haiti	1	0	-	-
Puerto Rico	0	3	-	610 to 1000
Saint-Martin and Saint Barthelemy	11	0	-	1500
Sint Maarten	4	1	250 - 300	1500 to 2000
Turks and Caicos	0	0	-	500
US Virgin Islands	3	0	-	1100 to 3300
USA	7	85	-	37500 to 62500
Total	44	89		

†(ECLAC, 2017)

‡Some damage data is acquired from CEDIM loss estimate[23]

2.4.3 Estimated Damage in Sint Maarten

In October 2017, a team of the Economic Commission for Latin America and the Caribbean (ECLAC) conducted a Damage and Loss Assessment (DALA). The aim of the mission was to provide technical assistance to the Government of Sint Maarten and to capture the full extent of the impact on communities and the island in the aftermath of Irma. The commission's research work included damage assessment, provision of policy advice and technical assistance focused on growth with equity (ECLAC, 2017).

The ECLAC team had meetings with various stakeholders including those representing sectors such as social affairs, housing, education, healthcare, transportation infrastructure, water and sanitation

[22] https://public.wmo.int/en/media/news/wmo-hurricane-committee-reviews-devastating-2017-season-retires-names

[23] https://www.cedim.de/download/FDA_Irma_2017_Report1.pdf

as well as collection and treatment of solid wastes, electricity supply and distribution, telecommunications, broadcasters, internet and tourism.

The DALA methodology used by ECLAC estimates damages, losses and additional costs in different sectors for the affected population of a natural disaster (ECLAC, 2014). In the case of Sint Maarten, the affected population was considered to be the whole island. The sectors under analysis were:

- Social sector: Housing and public building, Health and Education
- Infrastructure sector: Roads, port and airport; Telecommunications; Power; Water and sanitation
- Productive sector: Tourism and Commerce
- Environmental sector: Environment

The ECLAC team estimated that the total impact of Hurricane Irma in Sint Maarten is more than US$2 billion (Table 2.4). The impact is disaggregated into direct physical damage, revenue and other income losses, and additional costs.

The total direct physical damage was estimated at about US$1 billion. The social sector suffered the most in this regard representing about 50% of the total value of the direct damages. The productive sector and infrastructure sector were also heavily impacted with about 35% and 14% of the direct damage, respectively.

Revenue and other income losses were also estimated at about US$1 billion. The productive sector was also the worst affected, bearing 87.7% of the revenue and losses. The infrastructure sector bore 8% while the social sector assumed 3.7% of the losses. Additional costs were estimated at about US$53.3 million, of which 61% were in the infrastructure sector, 22% in the social sector and 17% in the productive sector. It is important to mention that the ECLAC report using the DALA methodology did not include the economic effects and losses due to the looting in the island.

In addition to impacts on the sector described above, the ECLAC team also conducted an analysis on the effects of Irma on the macroeconomic of the island and the final part of the ECLAC report contains recommendations for each one of the sectors that were assessed. Since the total impact on the island and in the region is massive, it could be estimated that the effects of Irma on the island will last several years.

Table 2.4. Summary of impacts of Hurricane Irma in US$. Source: Table is based on (ECLAC, 2017)

Sector Sub-sector	Damage	Losses	Additional costs	Total Damages	
	Total	Total	Total	Cost (USD)	%
Infrastructure	**139,998,109**	**79,331,806**	**11,627,266**	**230,957,181**	**11.4%**
Water, Sewerage and Solid Waste	7,133,234	9,896,393	1,761,056	18,790,683	0.9%
Telecommunications	50,660,565	11,813,186	1,061,240	63,534,991	3.1%
Power	5,919,931	24,576,010	1,018,020	31,513,961	1.6%
Roads, Airports &Ports	76,284,379	33,046,217	7,786,950	117,117,546	5.8%
Productive	**343,395,911**	**866,330,859**	**9,122,386**	**1,218,849,156**	**60.1%**
Tourism	223,395,911	855,513,312	9,122,386	1,088,031,609	53.7%
Commerce	120,000,000	10,817,547	0	130,817,547	6.5%
Social	**502,071,715**	**36,556,742**	**32,489,906**	**571,118,363**	**28.2%**
Education	4,428,050	1,760,425	738,762	6,927,237	0.3%
Housing	485,129,115	28,221,077	29,151,144	542,501,336	26.8%
Health	12,514,550	6,575,240	2,600,000	21,689,790	1.1%
Environment	**1,009,025**	**5,320,072**	**102,530**	**6,431,627**	**0.3%**
Environment	1,009,025	5,320,072	102,530	6,431,627	0.3%
Total	**986,474,760**	**987,539,479**	**53,342,088**	**2,027,356,327**	**100.0%**

2.5 Replay of Hurricane Irma

We used the MIKE21 two-dimensional hydrodynamic modelling software by DHI[24] to simulate the hurricane-related processes. The Cyclone Wind Generation in the “Wind” tool of MIKE21 Toolbox provides the facility to compute and generate travelling hurricane wind and pressure fields. Wind and pressure data generated by a tropical cyclone can often be described by models that are based on parameters like position of the hurricane eye, maximum wind speed and its radius, and central and neutral pressures. The generated space and time varying pressure and wind field within the model area are later used in a hydrodynamic surge simulation.

We used the best track data from NHC shown in Figure 2.3. The data provides the location and time of the eye, wind speed and central pressure. We used a neutral pressure of 1013 mb. Since there is no data on the radius of the maximum wind speed, the radius is used as a calibration parameter. Bathymetric data used in the model is sourced from the General Bathymetric Chart of the Oceans (GEBCO)[25]. We use the GEBCO_2014 Grid, which is a global 30 arc-second interval grid. Figure

[24] https://www.mikepoweredbydhi.com/products/mike-21
[25] https://www.gebco.net/data_and_products/gridded_bathymetry_data/

2.8 shows the model outputs on 5 to 7 September 2017, in which Figure 2.8b shows Irma's eye over Saint Martin.

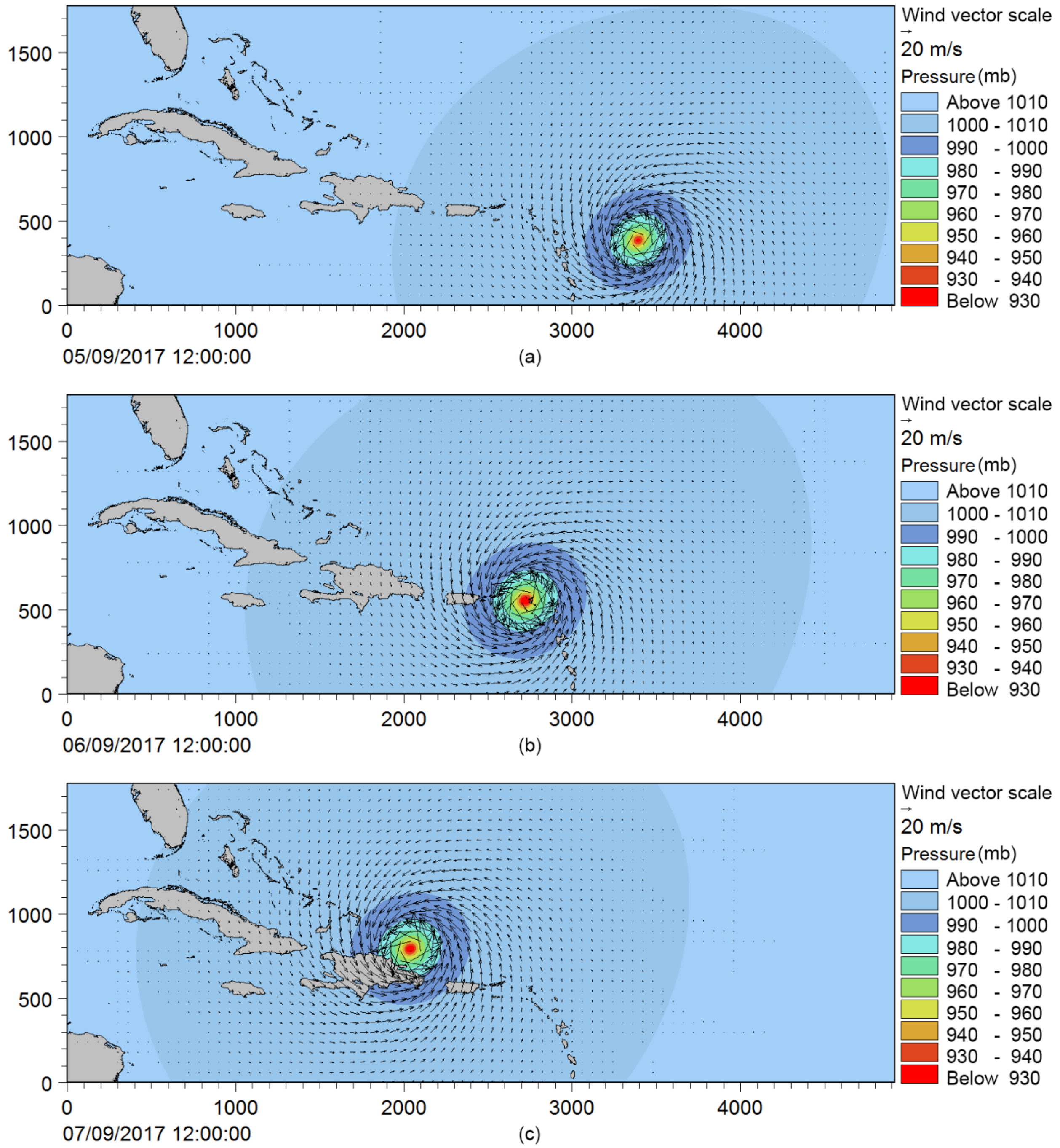


Figure 2.8. Model simulations of Hurricane Irma wind and pressure fields at 1200 UTC on (a) 5 September, (b) 6 September and (c) 7 September

3 Fact Finding Mission

The fact finding mission (FFM) was carried out by the PEARL project partners using research methodologies and tools that were developed mainly within the project. The FFM was carried out in the months of February, March and April 2018. Based on planned objectives, the FFM can be divided into five parts. The first one was a household survey that aimed to collect information regarding people's awareness and perception of hurricanes in general and Irma in particular. The survey also gathered information on warnings and evacuation behaviours. The second part was semi-structured interviews and stakeholder meetings with officials to gain a broad view of the impact of Hurricane Irma on the island. The third element of the FFM was to assess and gather data regarding the urban drainage infrastructure. These three parts were undertaken by the IHE Delft team from 2 February to 4 March 2018, and focused solely on Sint Maarten. The fourth part of the FFM was the risk root cause analysis (RRCA) that aimed at a backward-looking holistic assessment of the drivers of loss and damage by Hurricane Irma. It also aimed to examine recovery and reconstruction policies and transformation processes. This part was conducted by King's College London team from 14 to 23 March and focused both on Sint Maarten and Saint-Martin. The last part of the FFM aimed at understanding the needs and priorities of local humanitarian actors (i.e., first responders) to humanitarian emergency in the context of Hurricane Irma. Focusing only on Sint Maarten, this part used methodologies developed outside of the PEARL project and conducted from 13 to 21 April 2018 by King's College London.

In this section, we will describe all the FFM elements including the analysis and findings except for the urban drainage infrastructure data gathering. That part will be described in Section 5.1.

3.1 Household survey

As previously stated, IHE mission aimed to gather valuable information on the perception, preparedness, vulnerability and risk for hurricane and floods. The team designed a household survey to gather information regarding the experience of the inhabitants of the island during the direct hit of Hurricane Irma. The following sections describe the survey design and the main findings from the fieldwork.

3.1.1 Survey Design

Target Population

The population for this study was defined as residents who were living in Sint Maarten when Hurricane Irma hit the island on 6 September 2017. Based on different sources of data, we prepared a database of 11128 units of residential buildings as the target population size of the survey. Figure 3.1 shows a part of the database used to select the total target population of this study.

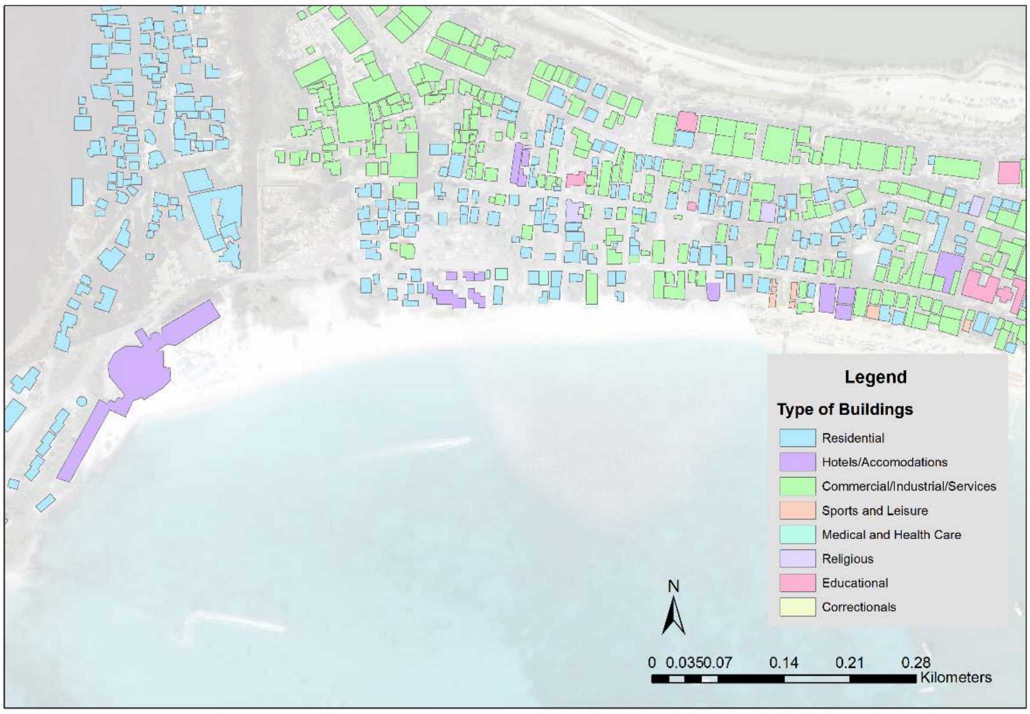


Figure 3.1. Portion of the spatial database showing the type of buildings in the Philipsburg area. The blue polygons are the residential buildings that make up the target population.

Sample Size

For a target population of 11128 residential buildings and a confidence level of 95%, the required sample size for the field work was 267 houses. Assuming a security factor of 90% estimated response rate, the sample size was adjusted to 296 residential houses. For practical reasons, we rounded up the sample size to 300 houses. The selection of the sample size for the household survey is presented in Table 3.1.

Table 3.1. Sample size selection for household survey in Sint Maarten

Sample Size Selector		
Population Size	11128	How many entities are in the group your sample represents?
Margin of Error	6%	Plus/Minus error that is acceptable for your research
Confidence Level	95%	Tells how sure the margin of error is
Required Sample Size	267	Minimum of respondents needed
Estimated Response Rate	90%	The estimated percentage of households participation in the survey
Adjusted sample size	296	Minimum number of entities out of the population is needed to ask to participate
Final sample size	300	Actual number of households selected/sampled

Household Random Sampling

We used the *Sampling Design Tool for ArcGIS* extension developed by the National Centers for Coastal Ocean Science of NOAA[26] to randomly select the 300 sample buildings from the database. The random selection is based on the number of residential buildings in the eight districts of Sint Maarten. A summary of the number of houses selected per district and its representativeness in the whole population size is shown in Table 3.2. It is shown that all the district were well represented and covered within the initial sample. The selected buildings shown in Figure 3.2 represented the sampled houses to be interviewed in the household survey.

Table 3.2. Number of existing and selected households per district

District Name	Number of Houses	% Houses in a district	#Houses per Percentage	# Houses Randomly Selected
Cole Bay	2071	18.6%	56	58
Cul de Sac	2524	22.7%	68	67
Little Bay	1079	9.7%	29	28
Lower Prince's Quarter	2389	21.5%	65	66
Lowlands	334	3.0%	9	5
Philipsburg	457	4.1%	12	11
Simpson Bay	367	3.3%	10	7
Upper Prince's Quarter	1907	17.1%	51	58

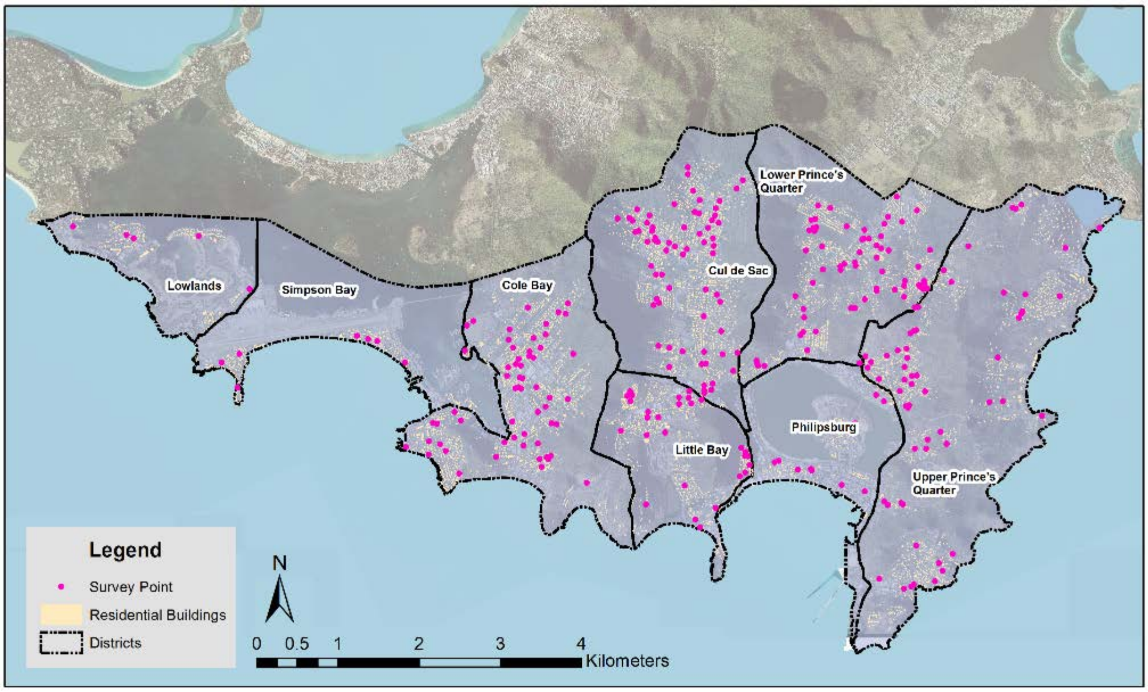


Figure 3.2. Initial 300 randomly selected households

[26] https://coastalscience.noaa.gov/project/sampling-design-tool-arcgis/

Collection Mode

The primary data collection method for this research was face-to-face administered interviews (or oral survey). As it was a challenge to conduct the total 300 face-to-face interviews during the field mission, a web self-administer version of the survey was used to collect the remaining sample.

The oral survey consists of three parts. The topics covered in those parts were general information, preparedness and reaction, and risk perception/awareness. The survey questionnaire consists of 46 to 51 questions (see Appendix A). The language selected for the survey was English despite the multiple nationalities present in the island. English is one of the official languages of the island and is also the preferred language within the population due to the high volume of North American tourists among other factors.

Since the oral interview was not sufficient enough to reach the required sample size of 267 household surveys (Table 3.1) and to cover the full geographic extent of Sint Maarten, an online version of the survey was created aiming to reach the sample size necessary to achieve the selected margin of error of 6% with confidence interval of 95% and to try to reach those areas that were not possible to survey during the field work

To create the online version of the survey, we used Google Forms. The link to access the survey was shared through Facebook pages of different organizations located in the island such as churches, aid/help groups created after Hurricane Irma and sent to individuals that were identified as active participants in those groups. Participants were asked to share and distribute the survey among friend and relatives in the island. The online version kept all the original questions of the oral survey, but it was reorganized in such a way that it optimizes the screen presentation and the navigation of the respondent. The final design consisted of 11 sections. The screenshots of the full online version of the survey are presented in Appendix B.

3.1.2 Data collection – On the Field

To operationalise the field work the team divided the area of interest into 45 maps that cover the 300 sample households (see Figure 3.3). In the maps, the geographic location of each household as well as the surrounding landmarks and roads were clearly identified to facilitate the survey. In addition, each point had assigned the unique identifier to be used in the printed survey and keep consistency in the field work. The face-to-face surveys were conducted by two PhD fellows from IHE-Delft.

(a)

(b)

Figure 3.3. Field maps prepared for the survey (left) and the printed version used during the survey (right)

To test the adequacy of the survey, a pilot study was carried out as a pre-testing to evaluate whether the initially chosen sampling frame and technique were adequate and effective for the characteristics of Sint Maarten. It was also used to assess the likely success and to evaluate the responsiveness of the inhabitants. Further, the survey helped to establish a common framework for the interviewers on how to perform the survey on the same premises. The pilot was executed on the first day (12 February 2018) and a total of 12 interviews were carried out.

For security and identification purpose, a vehicle used during the survey was properly marked as part of IHE Delft post Hurricane Irma impact assessment team. The interviewers also wore IHE Delft t-shirt and hat (see Figure 3.4). This turned out to be crucial because some respondents only accepted to participate in the survey once they were completely sure the team was not part of the government.

Figure 3.4. Team identification on the field

During the survey, if it was not possible to contact the initially randomly selected household, the interviewer proceeded to select a new one. Reasons that lead to change the target house were: a) no presence of people in the house, or b) no adult to respond at the time of the visit, or c) the house was abandon or under reconstruction and uninhabited after Hurricane Irma, or d) the person declines to participate. The new selection was done based on the closest house available to the original point that was willing to participate. After proper identification and explanation of the purpose of the survey, the interviewer proceeded to ask the full questionnaire. In addition to the questions of the survey, the final part of the interview allowed the respondents to give feedback as final remarks. In that part of the interview, a semi-structured approach was used to gain a deeper view on the topic related with vulnerability, exposure and risk to floods and hurricanes.

3.1.3 Response Rate

Oral Interview

The oral interviews were conducted in 207 houses out of the 300 final sample size for an overall response rate of 69%. Figure 3.5 shows the geographical distribution of houses that were surveyed and houses that it was not possible to conduct the interview. As illustrated in the figure, the areas with lower response rate or where the survey could not be implemented at all correspond to the high income areas of the island, such as Billy Folly, Diamond and Little Cape Bay in Cole Bay district; Rockland, Zaeger Gut and St John Estate in Cul de Sac; and most of the neighbourhoods in Little

Bay, Lowlands and Upper Prince's Quarter districts. The main reasons for the low or non-response rate in these areas were:

1. Difficult access to the house due to gated houses without a doorbell
2. Presence of dogs that make difficult or impossible to reach the front door
3. Houses currently uninhabited for reconstruction
4. Non-Permanent residents of houses used for summer holidays
5. No residents were found at the time and date when the visits were performed
6. Gated condominiums where security guards denied access to the team

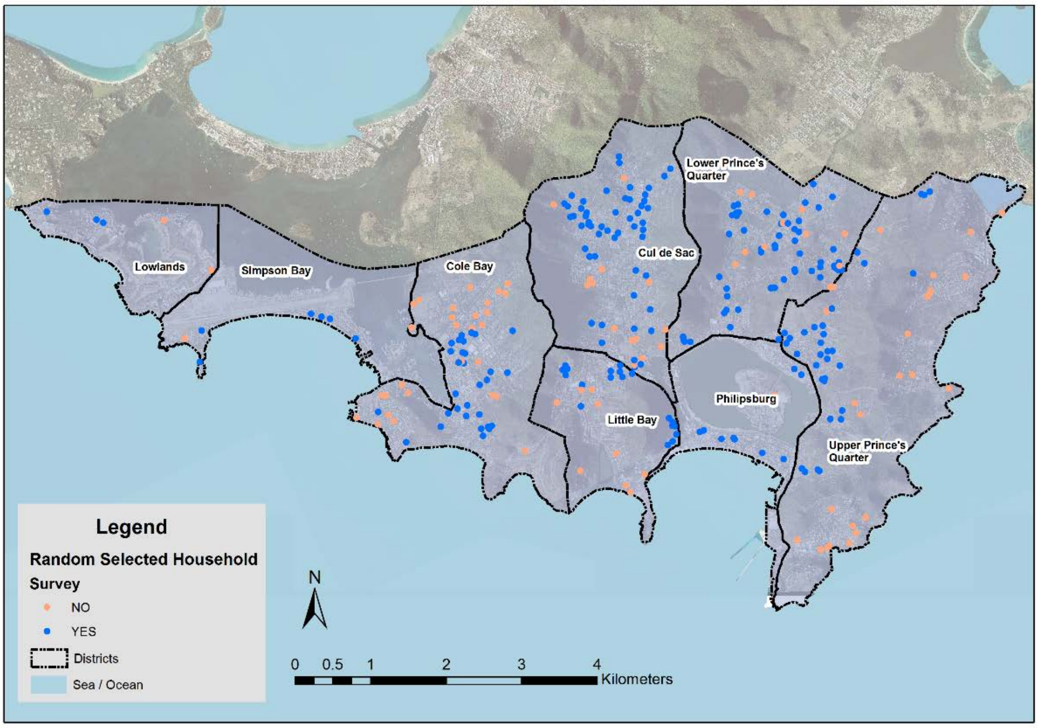


Figure 3.5. Geographical distribution of the initial random sample - Households that were surveyed vs Houses that were not surveyed;

Web Data Collection

The web version of the survey was posted initially on 9 March 2018 and it was kept online for a period of 3 weeks until 31 March to keep consistency with the number of weeks that the oral interview was conducted on the field. During the period that the survey was open, a total of 53 answers were received (see Figure 3.6). Of the 53 respondents, five reside in the French side of the island and hence removed from the analysis. The geographic location of the 48 remaining surveys is shown in Figure 3.7.

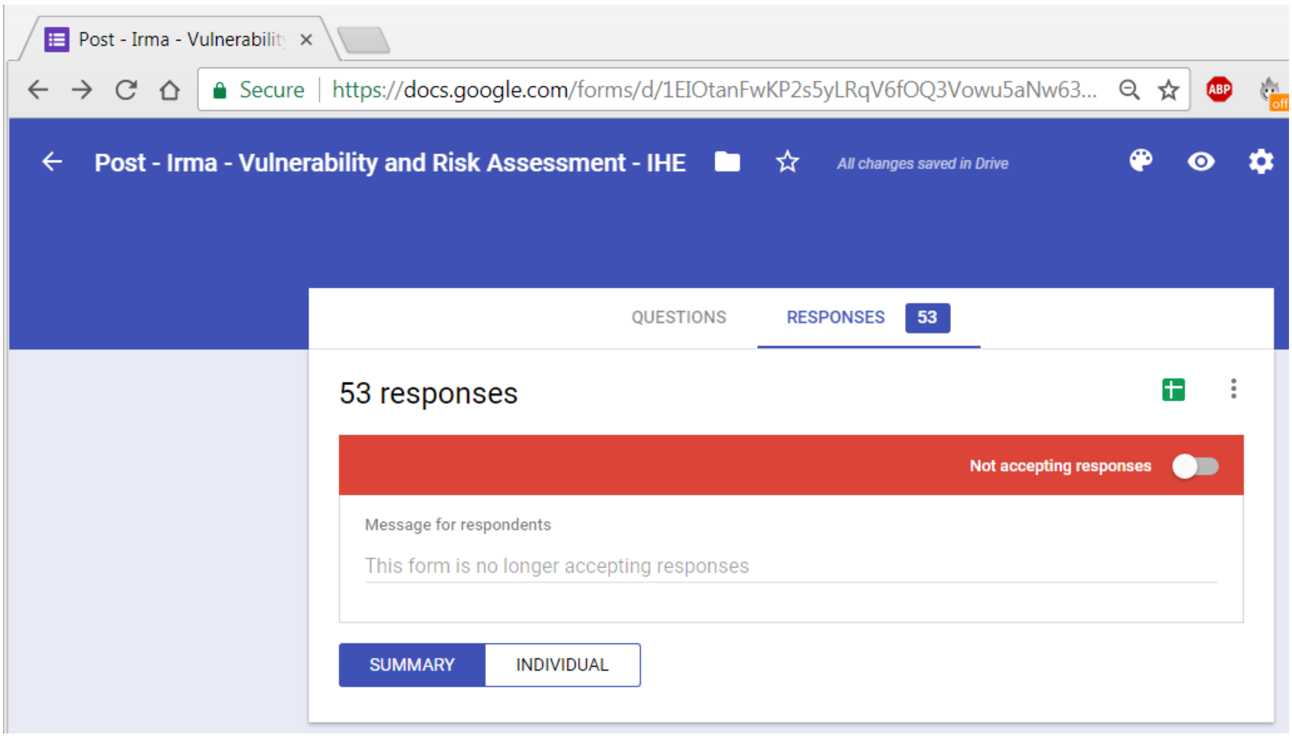


Figure 3.6. Total number of responses received on the online survey

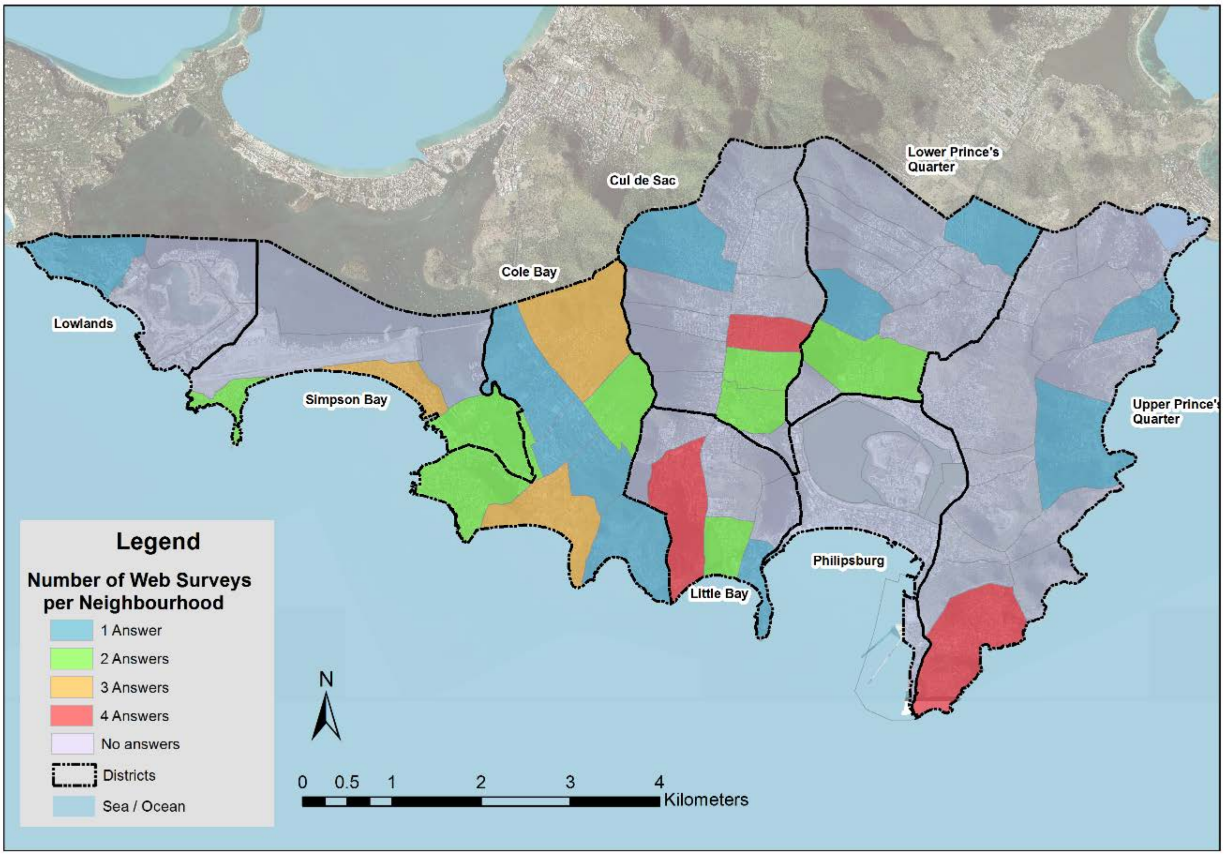
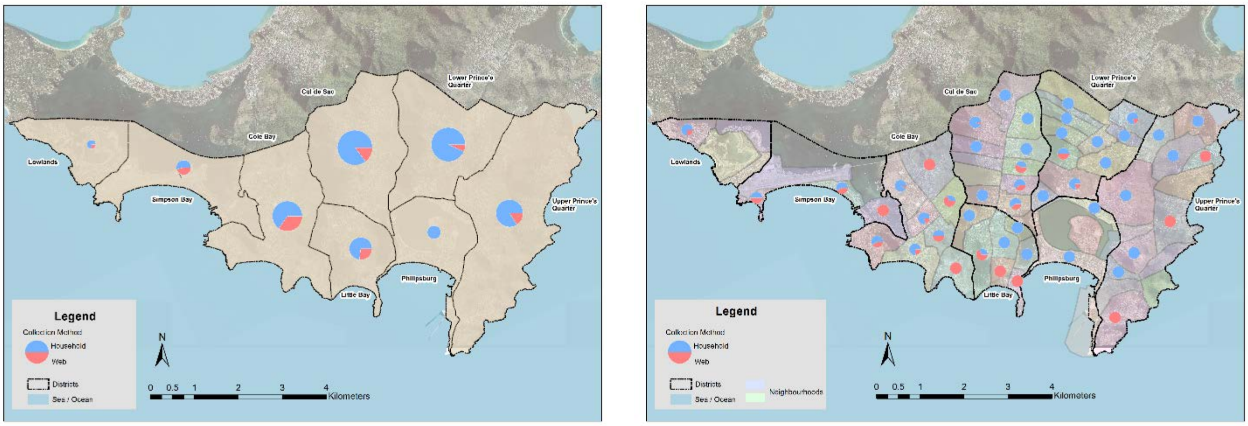


Figure 3.7. Geographical distribution of the web survey participants

Mixed Survey Results

To have a better overview of the geographical location of the respondents based on the collection method, Figure 3.8 shows the representativeness per district and neighbourhood levels for both methods.



(a) (b)

Figure 3.8. Survey collection methods (a) per district and (b) per neighbourhood. The blue and red colours show the proportions of face-to-face interviews and web-administered surveys

It is worth to note in Figure 3.8b that the web-administered survey covers those neighbourhoods that was difficult to conduct the face-to-face interviews. The total number of respondents using the mix data collection mode was 255. Hence, the real margin of error of the survey is 6.07% with a confidence interval of 95% as depicted in Table 3.3.

Table 3.3. Actual margin of error of the mix data collection mode

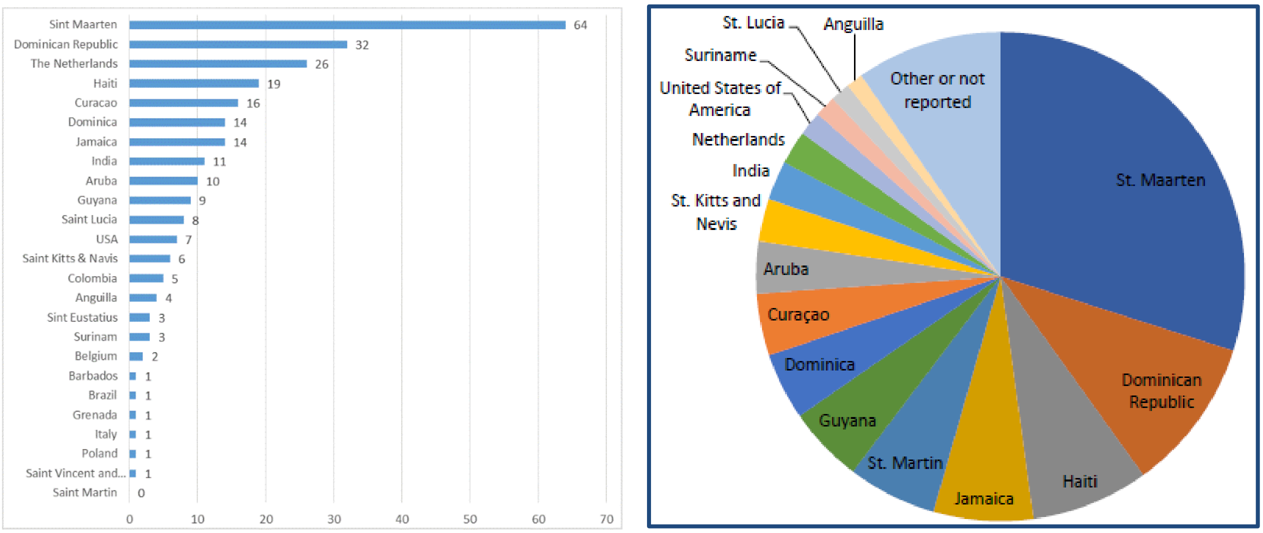
Sample Size Margin of Error		
Population Size	11128	How many entities are in the group your sample represents?
Number of Respondents	255	The actual number of respondents that answered the survey
Confidence Level	95%	Tells how sure the margin of error is
Margin of Error	6.07	Actual Margin of error of the survey in %

3.1.4 Survey output/analysis

From the mix-mode survey, the main finding can be grouped into 4 categories – household and demographic parameters, evacuation behaviour, awareness and experience, and risk perception. The main findings for each category are presented below. The complete results can be found in Appendix C.

Household and demographic parameters

A good correlation regarding the country of origin between the respondents of the mix-mode household survey and the official census data (2011) can be observed in Figure 3.9. This indicates the homogeneity of the research and that it is representative.



(a) (b)

Figure 3.9. Country of Origin of (a) respondents of the household survey and (b) the 2011 Census in Sint Maarten

As illustrated in Figure 3.10, about 60% of the respondents have been living in Sint Maarten for more than 20 years. Hence, they have experienced the previous major hurricanes such as Luis and Lenny. More adaptation and preparedness should have been expected from the community for Hurricane Irma than the observed during the extreme event.

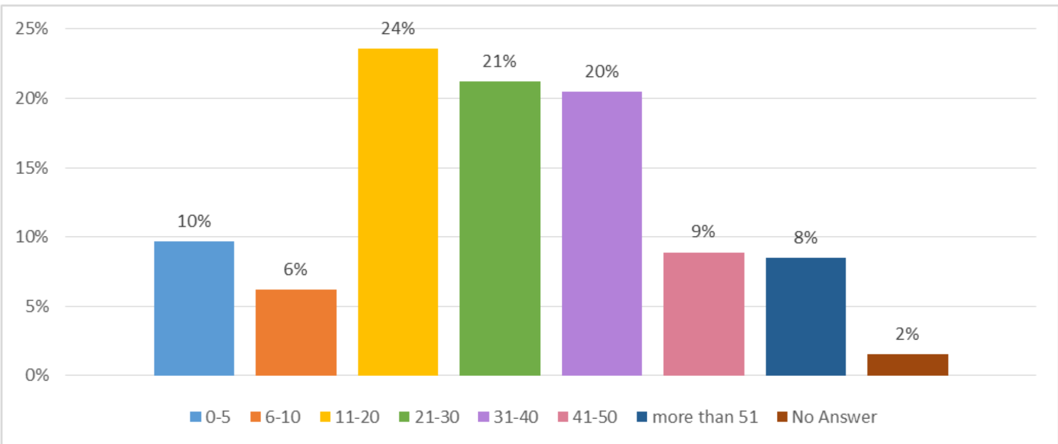


Figure 3.10. Number of years respondents has been living in Sint Maarten

Nearly one-third of the households in Sint Maarten has a size of two or less (Figure 3.11). This number is important in the assessment of vulnerability, measure as coping capacity[27]. Household size can be used directly to estimate this parameter (Sorg et al, 2018). The importance of household size lies on the assumption that an increase in household size decreases vulnerability due to mutual help (Welle et al., 2014).

[27] Coping Capacity is evaluated by strengths and resources of a community or individuals to take direct actions that leads to a reduction to a certain hazard situation (Birkmann and Welle, 2015).

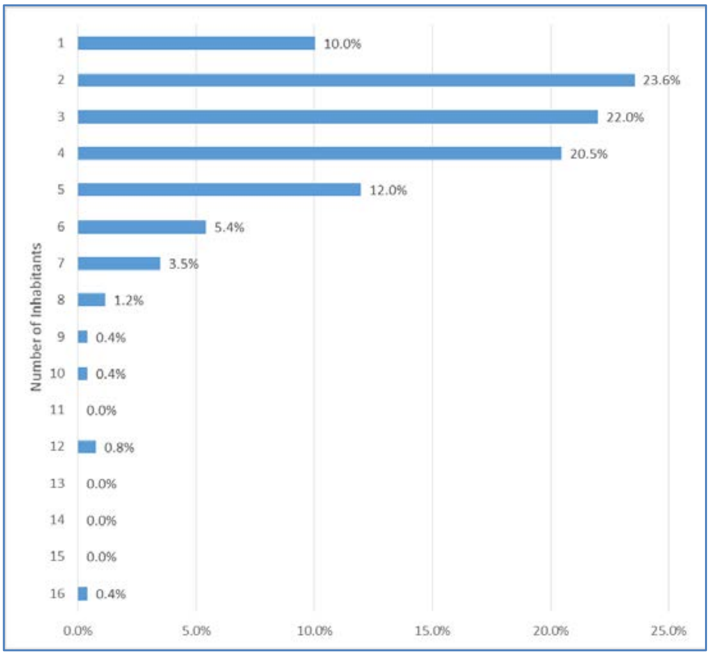


Figure 3.11. Household size

Regarding the age distribution, the elderly (i.e., group of people older than 65 years of age) is considered to be one of the most vulnerable age groups (see e.g. Jelínek et al. 2012; Welle et al. 2014) account for at least 12% (Figure 3.12). Amongst the elderly, the 25.8% expressed to live alone while 29% live in a two people household. When evaluated the response to evacuate of the elderly population, it results in a rate of evacuation of only 35.5%.

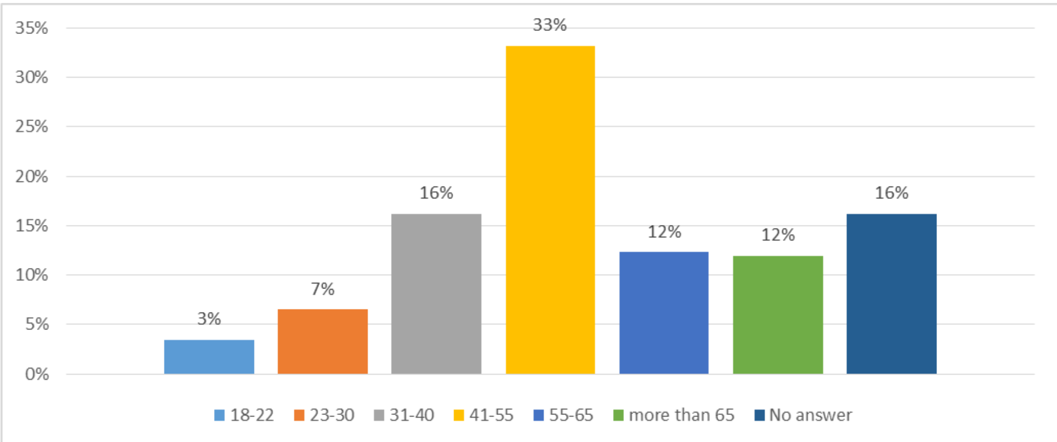


Figure 3.12. Age distribution

One of the key components that is leading to high vulnerability, exposure and risk to extreme events in Sint Maarten is the high percentage of rented houses. In terms of house ownership, slightly more households live in rental houses than in their own houses (Figure 3.13). Analysing this per district, the number is more critical in some of the poorest areas of the island. For example, in Lower Prince's Quarter and Philipsburg, 61% and 77.8% of the respondents are tenants. House ownership is an important factor that affects the vulnerability/resilience of households. Tenants may not feel the same responsibility in strengthening the houses they live in before hurricanes. On the other hand, landlords may take longer time to repair damaged houses. Further, in most cases, rented houses are not insured.

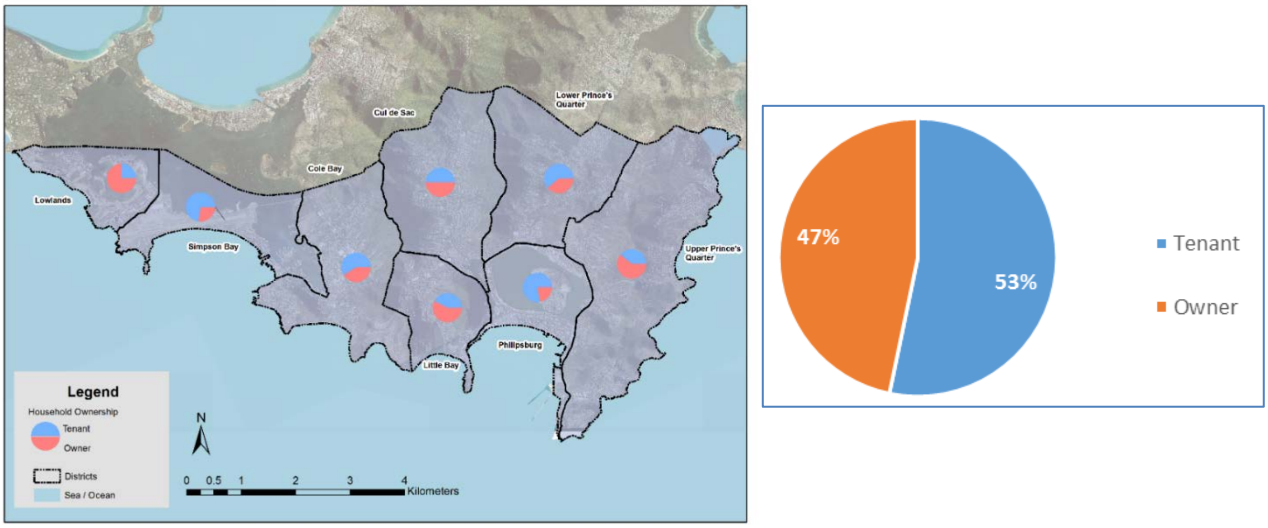


Figure 3.13. Household Ownership

Looking at the land ownership in Sint Maarten, there are areas that are leased by private landlords. In the leased lands, landlords usually do not allow the leaser to build concrete houses. Hence, even if it is against the building code, leasers may be obliged to build wooden houses. That also increase the vulnerability of some households. In our survey, around 20% of the tenants live in wooden houses. However, there is no enough data to correlate those wooden houses with the ownership of the land.

Around 60% of the houses in Sint Maarten were built after 1990 in which 40% were built between 1990 and 1999 (Figure 3.14) from which 86% were built using concrete as material of the walls (Figure 3.15). That decade is worth to mention since Hurricane Luis happened in 1995. Hurricane Luis was a tipping point in the history of Sint Maarten both in construction methods and awareness of hurricanes. As one respondent mentioned, "Luis gave us a crash course on how to build and prepare".

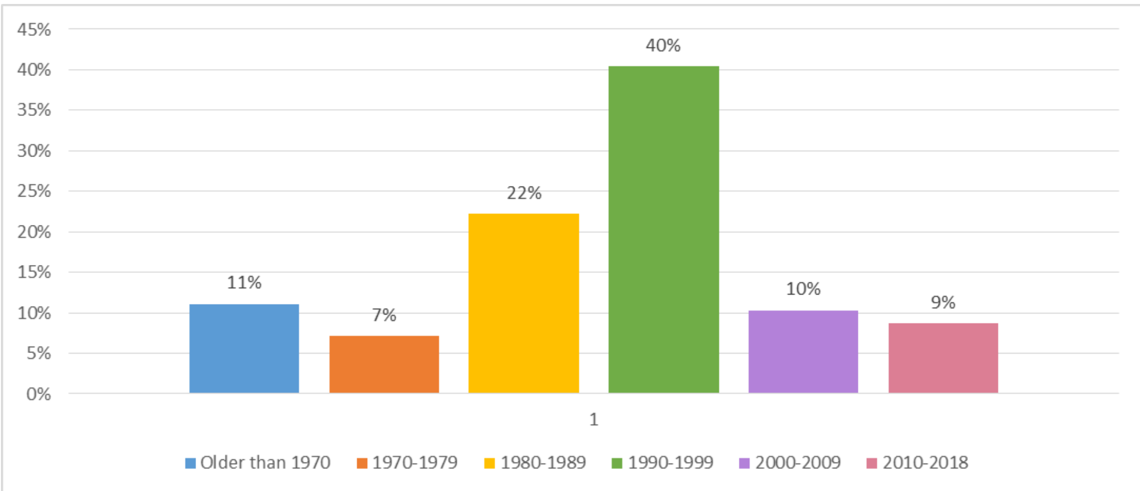


Figure 3.14. Decade of Construction of the House

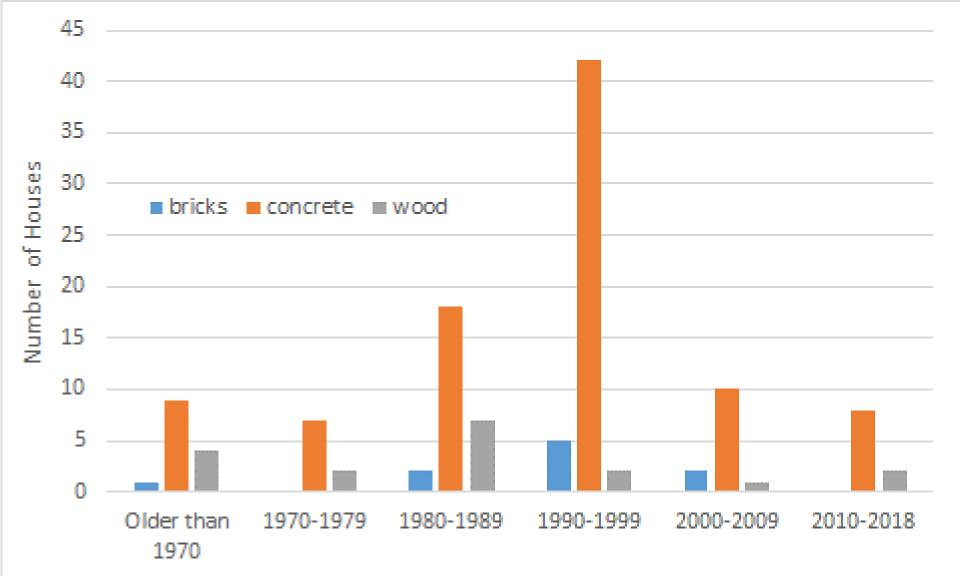
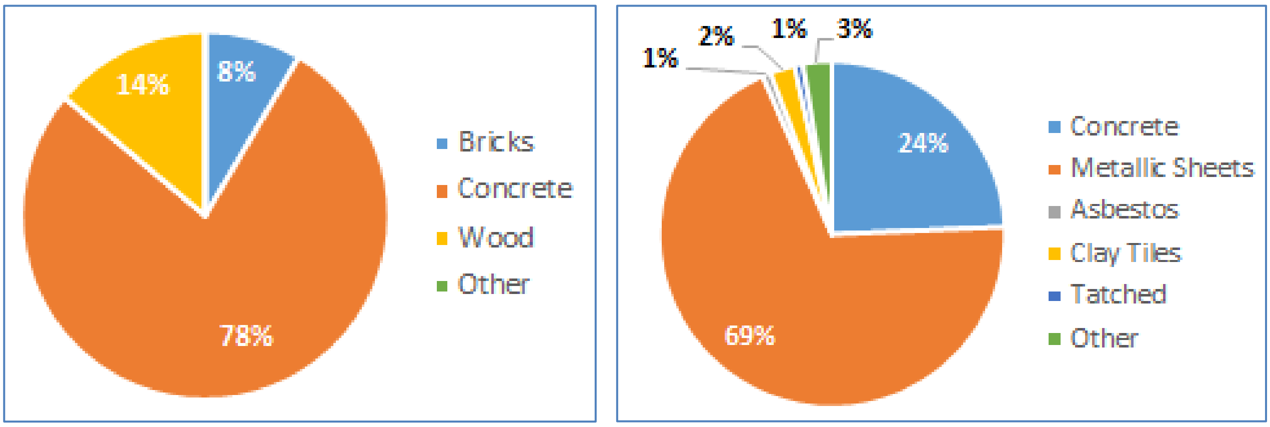


Figure 3.15. Residential building decade of construction vs number of houses built

In general, 78% of the surveyed households live in concrete wall houses (Figure 3.16a). Once again, a major shift in the construction behaviour is expected after the devastation of Irma. Regarding roof material, 69% of the respondents used metallic sheets/Zinc (Figure 3.16b). It was mentioned constantly by the respondents in the household survey campaign that after Hurricane Luis houses in Sint Maarten were rebuild to hold a category 4 hurricane in reference to their experiences with Hurricane Luis. Hence the great losses associated with Hurricane Irma. The research team has observed that people are rebuilding their damaged houses in concrete (i.e., concrete walls and roofs). Those who cannot afford concrete roof or who are not willing to build in concrete will use better reconstruction materials, for example, longer screws to fix metallic sheet roofs.



(a) (b)

Figure 3.16. Construction materials used to build (a) walls and (b) roofs in Sint Maarten

Regarding home insurance, the low coverage of home insurance to natural disasters in highly hurricane prone areas is alarming - 47% do not have insurance while 26% of the respondent "does not know" (see Figure 3.17). The finding is in contrast to the regulations that in Sint Maarten it is mandatory to have a home insurance to take out mortgages.

The main reasons for the low coverage, according to field mission findings, are:

- Insurance is too expensive on the island after the devastation of Hurricane Luis and prices never went down after that event.
- Low trust on the insurance companies, not getting paid what the house is worth and slow process to claim money back
- Poor client service
- Most people prefer to try to save money and do the repairs themselves

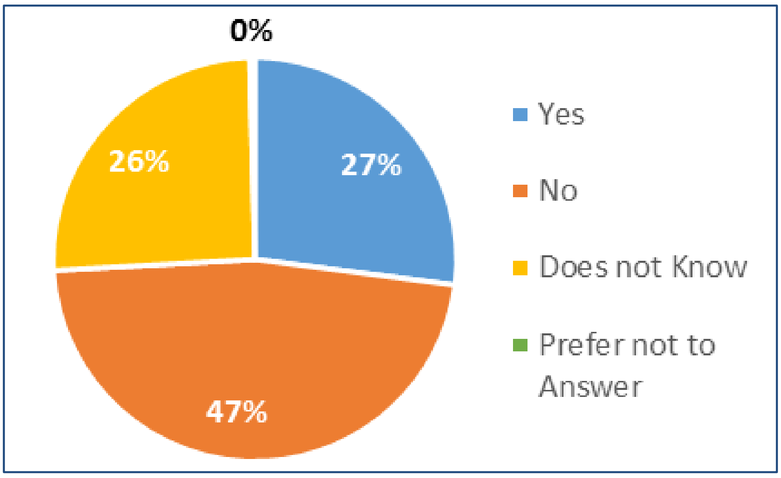


Figure 3.17. Home insurance coverage in Sint Maarten

When home insurance for natural disasters is analysed by district (Figure 3.18) and neighbourhood (Figure 3.19), high-income districts/neighbourhoods such as Lowlands/Cupecoy have more insurance coverage than low-income districts such as Windsor in Colebay. However, high-income neighborhoods such as Guana Bay in Upper Prince's Quarter have a low insurance coverage against natural disasters.

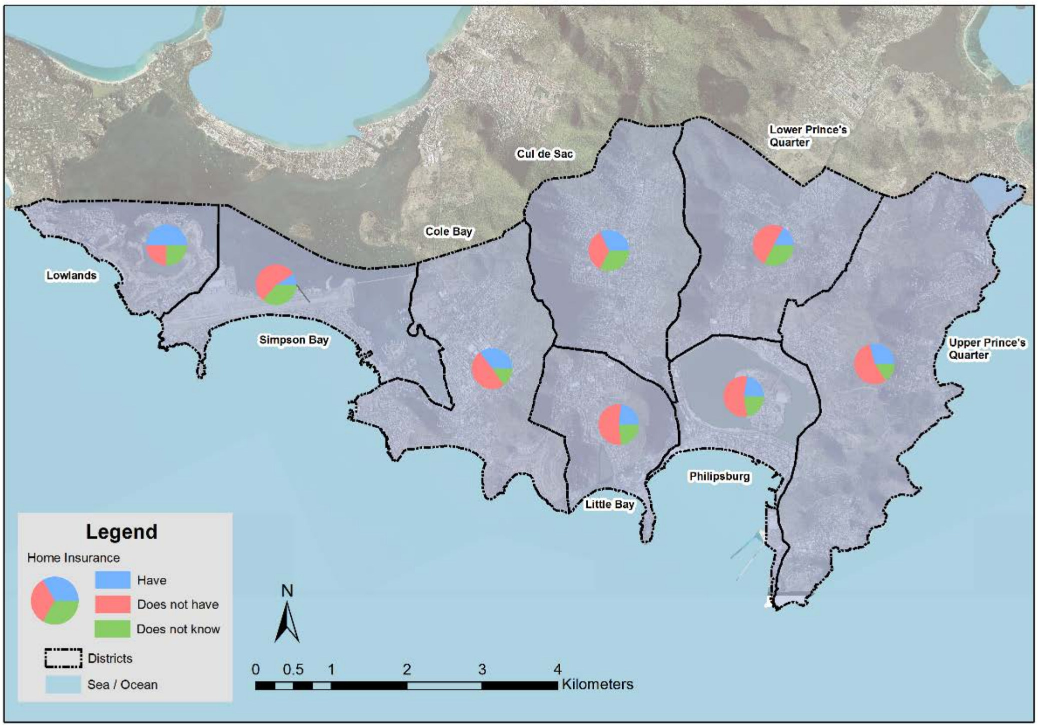


Figure 3.18. Home insurance coverage for natural disasters by district

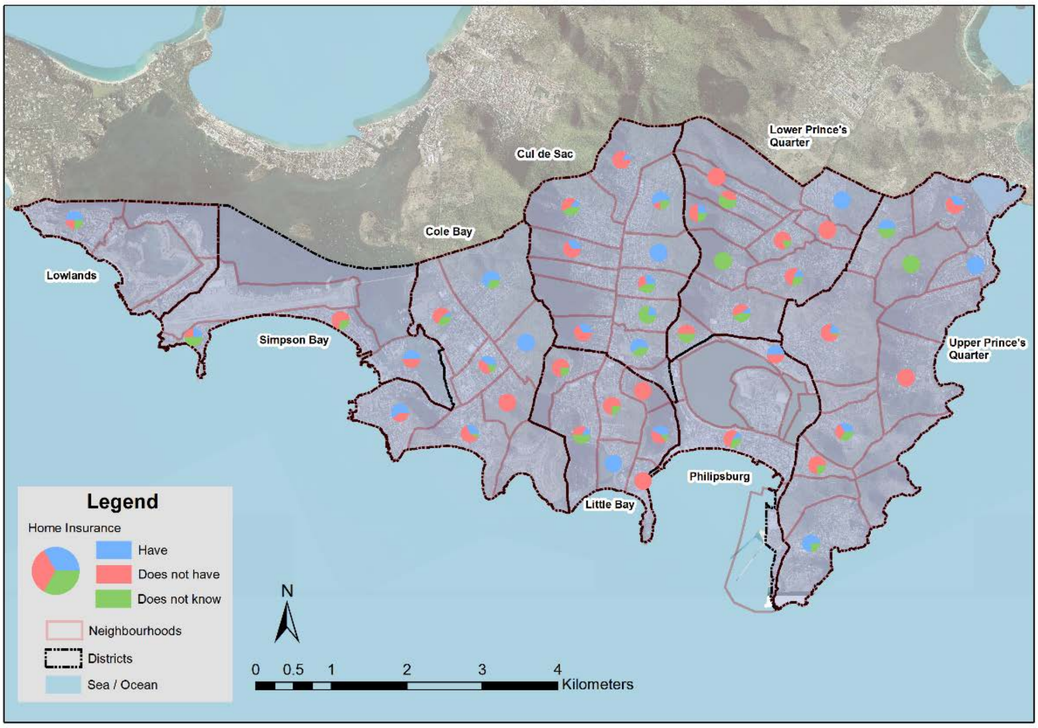
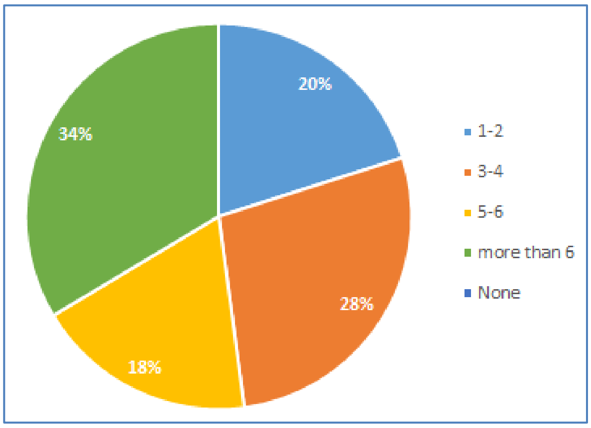


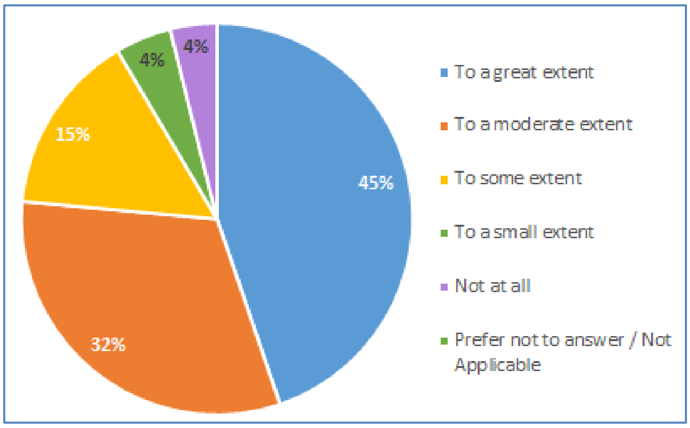
Figure 3.19. Home insurance coverage for natural disasters by neighbourhood

Information, Awareness and Experience with Hurricanes and Storms

In Sint Maarten, 80% of the people have experienced three or more hurricanes (Figure 3.20a). The experiences are important to prepare and be resilient as the people's awareness increases. Due to its strength and level of destruction, the 1995 Hurricane Luis is the most remembered hurricane in Sint Maarten. The behaviour of the island changed positively after Luis. However, Irma will be the strongest and most remembered, and it will boost the awareness of the people.



(a)



(b)

Figure 3.20. (a) Number of hurricanes remembered by the respondents and (b) Percentage to what degree people know where to get information about early warning and evacuation

Respondents know where to get up to date information on early warnings or evacuations when a hurricane is approaching the island - 77% of the respondents expressed they know where to get

information from a moderate to a great extent (Figure 3.20b). Radio, internet and television are the preferred methods to get the latest information during a hurricane (see Appendix C).

Our finding specifically about Irma is that the vast majority of people in Sint Maarten, 98%, was aware of the hurricane before it hit the island (Figure 3.21a). Most people knew about Irma well in advance to take measures to protect lives and property, 55% of the respondents expressed that they were aware of Irma in a range from 4 to 7 days and 19% from 8 to 14 days before the Irma's landfall (Figure 3.21b). But it was observed that the respondents were not fully aware of the severity in advance. About 80% of respondents only consider Irma as a real threat in a range of 0 to 3 days prior landfall (Figure 3.21c)[28].

Some people went to work until the morning of September 5and schools were open until September 4. This was one of the most common complains of the respondents since they did not have enough time to react and prepare to withhold the effects of the hurricane. Many respondents complain as well that they never received a clear warning on the severity of Irma. It was also clear that most people in the island have forgotten what a strong hurricane can cause on the island and did not prepare sufficiently.

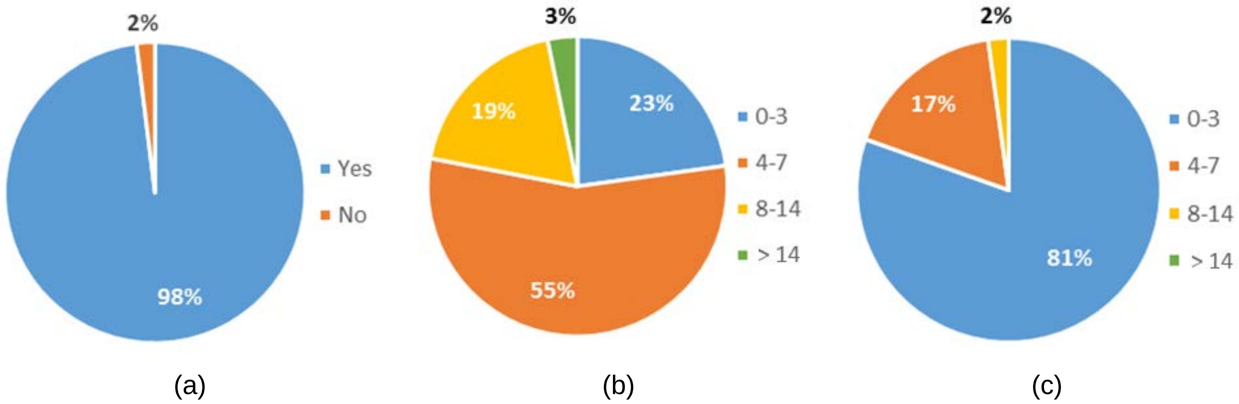


Figure 3.21. People's awareness of Hurricane Irma. (a) Percentage of people who knew about Irma before its landfall in Sint Maarten; (b) How many days in advance they knew about Irma and (c) How many days in advance they knew about the severity of Irma.

Evacuation behaviour

The majority of residents do not evacuate during hurricanes. During Hurricane Irma, 69% of the respondents did not evacuate (Figure 3.22).

[28] The question regarding the severity of hurricane Irma was only asked in the web survey.

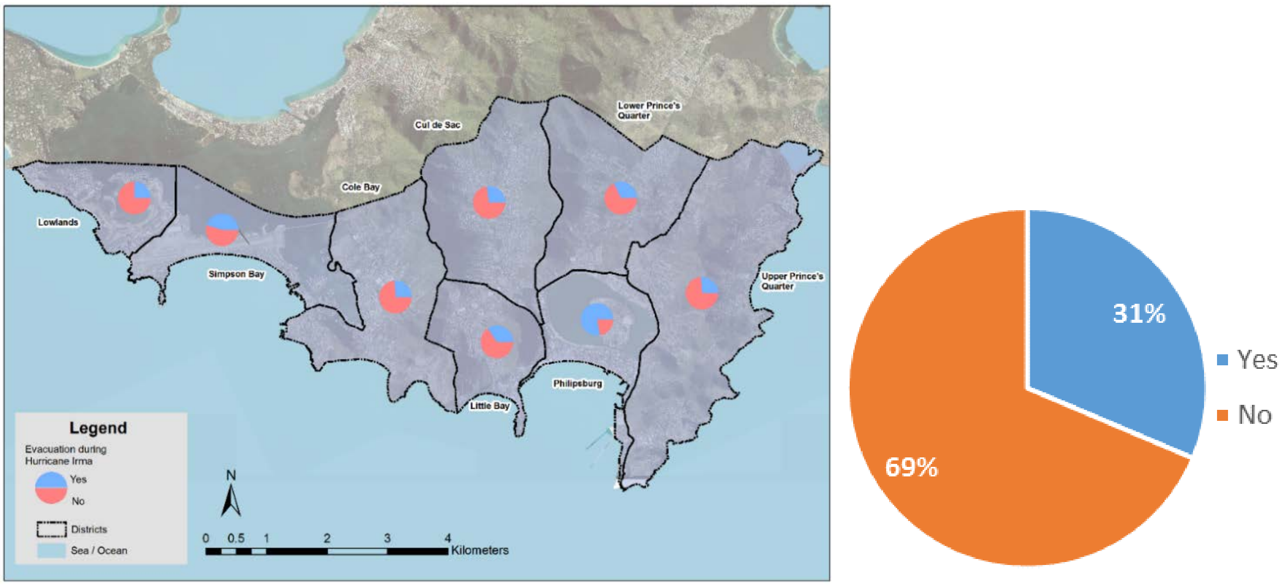


Figure 3.22. Evacuation percentage during Hurricane Irma in Sint Maarten

Of the 31% who evacuated, nearly 80% evacuated before the hurricane hit the island. But a remarkable 16% evacuate during the hurricane putting their lives in danger. Their main reason is that their houses collapsed during the storm and had to run to neighbors houses (see Appendix C). As illustrated in Figure 3.23, most of the people who evacuated, 63%, sought shelter at friends' or relatives' houses. Hotels were the preferred evacuation locations for 21% of the evacuated people. However, only 3% went to public shelters.

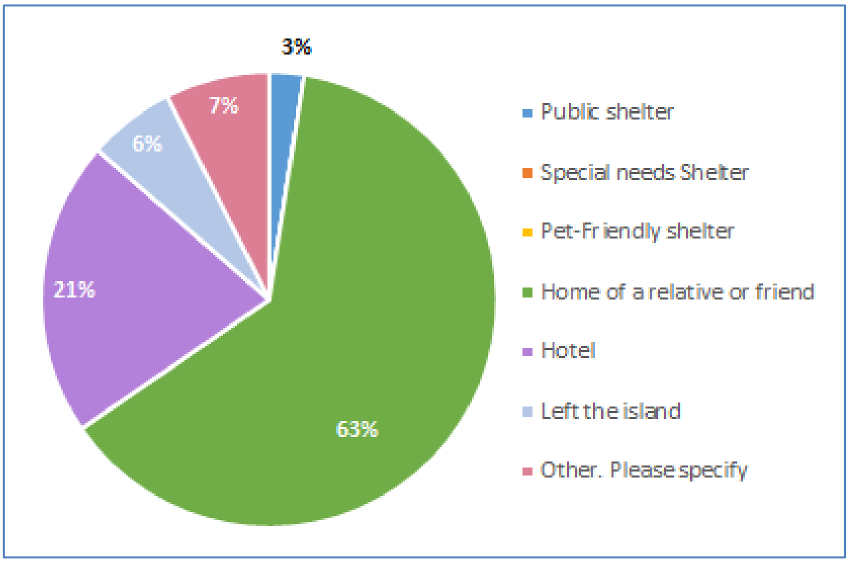


Figure 3.23. Choice of evacuation locations during Hurricane Irma

It was announced by the Prime Minister that public shelters in Sint Maarten would be closed before landfall of Irma. The main reason provided was that there were no strong shelters to guarantee the safety of those who choose to evacuate to one of the public shelters. Only in the afternoon of 5 September, a new order to open some of the public shelters was communicated to the public. However, according to the findings of the field work, this message did not reach the broader population of the island. That will play a vital role in the lack of trust in institutions for future hurricane seasons and warning and evacuation instructions.

Based on the survey, the main reasons for residents to not evacuate to shelters in Sint Maarten are:

- shelters are not seen as strong structures
- residents prefer to stay at home to protect their house against looting and to repair window shutters and secure doors during the hurricane
- shelters do not provide enough food, water or beds
- people believe their homes are stronger than public shelters

Due to the extensive damage caused to the hotels during Hurricane Irma (Figure 3.24), it is expected that the number of people evacuating to hotels in future hurricanes will decrease significantly.

(a) (b)

Figure 3.24. Damage to hotel infrastructure. (a) Great Bay Hotel – Philipsburg and (b) Oyster Bay Resort – Oyster Pond

To those respondents who decided not to evacuate during Hurricane Irma, a set of questions were asked to get a deeper insight of what were the reasons to stay at home rather than evacuate. The reasons people gave not to evacuate during Hurricane Irma were (Figure 3.25, Figure 3.26 and Figure 3.27):

- feeling that their houses were strong to hold the hurricane
- based on past experiences with hurricanes, from the residents perspective, is better to stay at home
- residents felt that Hurricane Irma was not a threat and
- respondents consider the conditions in shelters are not adequate

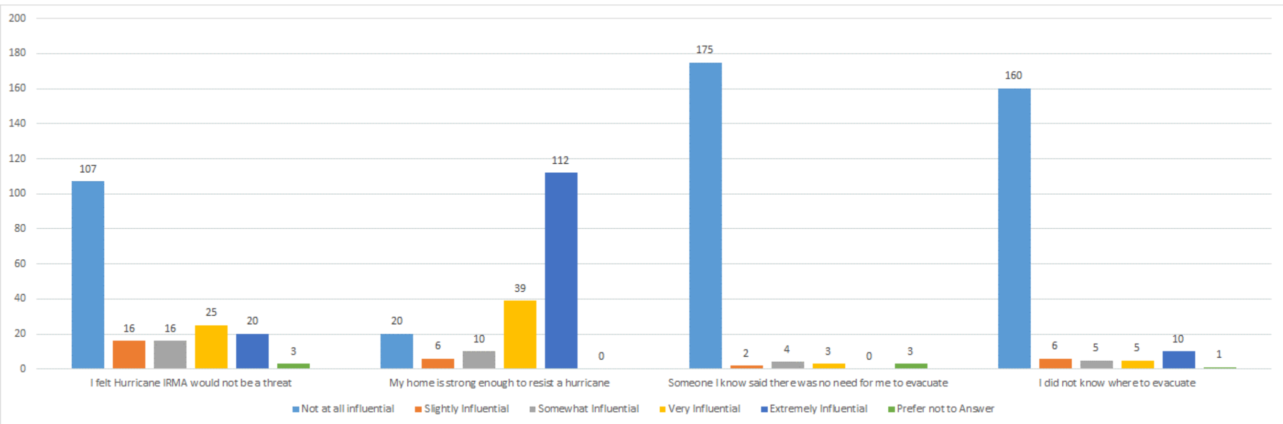


Figure 3.25. Factors that influenced the decision not to evacuate during Irma – Part 1

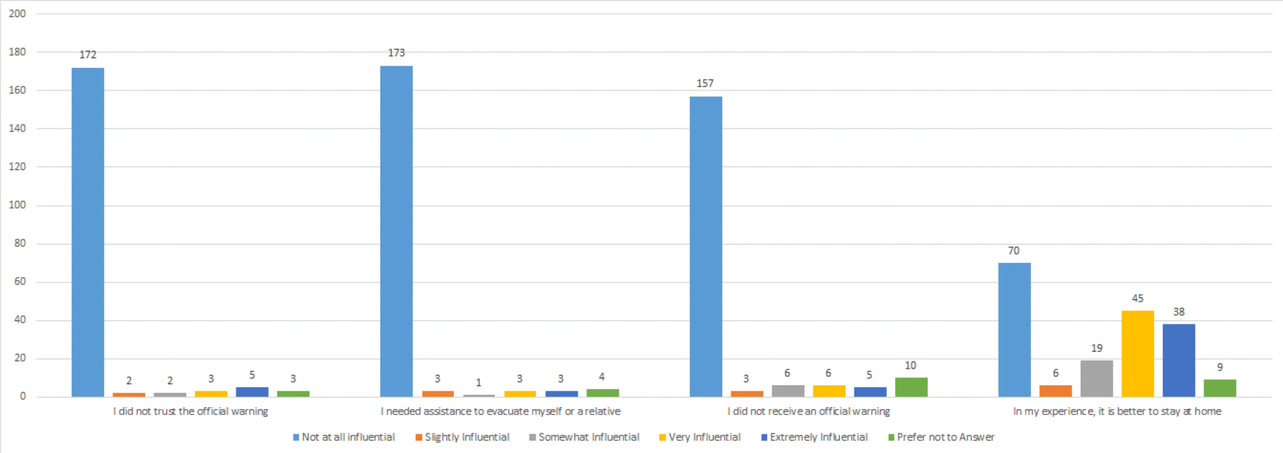


Figure 3.26. Factors that influenced the decision not to evacuate during Irma – Part 2

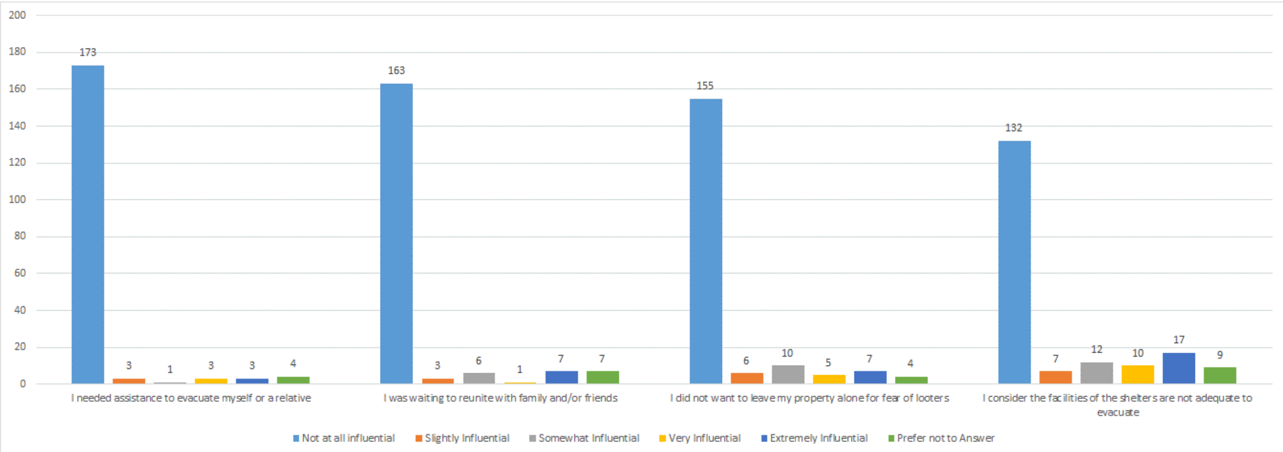


Figure 3.27. Factors that influenced the decision not to evacuate during Irma – Part 3

The perception in the island is that the current buildings that are officially designated as shelters are not strong enough and do not provide enough resources to evacuate. People do not see any added value to evacuate to those shelters. But the location of the existing ones is appropriate in terms of geographical coverage (see Appendix C).

Risk perception

Most of the respondents consider the Government of Sint Maarten as the main responsible actor to take actions to prevent losses during a hurricane. It is important to highlight that inhabitants recognize their own role in the disaster management during an extreme event (second in frequency of responses as shown in Figure 3.28) and that they still have a strong link with the Dutch Government.

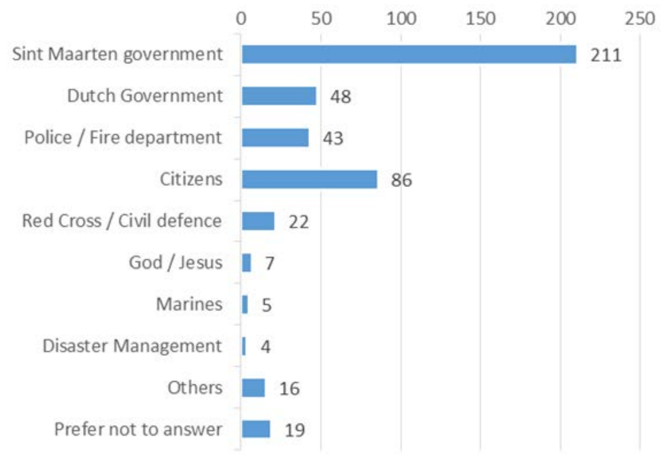


Figure 3.28. Perception to who is responsible to take actions during a natural disaster

More than 60% of the interviewees responded that the Government of Sint Maarten could have be better prepared to face the direct impact of Hurricane Irma (Figure 3.29). The perception of the citizens is that the government of the island could have a better regulation of the construction and the land use development on the island regarding material, methods and location of the houses. In addition, the respondents also mentioned that better warning information is needed from the authorities.

The role of the government in the immediate aftermath of the hurricane was also criticised. Interviewees mentioned that the destruction to the island economy due to the looting of supermarkets, shops, jewellery stores and other businesses in the immediate aftermath of Irma was significant, and will affect directly the trust in institutions in the future hurricane seasons.

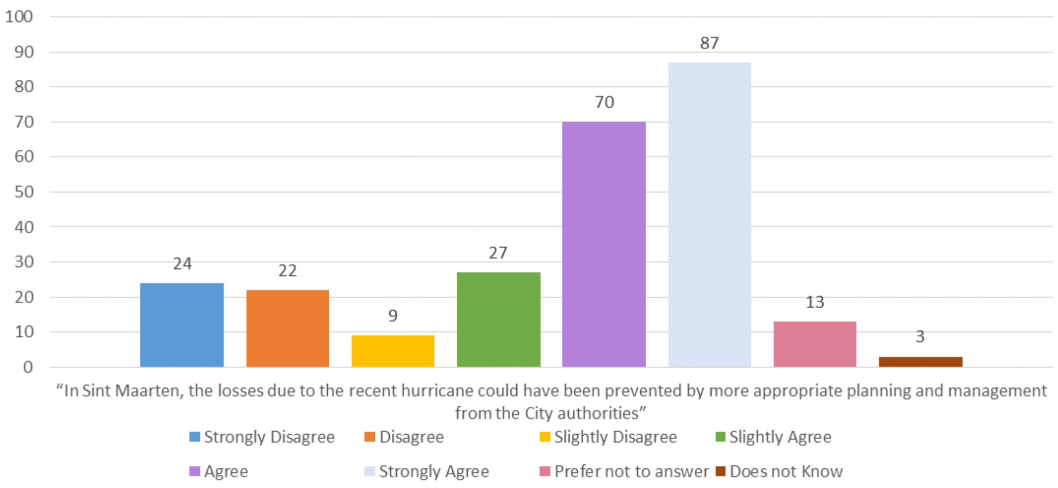


Figure 3.29. People's perception towards the Sint Maarten Government planning and management during Hurricane Irma.

Regarding the future evacuation behaviour in relation to severities of storms or hurricanes in upcoming hurricane seasons, the findings in Figure 3.30 show that with the increase in the magnitude of the forecasted hurricane, an increase of willingness to evacuate and a decrease in those that definitely would not evacuate is observed. It is remarkable that to a future hurricane category 5, the number of people who expressed a definite willingness to evacuate is almost as many as those that definitely would not evacuate.

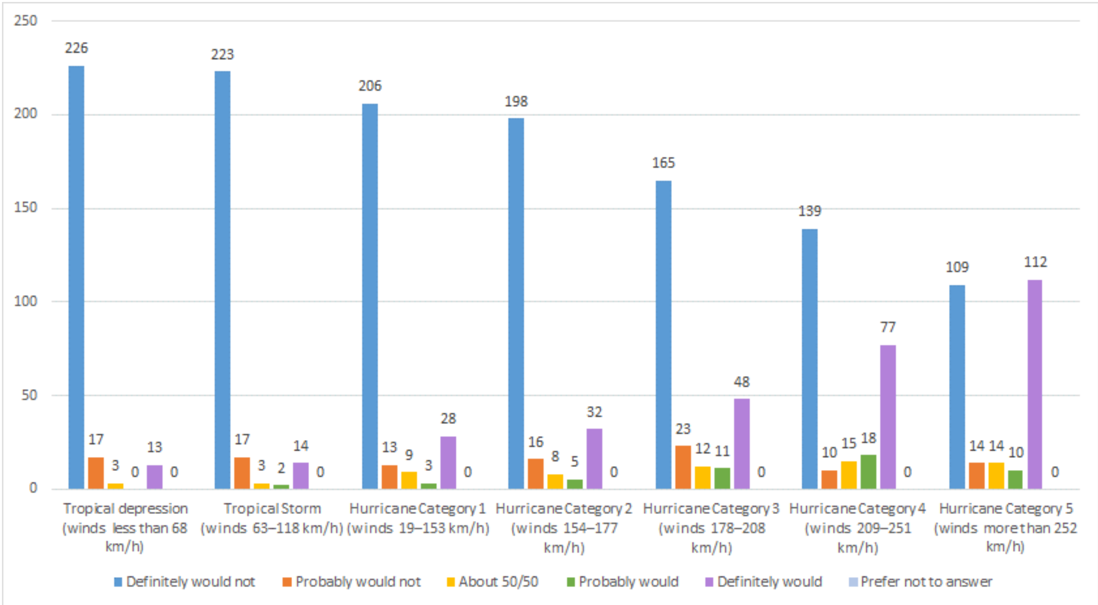


Figure 3.30. Future evacuation behaviour in relation to storm/hurricane categories

3.2 Semi-structured interviews and stakeholder meetings

During the fieldwork, the IHE Delft team had several stakeholder meetings (mainly government officials) and interviews to gain a broader view of the impact of Hurricane Irma on the island from the point of view of the interviewed actors. To identify the relevant stakeholders, IHE based the preliminary assessment using the organizational structure for disaster management in Sint Maarten. The disaster management structure is organized under the *Emergency Support Group* which in turn is composed of 10 ESFs as shown in Figure 3.31.

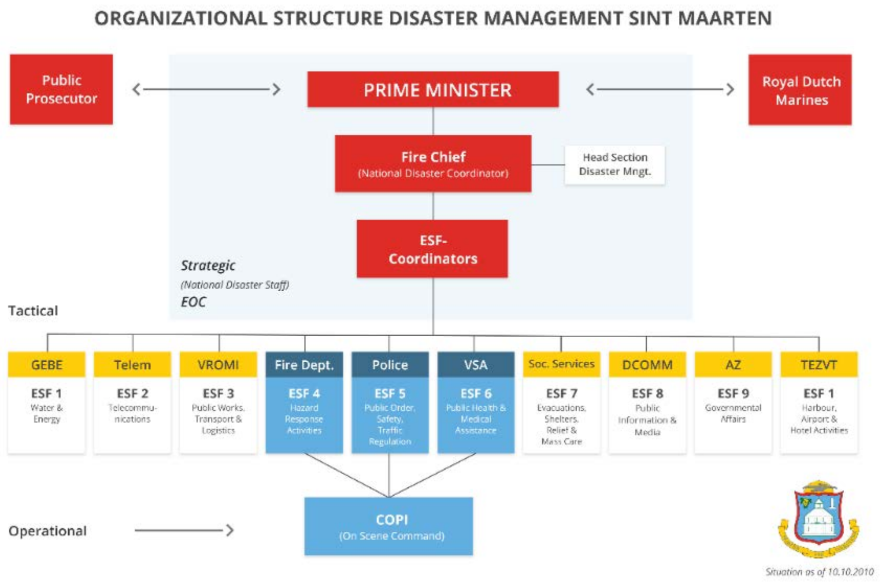


Figure 3.31. Sint Maarten disaster management organizational structure. Source: The official emergency website of the Government of Sint Maarten [29]

[29] https://www.sxmemergency.org/en/updates/relief/emergency-support-group/

Using this organization, we set up meetings with the ESFs that have a direct relation with the objectives of the mission such as representatives of the fire department, disaster management head, ESF-3, ESF-6 and ESF-7. In addition, meetings with representatives of the Met Office and Statistics Office were arranged.

3.2.1 ESF-3

ESF-3 represents VROMI. This ESF is responsible for public works, transportation and logistics. Among other things this group deals with temporary garbage and debris collection locations and pick-up dates. Waste and sewage management also falls in this group.

Meetings with ESF-3 were conducted to gain understanding of the housing policies, land development and the needs for reconstruction of the island. This ESF also participated in the assessment and data collection of the urban drainage system in Sint Maarten.

In addition official of this ministry fill in a questionnaire in regards to a Measures Selection Tool developed at IHE, the tool is used to help the selection of structural measures to cope with urban floods and the aim of this tool is to help technical decision makers with good knowledge about the problem and the area. The expected result is an ordered list of applicable measures for the site considered. The results of the use of this tool is presented in Section 5.2.5.

3.2.2 ESF-6

ESF-6 represents the Department of Public Health under the Ministry of Public Health, Social Development and Labour (VSA) and it is responsible for preventive and collective health during disasters. This representative give IHE team leads and contacts within other organizations to have access to census of the most vulnerable population, and refer the team to contact the White and Yellow Cross in Sint Maarten and members of the ESF-7.

The meeting gave valuable information on how the critical patients from hospitals were treated and evacuated before and just after Irma. Unfortunately, at the moment of the meeting, the statistics of these special procedures were not available. And the emergency plans for this actions are responsibility of each medical centre not under responsibility of the ministry. VSA only assist with support to create this plans but is up to each organization to implement and put it on action when needed.

Programs to assist population under stress after Irma is being run by the Association for Psychologists and Allied Professionals Sint Maarten[30]. This programs are run private and some enter under the health insurance coverage.

There is a lack of data or not a proper registry was done regarding post Irma associated outbreaks of mosquitos and/or diseases. At the moment of the interview, there are some data collected but is not reliable and is partial.

ESF-6 representatives during the meetings of the emergency support group prior the landfall of Irma, suggested to open the shelters before Irma hit. But the final decision was made by the Prime Minister and it was decided not to open them for the reasons already explained in this document.

[30] https://www.facebook.com/apapsxm/

3.2.3 ESF-7

ESF-7 represents the Department of Social Services under VSA and they are responsible for evacuation, shelter, relief and mass care including humanitarian affairs, care for the elderly, food and ration distribution for general public, domestic violence and other issues.

During this meeting IHE team was presented a report call "*Shelter Data Overview. Hurricane Irma, Jose and Maria*". This report collects the information on shelter occupancy and other details of the sheltering in Sint Maarten during the hurricane season of 2017. A copy of the main finding of this report was shared with IHE team. Some of the main facts of this report as well other key points discuss during this meeting are presented here:

- Reasons of PM to not open the shelters are not completely clear but mainly due to the lack of resources and security. As well buildings not strong enough for a category 5 hurricane.
- A last minute decision was made to open some of the official shelters of the island. The decision was made on the morning of Tuesday September 5. In the opinion of ESF-7, it was too late and the mix messages transmitted created confusion. ESF-7 representative expresses that this ESF group learnt a lot from Irma experience to implement in future hurricane seasons.
- Government cannot invest money in shelter maintenance of private buildings that are used as shelters. This creates an ambiguity when and whom is responsible to keep the shelter in optimal conditions to be used during the hurricane season. The lack of a proper maintenance program creates the image of poor or weak structures among the inhabitants of the island
- In the time line of Irma, ESF-7 have several meetings with Community leaders, red cross and social services to define which building can potentially be used for Irma. Once they defined those buildings they communicate it to Ministry of Public Housing, Spatial Planning, Environment and Infrastructure (VROMI) for them to do the structural assessment and give the green light or not to those selected. A list of hurricane shelter for the 2017 hurricane season was publish in June 2017 (Figure 3.32).

Hurricane Shelters 2017

1	**New Testament Baptist Church**	A.C. Cannegieter Street - PHILIPSBURG	542-2434 | 542-5727
2	**Sr. Marie Laurence School**	Ellis Drive - MIDDLE REGION	547-1134
3	**St. Maarten Academy**	Cupper Drive - CUL DE SAC	548-3780
4	**Milton Peters College**	L.B. Scot Road - SOUTH REWARD	548-3190 | 548-3776 | 548-4200
5	**Rupert Maynard Youth Center**	St. Peters Road - ST. PETERS	548-5022
6	**Leonard Conner School**	Venus Drive - CAY BAY	544-5246 | 544-2080
7	**Allan Halley Community Center**	Simpson Bay Road - SIMPSON BAY	-
8	**National Institute for Professional Advancement (NIPA)**	Building B, Jackal Road #4 -Cay Hill	543-0497 / 543-0498
9	**Christian Fellowship Church**	Welfare Road - COLE BAY	544-4048 | 544-3943

Figure 3.32. Hurricane shelters 2017. Source: Hurricane safety guide 2017 (scanned)

- There is one shelter that keeps the status of shelter all year round. Rupert Maynard Community Centre. It is used during any emergency in the island, not only in hurricane season
- ESF-7 has a manual of shelter management, which was made some 3 years ago in cooperation with personnel of the British Virgin Islands who are consider to be the experts on shelters on the region
- The National Institute for Professional Advancement (NIPA) was the most used shelter after Irma [31]. It was used to shelter some of the tourist that were in the destroyed hotels. They were demanding to have hotel experience in the shelter. i.e. 3 meals, internet, etc. Government provide those facilities, so "it was a 5 star shelter".
- Sister Marie-Laurence School was one of the shelters open on Tuesday before Irma arrive. This shelter lost the roof during the hurricane. Fortunately no human losses were reported from this.
- No discrimination on the migration status was made on the shelters before or in the aftermath of Irma. On arrival to shelters people were asked only for nationality and name
- Even though they communicate to people that they have to bring their own supplies to the shelter they as government always have a minimum of water and food for each person that enters the shelter. To be used as a backup in case the person came without the supplies.
- One interesting fact is that WhatsApp was used a communication tool among the ESF-7 team before, during and in the aftermath of Hurricane Irma
- Accounting tourist, immigrants in non-official shelter and official shelters, the official report of ESF-7 estimates a total of 1000 people look for some type of shelter for the three events (Irma, Jose and Maria).
- ESF-7 is presenting a plan to build 8 new multifunctional buildings to be used as shelters. One per each district. The plan is to use the money fund from the Netherlands. It is estimated that each building will cost around US$1.5 million.
- The perception of the ESF representative in regards to mandatory evacuations in most vulnerable areas will not work in Sint Maarten. Illegal immigrants will never follow and order and Sint Maarten does not have the police force to mandate an evacuation.

3.2.4 Head Section Disaster Management

The meeting with Mr Paul Martens, head section of Sint Maarten Disaster Management was intended to gather information of the timeline of Irma and how different components of the disaster management group interact and are set on action before the disaster as well in the aftermath of Irma. The main information gather in this interview is presented here:

- The information about hurricanes comes from the NHC in Miami. As standard procedure. Then is up to each state/government to analyse this information and decide for their own

[31] Note that this was not listed initially as a shelter for the 2017 hurricane season

territory. In Sint Maarten, this information is manage by the Met office, which is part of the ESF.

- All shelters in Sint Maarten are run by volunteers i.e. School Director, community centre manager, etc. During Irma they wanted to stay at home. Without his/her presence the shelter cannot be open. Shelter manager is responsible for preparation of the shelter.
- All Shelters to be open need the presence of security forces. These forces can be: Police or the armed community organizations (local defence) of each district. The police can ask the marines to provide this security. In addition shelters also need at least the presence of Red Cross volunteers for the medical care in the shelters.
- Sint Maarten does not have, and is not considering to have mandatory evacuations:
  - Limited resources. Shelters only provide roof. People that is going to a shelter is requested to bring Food, Water and Blankets for themselves
  - Standard Sint Maarten inhabitant does not want to evacuate. To protect the house and to stay only with family and friends
  - Trust in the warning is limited due to previous False alarms
  - The island does not have the number of police force or military to do a mandatory evacuation
- At the beginning of each hurricane season a team from the different ESF (VSA, VROMI, Fire Department, Police and Red Cross), visit the possible shelters and assess the structural and staff conditions of the buildings to evaluate which ones will be potentially used in that year.
- Illegal immigrants can go to shelters. During a disaster they do not ask for legal status. Only basic information is asked to register when they arrive
- Every year the disaster management section and the fire department launch hurricane awareness campaigns
- Sint Maarten install as a test 7 sirens in in 2006 after the flood in Cul de Sac. They are install only in flood prone areas. The system was designed for the sirens to operate in an automated way and there were technical issues since they were installed such as with the setup of sound to reach the surroundings, problems with corrosion and maintenance and also with thunderstorms. The sirens used to be tested each month but were not used during Hurricane Irma. In fact, they are not in use anymore because it is an outdated technology and they are evaluating alternatives to replace them: (1) Sint Maarten want to use something similar to NL alert as SMS to all cell phones –CAP alert protocols. (2) Also they are evaluating the legal framework to take over radio station frequencies (forced) to replace the sirens.
- It was mention during the meeting that community centres were built with the intention of being used as dedicated shelters in the island under the Sint Maarten Government administration. That did not happen, and now those centres want to stop being listed as shelters.
- They do not see dedicated shelters to be constructed/build in Sint Maarten in the near future. The government does not have the resources to have a standby building.

- Regarding maintenance of shelters there is an ongoing discussion who is responsible. If is a private building the government cannot made any investment, but later they need to use it and is not well perceived by the owner of the building. In addition there is an internal ambiguity who is responsible within the government for the maintenance between VROMI and VSA ministries.
- Regarding communication during Irma, he estimates that around 50% of the island communication was damage because of Irma. Only one radio station was working most of the time during the hurricane (it stops only a couple of hours). DSL internet provider has underground network, they did not lose Internet provision in some areas of the island. One of the challenges of communication in Sint Maarten is the hilly topography that requires more transmission towers to have full coverage of the island, making very vulnerable the communication sector in the island.
- Regarding the management of tourists, the government cannot force them to leave. Management of tourist is done by the hotels themselves. The hotels are organized in an association called Sint Maarten Hospitality and Trade Association. They received the bulletins of the meteorological office and decide what actions to take. It was mention that some tourist wanted to stay on the island to have the hurricane experience. Tourists were evacuated using military and cruise ships on Friday, after Irma.
- One influential factor is the time sharing scheme that runs in most of the big hotels on the island. Most of the people under this scheme are USA citizens and they want and love routines, because of that if they have their time share during the hurricane season they do not want to make changes to their holidays plans.
- Some tourist and local that wanted to evacuate before Irma could not do it because all flights were fully booked and no extra flights were arranged for Irma preparation, even the last flight from KLM (Royal Dutch Airways) was returned with the people that came on board, the people that was supposed to take those seats could not board.
- Elderly population was manage by the withe and yellow cross. Most of them evacuated prior the arrival of Hurricane Irma to the St Peters location in the nursery home.
- Land development – lease model is a concern for the disaster management team. There is always an advice from the fire department which areas should be forbidden to build and type of materials than should be used, but is up to the politicians to decide and rule about it.

3.2.5 Fire Department

Meeting with Section Head Prevention, Education & Training of Fire Department was held to collect information on the plans and actions taken from this department and to build a time line of the event in the island. The main points of this meeting are summarized here:

- First meeting regarding Irma was held on Thursday 31 August 2017 between Fire Department and police.
- Some procedures from the Emergency Operational Management were put in action on Friday 1 September 2017:

  - They ask for military assistance. Urban search and rescue and patrolling the island after Irma
  - Damage assessment plan
  - Need for curfew – Tuesday 5 September (6 to 8 pm) until further notice. Border with the French side was closed
  - The decision to not officially open the shelters was made this day. The reasons were because they knew they do not enough resources and no security can be guaranteed
- Operational meetings were held 3 to 5 September.
- On September 3, they discussed the need to close businesses, school and commerce. It was decided not to order it yet.
- Only on Monday September 4 they were certain of the category and that Hurricane Irma would hit the island. Before that, Irma was consider category 3 and widely spread
- On Tuesday 5 September, they advised to open some shelters and gave the military the control over the shelters.
- During the meeting they organized the action plans for different scenarios. For example, what to do if communication is no possible? Who is going to be responsible of what? What to do if roads are blocked?
- The four priorities for the Fire Department during the aftermath of Irma were:
  1. Accessibility
  2. Damage assessment of critical infrastructure (hospital, fuel, communication, etc)
  3. Rescue people in need[32].
  4. Public order in place
- First marines arrived in the island on Sunday 3 September.
- On Saturday 9 September, the curfew was temporary lifted to allow people to get food and water. After Monday 11 September, the curfew was lifted for the daylight.
- Mobile communication was blocked and limited in the aftermath; hence, they relied on radio.
- Lesson learnt from Irma: Awareness of the role of everyone in the disaster management. More preparation and awareness from each one of the action groups involved in the disaster management of the island. Too many actors involved and not clear who is responsible of what in the chain of decision making. It is necessary to have a simulation of the disaster management and evaluate how it goes and take actions for the real event
- When the 911 (police) line went off, the calls were re-directed to the Fire Department line.

[32] No one called the Fire Department to ask for help to be rescued

3.2.6 Met Office

The meeting with the Met Office was meant to collect data to be used in the hydrodynamic and hurricane models of IHE Delft as well to gain insights of how hurricanes are forecasted and communicated in the island since this office is the officially responsible in the island. The main points discussed in this meeting are presented here:

- Data recording was lost at around 2 am on Wednesday 6 September
- Only two sensors of wind speed, one at each side of the airport
- Only rain gauges in the area near the airport is measure in the island
- The data collection (rainfall and wind) was re-establish on 2 October
- Hurricane models are collected from several web sites. NOOA and one Canadian and Weatheronline.uk are the most used one
- During Hurricane Irma they release bulletins every 6 hours and when the hurricane was closer bulletins were issued every 3 hours. The bulletins were posted on the meteorological web page and the official Facebook page of the Met Office.
- They send it also directly to: Airlines, Airport Management, Harbour/ Marine, ministers/S.G/ Prime Minister, Radio stations, DCOMM, hoteliers, disaster / Fire, Health Department and private individuals who asked to be included in the list.
- They kept a direct line/communication with the only radio station that was working on the island before, during and after Irma. When telephone was down, they drove to the station to continue providing information

3.2.7 Statistics Office

To gather valuable information regarding population statistics to be used in the computation of the PEARL vulnerability index, a meeting with the Statistical Department of Sint Maarten (STAT) was held during the field mission to show them the scope of this mission and to ask for the necessary information. The topics discuss during this meeting and follow up communication emails are summarized here:

- Most of the census data of Sint Maarten is online through the web page of the statistical office[33]. The available data dates back to the year 2011 census. In 2014, Civil registry ask STAT to check the population number of the census. The 2014 work was used to update the number of inhabitants of the island, the numbers of the work of 2014 were used to update the 2011 census and the number that are online already have the correction
- No census after Irma is planned to be carried out. Next census in the island will be in 2021 (every 10 years)
- At this moment STAT is performing a census on Businesses after Irma in cooperation with the chamber of commerce as well as labour – Force survey. This work is expected to be finish by October 2018

[33] http://stat.gov.sx

- After Irma the ministry of VSA did a survey of affected population. People that needed assistance needed to go to VSA ministry and report percentage of damages job status before the hurricane and salary. The questionnaire was extensive. VSA request the help of STAT to process and analyse the data that was collected but at the moment of the interview STAT has not received anything of these information to be processed.
- There is no census of evacuated people. Not of people that already left the island permanently because of Irma.
- STAT is currently working on the preparation of 5 Census tables at neighbourhood level to be used in the computation of vulnerability and risk to floods and hurricanes using the PEARL approach.

3.2.8 Tsunami Workshop

The tsunami workshop was organized for ESF 6 by the Ministry of VSA and the Association of Netherlands Municipalities (VNG), with support of IHE Delft. ESF 6 is in charge of the health sector during disasters and crises. The IHE Delft team presented a computer based scenario of a tsunami model and insights were given in the consequences and dilemmas that need to be addressed in the situation of a tsunami crisis. Step by step the participants were taken in the different phases of the scenario in order to clarify the different roles and responsibilities. The table top (Figure 3.33) focused on decision-making and communication processes and the strategic management of healthcare institutions during crisis situations and with chain partners. The information that has been gathered by testing in the simulation workshop will be further used to improve the specific material developed and strengthen the processes of disaster management preparedness.

Figure 3.33. A table top tsunami simulation workshop in Sint Maarten

3.3 Applying Risk Root Cause Analysis to understand Irma's impacts and post-Irma reconstruction pathways

3.3.1 Background to Risk Root Cause Analysis in PEARL: Aims and Application

The PEARL project included Risk Root Cause Analysis (RRCA) in the design of an integrated flood risk assessment methodology as a keystone methodology for understanding the holistic drivers of risk, and the actors and decision-making pathways associated with driving risk in the socio-economic and governance domains, interacting with physical processes and informed by the nature of risk perceptions. The structural focus on 'root causes' aimed to move beyond conventional risk and vulnerability assessments focussed on capturing contemporary vulnerabilities, capacities and post-disaster conditions to tackle the underlying factors that explain why risks accumulate. This frame is critical to support movement from short-term, partial policy solutions to measures for sustainable reductions in disaster loss and damage.

The PEARL RRCA was adapted from the IRDR FORIN (Forensic Investigation of Disasters) approach to provide a structured methodology for investigating the root causes of small-scale but high-impact disasters which predominantly manifest at the local scale (Fraser et al., 2016). The RRCA shared FORIN's intent to deepen the spatial and temporal scales of disaster analysis and integrate a systematic understanding of the links between disasters and development (IRDR, 2011; Oliver-Smith et al., 2016). By way of extension, however, the PEARL RRCA aimed not only to trace the historical root causes of disaster but also to reflect on the role of these factors in driving risks in the present and into the future. It used disaster(s) as focusing events to understand the intervention of particular drivers before, during and after an event. Through a systematic review of both FORIN and other cognate root cause analysis studies, the PEARL RRCA incorporated critical elements for understanding both the nature of risk but also highlighted the centrality of the governance context, and the role of the disasters cycle (as embedded in the governance context) in influencing risk accumulation or reduction processes (Fraser et al., 2016). By incorporating local risk and loss, the PEARL context brought a focus on the role of local actors as mediating institutions between local risk/loss and national and international actors and root causes – a long-standing gap in studies of disaster risk (ibid).

The conceptual framework for the RRCA is included in Appendix D. As shown, it is centred on dynamic physical, socio-economic, governance and risk perception processes. These four are interlinked in a non-linear fashion and in continuous exchange. Therefore the risk – as a function of hazard, exposure and vulnerability – is displayed at a single point but could be assessed at any given time step. Following the disaster, Disaster Response, Recovery, Reconstruction and Transformation processes both influence the physical, socio-economic, governance and perception factors within a spatial entity and are influenced by the historical physical, socio-economic, governance and perception context. These aspects contribute, either positively or negatively, to the accumulation and production of risk.

The application of the PEARL Risk Root Cause Analysis framework centred on case study analysis of flooding in urban coastal contexts of Europe (Genoa, Italy, and Rethymno, Greece) and the Caribbean (Sint Maarten) (see Fraser, 2016; Mavrogenis, 2016; Scolobig, 2016). The case study research used qualitative investigation to draw out narrative attributions of root causes and drivers for key focal disaster events, and explore the manifestation of these root causes and drivers into the present and possible future, across as wide as the range of stakeholders as possible involved in

different phases of the disasters cycle, from land use planning pre-disaster to emergency response post-disaster, and across different spatial and jurisdictional levels of governance. The possibility for a comparative RRCA for Sint Maarten and Saint-Martin – as adjacent municipalities on the same island experiencing the same hazards context – was flagged as a potential opportunity to develop understanding of the role of different governance regimes in influencing the mediating functions of local institutions and resulting risk / loss, as indicated by the grey literature. However, while a number of avenues for further investigation were derived from stakeholder interviews and relevant background literature, time constraints and the initial lack of engagement by stakeholders in Saint-Martin limited further conclusions.

Box 3.1. Saint-Martin/Sint Maarten: A binational island with two political systems

Saint-Martin/Sint Maarten is an island of the lesser Caribbean with one part administered by France and the other regulated by the Netherlands. In relation to their metropoles, both sides of the island have substantially different statuses. Since 2007, ***Saint-Martin*** is a French overseas collectivity (COM, a French acronym for *Collectivite d'Outre Mer*) with more autonomy than metropolitan French regions but less than Sint Maarten. Since 2010, ***Sint Maarten*** is one of the constituent countries of the Kingdom of the Netherlands with the Netherlands, Aruba and Curacao. Sint Maarten has its own government, Prime Minister, and Parliament, whereas Saint-Martin is administered by the French government and historically many public services have been based in Guadeloupe. In relation to the European Union, Saint-Martin is an Ultra-Peripheral Region (UPR), in which European directives and regulations applies, whereas Sint Maarten is part of Overseas Countries and Territories and, is not subject to European legislations. Both Sint Maarten and Saint-Martin have seen their administrative and political status change regularly and the trend is generally towards more autonomy. However, in times of disasters, the tensions regarding the nature of the relation between the metropole and the island re-emerge, for both sides, and different perspectives are made visible. In relation to Irma, this entails in particular controversies over the distribution of responsibilities regarding the reconstruction, and the form it should take, but also regarding longer term governance arrangements.

3.3.2 Application of RRCA to understand Irma's impacts and post-Irma recovery and reconstruction pathways: aims and research questions

In the context of the loss and damage caused by Hurricane Irma in Sint Maarten, and the demand for research to support policies for reconstruction on the island, the re-testing and validation of the PEARL RRCA undertaken in Sint Maarten in 2015-2016 for the new context of Irma was seen by the PEARL research team as an important component of any holistic assessment of the drivers of loss and damage (backward-looking). This was the first aim of the 2018 RRCA study.

In line with the PEARL RRCA framework's emphasis on understanding the expressions of root causes in the contemporary and future context, the RRCA also provided a framework through which to benchmark the scope of contemporary and futures-oriented plans, policies and intentions against root cause drivers, with the aim of supporting reflection on the holism and sustainability of existing efforts – whilst acknowledging the potential discontinuities as a result of Irma.

The RRCA framework incorporated Disaster Response, Recovery, Reconstruction and Transformation processes as both influencing the physical, socio-economic, governance and perception factors within a spatial entity and influenced by the historical physical, socio-economic, governance and perception context. These aspects contribute – either positively or negatively – to

the accumulation and production of risk. Through disaster response, recovery and reconstruction measures valuable opportunities arise to reduce and prepare for risk in ways that not only build back to 'normal', or the state of affairs prior to the disaster event, but 'build back better', preventing the disaster from re-occurring, or at least to the same magnitude. This is captured by the inclusion of the term Transformation, to refer to the process of re-aligning the structures underpinning the disaster to ensure a resilient and sustainable future in a given context (PEARL, 2014).

Post-Irma RRCA analysis in PEARL aimed to also examine recovery and reconstruction policies and transformation processes as embedded in the disaster risk management cycle and governance domains identified in the RRCA framework, and in particular across the governance scales identified as critical to local government risk management in the 2015 RRCA (but acknowledging the need to move from the original analysis of small-scale events to a national-scale disaster event). The aim to understand the opportunities and blockages to transformation scales led to the development of a more structured framework for thinking about actor decision-making in a co-evolving system – the over-arching conceptual model for PEARL. This aimed to reveal the drivers of contemporary decision-making pathways, and related actors, but also capture the pre and post-Irma capacities, knowledges and futures-oriented visions (imaginaries) of decision-makers. While research at this point in time cannot yet access the long-term trajectories of potentially transformative change encapsulated in the RRCA framework, understanding the visions of different actors was a key device for understanding the possible openings for structural change, albeit mediated by governance. This overall framework also provided a structured reference point for tracking change in decision-making processes, and was applied as a comparative framework in both Saint-Martin and Sint Maarten.

Commensurate these aims, the research questions were as follows:

1. What were the root cause drivers of Irma's impacts in Sint Maarten and Saint-Martin? How far did the changed hazard context of Irma alter the root cause pathways as experienced across the two governance regimes?
2. What are the root cause drivers of current decision-making plans and processes about current and future reconstruction and recovery?
3. What are the capacities, knowledges and visions of the different policy actors at different governance scales involved in reconstruction and recovery processes and how have these changed since Irma?
4. How far do current recovery and reconstruction plans, policies and initiatives address root cause drivers on both sides of the island? What are the implications for the opportunities and challenges for transformation?

New possibilities for household and community-scale work on Sint Maarten also opened up the potential for the RRCA to incorporate local perspectives, beyond the previous focus on expert opinion and the viewpoints of stakeholders across government and economic sectors.

3.3.3 Deploying RRCA research post-disaster: methods and approach

Fieldwork for the 2018 post Hurricane Irma PEARL study took place during a two-week period in March on both the Dutch and French sides of the island, a field visit to interview French officials in Paris in April and through accompanying telephone and skype interviews throughout January-April. 23 interviews were conducted in total. Researchers re-contacted stakeholders interviewed in 2015 judged to be key informants for the 2018 study based on their sectoral expertise and experience in providing credible, in-depth information, snowballing out from these initial actors to accommodate

new actors and capture a variety of perspectives, particularly across different levels of state decision-making. Capturing the perspectives of state actors was seen as particularly important given the government's role in setting regulatory frameworks for land and housing, as well as in financing the reconstruction process. As well as focussing on the over-arching root cause pathways and recovery and reconstruction trajectories, the research focussed on core sectors in order to delimit and add depth to the study. The principal sector of focus was land use and housing, given the critical role of land use planning and building regulation as a root cause driver of risk from the 2015 study (see below), and the related role of housing as the sector of highest social impact post-Irma. As critical insights and contacts emerged during fieldwork, further sectors explored were waste management, environmental protection and risk forecasting and warning, although time and the availability of stakeholders limited the depth and extent of these sectoral studies, as compared with land use and housing. A list of interviewees is provided in Appendix E.

In-depth semi-structured interviews were conducted according to an interview guide which asked interviewees to a) identify the impacts and drivers of impacts of Irma in their sector or area of expertise b) discuss the actions of their organisation in the recovery and reconstruction phase following Irma c) identify the knowledge and capacities of their organisation in the recovery and reconstruction phase d) describe the vision of their organisation with regards to 'Building Back Better' and e) identify current opportunities and challenges to realising that vision, in terms of current and future capacities and knowledges (interview guidelines are included in Appendix F).

Ethics guidelines for conducting the research previously agreed according to KCL's research ethics code were adhered to during the research, including disclosure of the purpose of the study with participants, and guaranteeing participant requests for anonymity and data confidentiality.

The short time frame for the research as well as the recovery context in Sint Maarten led to the necessity of a rapid approach to RRCA, acknowledging that it was not possible to interview all relevant stakeholders but also that some stakeholders were experiencing research fatigue, or were overwhelmed by the pressing priorities of responding to the need for reconstruction, especially prior to the oncoming hurricane season. The political sensitivity of negotiations over the financing, governance and prioritisation of recovery and reconstruction efforts also impeded access to interviews as well as to information about key reconstruction processes. In this distinct context, researchers needed to be highly sensitive and flexible to accommodate the needs of stakeholders and related confidentiality issues, but also highly reflexive about the ability to draw conclusions from a limited data set, which reflected both partial viewpoints as well as a particular moment in a fast-moving policy environment. To supplement interview perspectives, analysis of national and local media and web-based articles was undertaken alongside the interviews across the time period from Irma to end April 2018, using systematic searches conducted through the Lexus Nexus database (search terms: Irma & Saint Martin; Irma & Sint Maarten) as well as searches of local newspapers not reported in this database.

3.3.4 The historic trajectories of risk causation in Sint Maarten and Saint-Martin and their manifestation in Irma's impacts

Interviews undertaken in 2018 affirmed the core tenets of the RRCA conducted and analysed in 2015-2016, in particular bringing to the fore the interaction of root cause drivers in the physical, socio-economic and governance domains. A critical root cause pathway remained the lack of land use planning despite dense development, manifest in the high exposure of people and buildings to

the impacts of winds from Hurricane Irma. The physical vulnerability of housing structures reflected the lack of updated, monitored and enforced building code (with the current code dating from 1935 and applied from Curacao, a Dutch Caribbean island which does not suffer from hurricane impacts) but also the failure of improved building construction practices post 1995 Hurricane Luis (revealed through the earlier RRCA) to withstand weakening from repeated storm impacts whilst construction maintenance faltered in the intervening period – a phenomenon revealed through household-level interviews conducted in 2018 (Section 3.1). Increased emphasis was also given in the 2018 interviews – triangulated through the household survey of evacuation practices - to the practice of leasing land for rent, creating a situation of regulatory uncertainty over housing improvements and maintenance. Whilst the emergency management systems and procedures embedded since Hurricane Luis were identified in the 2016 RRCA report as a possible source of resilience on the island, and the system of forecasting and warning was verified across stakeholders as having been adequate and timely during Irma, the politicisation of emergency management during Irma – with the Prime Minister reverting to decision-making through the Council of Ministers rather than the Disaster Risk Management Coordinator and appropriate task forces – reversed this situation (although the subsequent impacts were unverified). The intensity of the storm also challenged key infrastructures for disaster risk management, in particular the fact that storm shelters could not withstand a Category 5 hurricane (which led to the late government opening of shelters) and the loss of communications after the storm, as well as physical infrastructures for key services, such as the Sint Maarten Met Office.

Stakeholder-identified triggers and drivers of Irma's impacts from the 2018 study connected to the historical analysis of root causes as identified by the 2016 RRCA. These historic root cause drivers – such as small island status, economic development and colonial marginalisation influencing the lack of capacities and regulations – and their manifestation in high population density, unplanned urbanisation and increased risk exposure are shown in Figure 3.34. The figure shows through colour coding the historic break points identified in the earlier RRCA related to 1995 Hurricane Luis and the 2010 decentralisation of power to the Sint Maarten government. Although particular drivers – such as the historic lack of Dutch-French cooperation and the impacts of the 2010 reform – were not explicitly identified in the 2018 interviews as directly contributing to Irma's impacts, such drivers are nevertheless shown by the RRCA to have indirectly contributed to a situation of limited resources on the island.

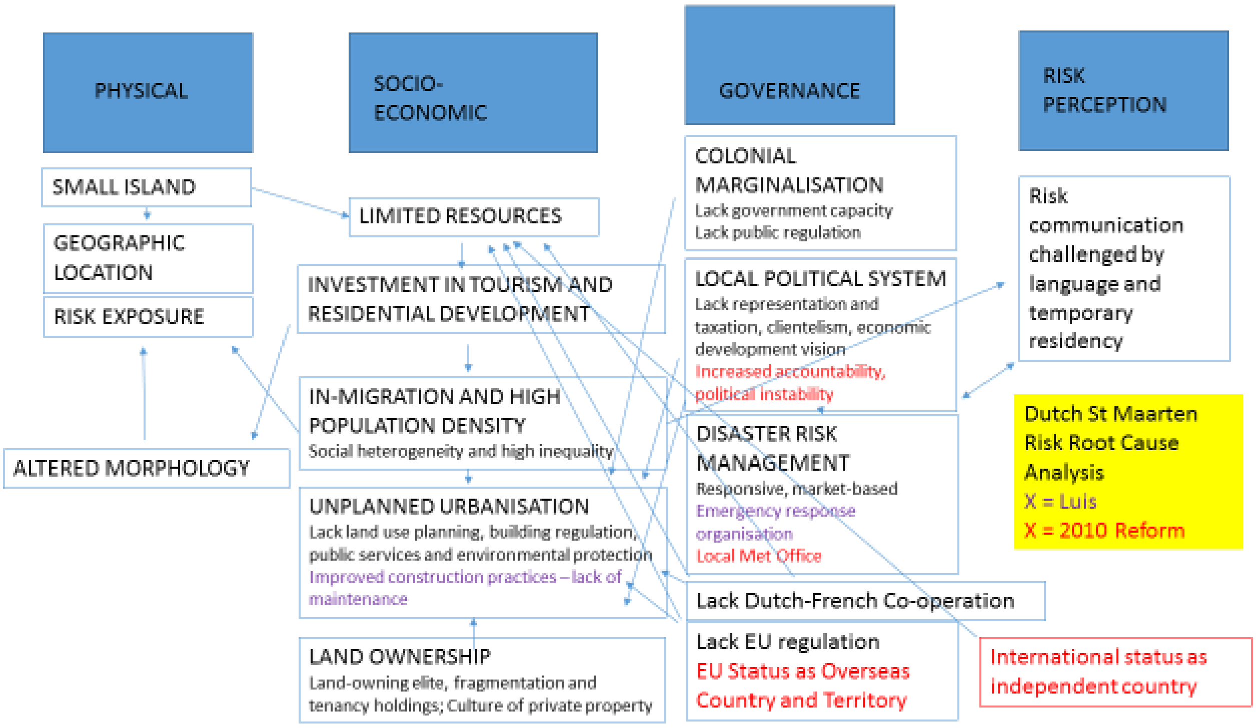


Figure 3.34. Risk Root Cause Analysis, Sint Maarten. Source: Fraser (2016), interviews 2018

Root cause analysis for Saint-Martin – begun in 2015-2016 and extended through the 2018 study – confirmed similar historic interactions between the physical, socio-economic and governance pathways arising from Saint-Martin's small island status in an exposed geographic location, investments in tourism and residential development leading to in-migration and unplanned urbanisation and colonial marginalisation reinforcing weak local government capacities and the neglect of regulation. Unplanned urbanisation and the exposure and physical vulnerability of residential housing emerged – as for Sint Maarten – as the core manifestation of such structural causes, and the principle driver of loss and damage from Irma. Core differences in the socio-economic pathway – the later onset of deregulation and investment on the French side (from the 1980s), the different model of tourism development on the French side (high-end rather than mass tourism driven by cruise arrivals on the Dutch side) and lesser population density, as well as some differences in governance regime referred to in Box 3.1 (such as the continuation of meteorological services from Guadeloupe) were not reported to have resulted in direct impacts. Figure 3.35 illustrates the Risk Root Cause pathway for Saint-Martin, illustrating the impact of the devolution of power to the local collectivite undertaken in 2007. This can be seen to have compounded the weakness of local capacities, and the lack of regulation. In a report assessing the actions of the French Government for the period 2007-2017 in Saint-Martin, the French Audit Court emphasized sub-administration as a key issue.

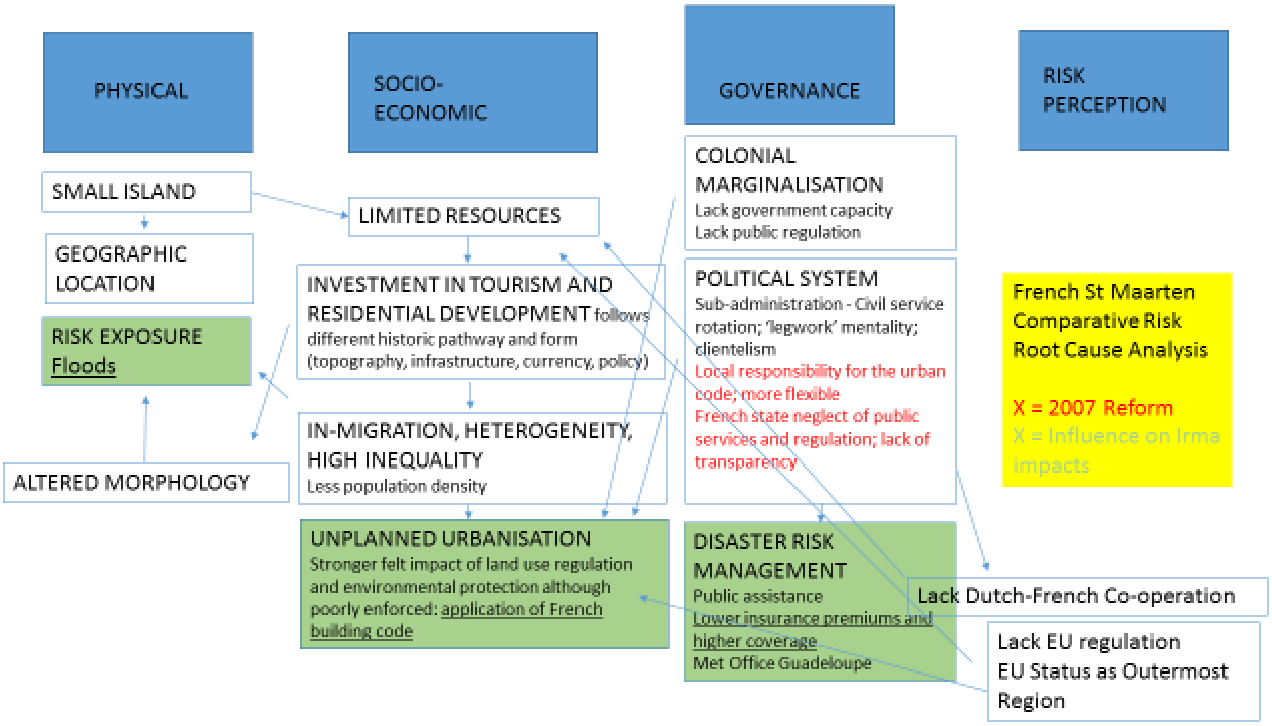


Figure 3.35. Risk Root Cause Analysis, Saint-Martin. Source: Duvat (2008); interviews 2015 and 2018

The damages caused by Irma nevertheless fell disproportionately on Saint-Martin rather than Dutch Sint Maarten, and the recovery into reconstruction phase has been experienced more slowly. The core root cause pathways leading to these outcomes is highlighted in green in the Figure 3.35, and the role of insurance mechanisms discussed in more detail below. In terms of the damage and loss from Irma, the difference across the two sides of the island is explained a) through the physical root cause pathway and b) through the socio-economic and governance pathways as they relate to building regulation.

Island topography and the hurricane's pathway influenced the immediate loss and damage to man-made structures. Irma also had a stronger reported impact on the natural landscape including beaches, causing coastal erosion, and damaging mangroves, although the lack of published assessment for the Dutch side restricts firm conclusions[34]. While both sides were affected by high speed winds, damages due to marine submersion and flooding were more important on the French side, as related to the particular trajectory of Irma and also to the topography of the island. This also links to pre-existing unregulated urbanization, related to both governance and socio-economic root causes, which had already affected the ability of ecosystems to fulfil their protective functions and exposed areas (e.g. Sandy Ground, Orient Bay, Grand Case, Oyster Pond, Simpson Bay, and Philipsburg) got highly damaged on both sides. Salt ponds did not have capacity to retain water causing extensive flooding.

A finding of the 2015-2016 RRCA was the stronger felt impact of hazard mapping and building regulation in Saint-Martin compared to Sint Maarten, despite ongoing deficits of enforcement – in part due to the obligation to comply with EU directives, as well a different system of building control and contractor liability. Indeed, the mode of building control (*bureau de controle*) was shown to be

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[34] See http://reservenaturelle-saint-martin.com/journaux-pdf/2018/journal31.pdf

particularly salient in reducing loss and damage on Saint-Martin in comparison with Sint Maarten post Luis (Gibbs, 2003). Under Irma, however, interviews revealed the paradox that the stronger application of a national building code from France which was too light in specification for Irma's winds contributed to greater damages. In Sint Maarten, better construction practices despite the absence of an appropriate code, to some extent minimised the relative damage to structures.

The lesser impact of Luis on the French side (Gibbs, 2003) also had the paradoxical effect that the French experienced more damages to their infrastructure, e.g. electricity networks, under Irma as core infrastructure was not buried underground, unlike in Sint Maarten. This has set up a dynamic in the current reconstruction phase for large French companies to develop large infrastructure projects in Saint-Martin (particularly in electricity and in water, where major damages were sustained due to the effect of flooding).

The following sections extend the RRCA to understand the recovery and reconstruction pathways on both Sint Maarten and Saint-Martin, and the possible opportunities and blockages to transformation post-Irma.

3.3.5 Visions for Building Back Better (BBB) and recovery pathways

Building on the PEARL RRCA framework, the Building Back Better concept introduced in the context of disaster risk reduction represents an opportunity to reconstruct differently and to transform. BBB is a concept which suggests that reconstruction is not just about restoring what has been damaged, or building the same. At the global level, the Sendai Framework on Disaster Risk Reduction (2015-2030) suggests that BBB is about increasing community resilience via the restoration of physical infrastructure but also societal systems. Similarly, the Sustainable Development Goals (SDGs) provide a framework for connecting risk prevention with development processes. From this perspective, achieving transformation means addressing the root causes of vulnerability (section 3.1). An overarching question here is therefore whether Irma is encouraging shifts and structural changes in the development pathways of the island. While it is too early to know about long term changes, different visions (see Table 3.4) of what BBB might be are already manifest in on-going reconstruction processes. We compare these here and reflect on whether they address the risk root cause pathways identified in the previous section, in particular in the socio-economic and governance domains.

In the wake of Irma, different visions regarding the form that BBB should take have been promoted, either explicitly or implicitly. While many nuances exist between individual actors, we outline here the visions held by the main institutional actors: the Netherlands, the government of Sint Maarten, the French State and the Collectivite of Saint-Martin. Table 3.4 is based on materials emerging from secondary sources including official reports and newspaper shortcuts as well as interviews. Irma is creating a new dynamic among institutional actors contributing to a renewed dialogue between French and Dutch States in a number of areas including border control, immigration, and water management. But the logics underpinning reconstruction processes on both sides are different due to the different political systems in place and to the architecture of funding arrangements adopted to support reconstruction efforts. In both cases, these arrangements also delineate how ideas for BBB can circulate. In Sint Maarten, the World Bank is acting as an intermediary between the Netherlands and the government of Sint Maarten with funding given until 2021 and to be used by 2025. The particular status of Sint Maarten, being an autonomous country, also makes it easier for the international development community to develop actions on the Dutch side. These factors explain

why Sint Maarten is attracting significantly more international attention and expertise than Saint-Martin, therefore allowing for circulation of new ideas and standards regarding how to BBB.

In Saint-Martin, the reconstruction is framed by a protocol between the French State and the Collectivite and a range of pluri-annual investments plans (2018-2023) targeting a number of areas (e.g. public infrastructure, health). There is less international attention and a French Foundation (*Fondation de France*) plays a key role in supporting projects in Saint-Martin, mobilizing predominantly locally based and metropolitan actors, similarly a number of French companies are involved in large-scale infrastructural projects (e.g. EDF). These funding arrangements reflect the different political situations of Saint-Martin and Sint Maarten and legitimate and/or reinforce different actors. On French side, the State is currently reinforcing its capacity and authority while promoting Saint-Martin as an exemplary territory for sustainable development in the context of climate change. The plan presented by Philippe Gustin (head of the inter-ministerial delegation in charge of the reconstruction in Saint-Martin and Saint Barthelemy[35]) is organized around the following ideas:

- Reinforcing the presence of French authorities on the island to ensure a better enforcement of legislations and regulations;
- Ensure local safety by supporting local businesses during the transition and make sure they benefit from the reconstruction;
- Engage a reflexion towards a viable model for tourism in the island;
- Improve relations between French and Dutch parts of the island by reinforcing bilateral cooperation and a dialog form (Q4) which gathers French and Dutch governments, Saint-Martin collectivity and Sint Maarten government;
- Initiate a responsible urban planning policy and carry out a diagnostic of the territory, update local urban plans and fight against illegal constructions

In Sint Maarten, the Dutch government is also involved in the reconstruction but its influence is different. In particular, one of the conditions presented by the Netherlands to fund the reconstruction was the establishment of an 'integrity chamber' in order to avoid corruption (leading to the resignation of Sint Maarten Prime Minister at the time). According to the 'good governance' discourse, the objective is to reinforce the capacity of the government of Sint Maarten so the focus is not immediately on climate change nor sustainable development. However, sustainable standards may come in via the World Bank as the organization has already identified waste management as a priority in Sint Maarten. The historic 'dump' site in Philipsburg is often generating fires and toxic fumes contaminating neighbouring areas posing a threat to health and the environment. The amount of waste generated by Irma has led to the creation of a second pile of waste therefore reinforcing a pre-existing issue. In contrast, in Saint-Martin the priority is water infrastructure (leading from the impacts of Irma on the French side): the entire distribution network is to be reconstructed. Cooperation projects between the two sides of the island also aim at addressing water management and treatment issues (e.g. Belle Plaine, Simpson Bay). In terms of regulatory context and access to funding it is also worth underlining here the influence of the European Union: Saint-Martin (Ultra-Peripheral Region) can access EU funding more easily than Sint Maarten (Overseas Countries and Territories).

As summarized in Table 3.4, visions promoted by the French State and the Netherlands do not overlap neatly with the ones held by local actors. They create concern regarding the pace of the

[35] In May 2018, Philippe Gustin has been nominated *Prefet de Guadeloupe*.

reconstruction: on one hand because of the ‘experimental’ dimension of the French vision, on the other hand because World Bank processes place much emphasis on assessment and reporting efforts. For example, both the French Collectivite and the government of Sint Maarten emphasize the need to build back quicker and to respect local agency. However, while a plan has been presented by the President of the Collectivite, no official ‘vision document’ has been presented publicly, and recently, by the government of Sint Maarten. An earlier recovery plan (NRP) outlined some elements emphasizing the need for a quick economic recovery. While the focus on climate change and sustainable planning promoted by French State seems to address the root causes identified previously regarding urbanization, one question regards whether these efforts will be sustained over time. The need to reinforce the presence of the French State locally, which has been reiterated recently in a report published by the French Audit Court (December 2017), has been acknowledged. In Sint Maarten, ‘good governance’ seem to address some of the root causes of weak governance but one question regards local capacity: diverse international actors (e.g. UNDP, UNICEF) are currently operating in Sint Maarten, bringing in expertise and insights from different regions, but in order to benefit Sint Maarten over the longer term knowledge exchange and capacity building needs to take place. To date, it is also unclear to date whether some policy changes with regards to housing and land use will take place. We develop this sectoral analysis further in the section below.

Table 3.4. Institutional visions for Building Back Better

	Actors & 'Allies'	**Description**	**Key documents and Examples**
Good Governance	- Dutch Government - VNG - World Bank	Focus on transparency and accountability, anti-corruption discourse, building on alliances with international actors such as the World Bank to have a 'neutral' intermediary. Willingness to support government capacity (e.g. reinforcement of police staff)	'Integrity Chamber' National Recovery and Resilience Plan
Affirming local autonomy & Building Back Quicker	- Sint Maarten government	Focus on re-starting tourism quickly to resume economic activities and investments which are key for recovery. Critical approach to conditionality of Dutch funding and willingness to maintain local agency	NRP
An exemplary reconstruction in the context of climate change	- French national authorities - Some local actors	Irma as providing an opportunity to shift the development trajectory of the island towards a more sustainable pathway including for tourism. Willingness to re-inforce the capacity of public services locally with regards to monitoring and enforcement of existing EU and national regulations.	Rapport Gustin
Reinforcing local autonomy and capacity	COM	This vision resonates to some extent with the previous one as there is also a focus on strengthening the resilience of the island, but also willingness to maintain a degree of autonomy which leads to divergent interpretations in some areas (e.g. on the question of expropriation in risk areas) Critical approach to the experimental nature of the 'exemplary reconstruction' – need to build back quicker	Plan Phoenix

3.3.6 Pathways for recovery-reconstruction in land use and housing policy

In this section we compare the regulatory landscape regarding land use and housing policy in Saint-Martin and Sint Maarten before and after Irma in order to illustrate how the visions described above materialize in an area which has been identified as one of the main root causes of vulnerability. We outline challenges and opportunities.

Table 3.5 and Table 3.6 summarize existing policy relevant to land use and housing in each side and describe how the actors, capacities, knowledges and visions have changed after Irma. These tables outline key elements useful for our analysis but are not exhaustive. One important difference

is that in Saint-Martin policy and regulations on land use, and housing, comes from a broader range of actors: the European Union, the State, the Collectivite. The fact that the State is competent for environmental matters also isolates locally based environmental actors, with a national mandate, (e.g. Reserve Naturelle Nationale) from local politics. In contrast, in Sint Maarten the government is autonomous and responsible for legislation in all these areas. These different political systems are also associated with different social policy, for example while social housing exist in Sint Maarten financial support is limited and the French system is more encompassing.

Sint Maarten

As stressed by the RRCA, urbanization has been largely unregulated in Sint Maarten and there is no formally adopted land use plan to date. Environmental policy is limited to some specific areas (e.g. hillside policy, beach policy) and environmental risks are largely overlooked. For example, flood maps exist but are not integrated into planning documents. With regards to housing, an outdated building code (1935) has been imported from Curacao[36], a region where hurricanes are less frequent. It is unclear whether Irma, and other weather events, are triggering policy change regarding land use and housing. To guide housing repairs, some guidelines have been drafted by an engineering company, formalized with Red Cross and the infrastructure Ministry (VROMI), and circulated to NGOs conducting repair work. However, most people have been doing self-repairs and the extent to which these guidelines have been taken up remains unclear. In contrast to Saint-Martin, where guidelines are being drafted by the state with some local actors, these discussions have been initiated outside of government context in Sint Maarten. The World Bank may put forward new standards and frameworks (e.g. Sustainable Development Goals).

[36] However discussions regarding how to update the code have taken place and expertise from a private company which has provided advice for building codes in Saba and Eustachia is being considered.

Table 3.5. Overview of regulatory landscape for land use and housing in Sint Maarten

	Pre-Irma	Post-Irma
Policy/regulations	1935 Building Code 1990s Beach and Hillside policy; Dutch subordinated land use plan not passed Compulsory insurance for mortgages	Guidelines for issued rebuilding permits issued by VROMI
Actors	VROMI Sint Maarten Housing Development Foundation (SMHDF) Nature Foundation	Now also includes a range of NGOs doing housing work: White and Yellow Cross, Red Cross, Samaritan Purse, Salvation Army and intergovernmental actor: UNDP. World Bank as arbiter of the Trust fund Mechanism.
Capacities	Government monitoring and enforcement capacities weak	Attempts to harmonize work to avoid duplication in the context of a 'housing and repair working group' coordinated by VROMI. Government capacities to coordinate weak.
Knowledges	UNESCO-IHE hazard and risk maps available in GIS (not widely used)	Independent Consulting firm (ICE) / Red Cross issue repair guidelines - Uneven take up
Visions	Political vision of tourist development: 'Build and they will come'	Technical vision (government, e.g., VROMI): 'Build Back Stronger' (referring to need to reinforce physical infrastructure) NGOs: Build Back Safer – but avoid operating amidst local politics and regulatory uncertainty; tensions with local agency SMHDF: Long term idea of mixed use housing development planning from the Netherlands

Saint-Martin

The distribution of roles between the French State and the Collectivite is key to changes in the sector in the post-Irma environment. While the French State is responsible for environmental regulations, the Collectivite is autonomous for urban policy and has its own urban Code (since 2015) which is more permissive than the national one. Different kinds of regulatory documents exist: a Natural Risks Prevention Plan (2011) and a land use plan which needs to be updated. Although a zoning plan exist there is no comprehensive planning strategy to date indicating future orientations. Historically, there has been a lack of enforcement of existing regulations with shared responsibilities between the State and the Collectivite. Numerous buildings have been constructed without building permits (about

60%) and constructions in vulnerable areas have taken place. This has resulted in the erosion of natural ecosystems which should otherwise fulfil protective functions: beaches, mangroves, ponds. Beyond hurricanes, this also increases the vulnerability of Saint-Martin to other weathers events such as floods. In the wake of Irma several changes have happened, driven by both the State and the Collectivite:

- Realization of a diagnostic of the damages caused by the submersion wave and the winds and a new hazard map has been provided by the CEREMA. This document indicates new risk areas and the Collectivite has been asked to take it into consideration in the context of the reconstruction.
- The Collectivite has set up a task force to monitor places where reconstruction work is taking place. This involves in particular the use of a GIS system that allows compiling data on the type of work taking place, and makes it easier to identify infringements and take judiciary actions.
- Renewed dynamic with regards to environmental and urban police (COPOLENU) with cooperation between local and national actors.
- With regards to housing, in order to facilitate reconstruction processes, the Collectivite has adopted a specific procedure (*Declaration Prealable travaux Irma*) which differentiates between repairs work and reconstruction, and between private and commercial buildings. This aims at facilitating processes for those undertaking repairs. For complete reconstruction there is a juridical uncertainty for those situated in a risk area as there is a 2 years moratorium – which means that from a strictly legal standpoint they are at risk of expropriation. This is a key area of debate between the French State and the Collectivite. For new constructions, the Collectivite has also adopted new regulations stipulating that these should include a safe room (and advised those undertaking repairs to do the same).
- The inter-ministerial delegation for the reconstruction is coordinating a range of activities aimed at providing technical advice to the Collectivite including guidelines for house repairs. One difficulty is that these have to be compliant with EU standards but this proves difficult to achieve in Saint-Martin as there is no appropriate supply chain for such materials.

Table 3.6. Overview of regulatory landscape for land use and housing in Saint-Martin

	Pre-Irma	**Post-Irma**
Policy/ regulations	Collectivite: - Land use plan (POS) - Urban Code (since 2015) National - National (environmental protection) - National Risk Prevention Plan (2011) European: - Flood Directive (2007) - Insurance policy: Compulsory to have insurance for those renting houses or living in co-owned or shared property - not compulsory for home owners	Special simplified process (DPI) to guide repairs and reconstruction Modification of Urban Code to include 'safe room' in new constructions (March 2018) On-going discussions to have an updated land use document (PLU) Hazard map with new risk zone to be incorporated in National Risk Prevention Plan (2019) Discussion around a climate and energy territorial plan (compulsory in France) Insurance policy: increased coverage and more relied upon
Actors	Collectivite: - Prefecture - Nature Reserve of Saint-Martin (RNN) - Coastal Conservatory	Collectivite: - New task force in the urban department to monitor reconstruction and repairs work - Collaboration between French State, Collectivitie, Border Police and other actors in the COPOLENU (urban and environmental police) NGOs: - *Fondation de France* supporting housing projects with *Batisseur de France*
Capacities	Weak monitoring	Capacities have increased for public actors, for example the new urban task force has been staffed with 6 people (see above), and NGOs are also bringing in new resources, human and technical. The main question regards whether this increased capacity will be sustained over the long term.
Knowledges	Hazard maps	Use of GIS system and smartphone app to guide approval of repairs and reconstruction Hazard mapping by CEREMA (Risk institute based in France) Interministerial delegation for the reconstruction of the Saint-Martin and Saint Barthelemy: providing technical advice on reconstruction guidelines in collaboration with local actors; also coordinating diagnostic to assess damaged infrastructure including invisible damages
Visions		Differences over expropriation from new risk zones between national and local actors

3.4 Local Community Based Organisations (CBOs) and first responders' experience of the response after Hurricane Irma in Sint Maarten

3.4.1 Project Rationale

This strand of the research is focusing on local humanitarian actors in Sint Maarten e.g. NGOs, community associations, and church and self-help groups. It is important to consider this constituent when looking at Sint Maarten's preparedness capacity and ability to respond to a Hurricane Irma. As first responders, local community groups and CBOs 'have a deep understanding of the context. They have the legitimacy to act and they work with communities before, during and after disaster.' (Oxfam Novib, 2016). First responders to a humanitarian emergency will be in situ before any international – and probably any state – aid is mobilised.

There is also an opportunity here to corroborate and compare CBO perspective with other stakeholders targeted in this report, i.e.,

i) The household survey, which focuses on collecting information on people's awareness and perception of hurricanes in general and Irma in particular – and on warnings and evacuation behaviours

ii) Semi-structured interviews and stakeholder meetings with officials to gain a broad view of the impact of Hurricane Irma on the island

iii) The Risk Root Cause Analysis (RRCA) that assessed the drivers of loss and damage by Hurricane Irma – and recovery and reconstruction policies and transformation processes from institutional actors.

Reflection on this is provided later in the text.

The primary focus of this strand, therefore, will be to understand their needs and priorities as first responders to humanitarian emergency. This will not only help highlight beneficiaries' requirements post-Hurricane Irma; but detail the barriers and the enabling factors required for local responders to meet survivors' needs.

The project has adopted key elements of an associated research programme – Linking Preparedness, Response and Resilience (LPRR)[37]. This was a three-year project, ending April 2018, and was part of the Disasters and Emergency Preparedness Programme, funded by DFID[38]. The overall goal of LPRR was to see how humanitarian response can be strengthened to enable (and not undermine) long term community resilience building. As the LPRR focused on case studies in low-income countries in Latin America, Asia and sub-Saharan Africa analysis of Sint Maarten as a small Caribbean island, with middle-income country status will be a valuable comparator. Outputs from this strand of work will also sit within the LPRR's larger body of evidence.

3.4.2 Research Methodology

The methodology is borne out of the aforementioned LPRR project process, i.e., to decipher the needs and priorities of survivors and first responders before, during and after humanitarian disaster.

[37] https://disasterpreparedness.ngo/project/linking-preparedness-resilience-response/
[38] project information and outputs can be found here https://bit.ly/2Hv9VrP

327 responders and first survivors from seven different country contexts were interviewed – a mixture of post-disaster and protracted crisis settings – and their needs and priorities translated into six key areas or principles, which were seen as critical to community resilience (with well-being at the centre). The LPRR community resilience principles are:

1. Allow and enable the community to co-run the response
2. Where feasible, coordinate interventions and work with the government
3. Support community cohesion and establish effective two-way communication between crises survivors and implementing organizations
4. Address underlying causes of vulnerability: protect and prepare
5. Recognize psycho social support
6. Livelihoods and savings

This "bottom-up" methodology – progressing from individual elements to a whole – was suited to the Sint Maarten target audience, i.e., survivors and community first responders from Hurricane Irma in September 2017. The principles were unpacked and presented at a workshop for local humanitarian actors (see Appendix G) in April 2018 in Sint Maarten and tested out to see if they are useful, appropriate and can be practically implemented. There was no set methodological guide but rather the focus for participants was an open discussion on rebuilding principles post-Hurricane Irma. The focus for the research was an analytical one:

- To ascertain and examine local humanitarian actors priorities and needs (rebuilding principles) to see where the gaps are in the response
- To detail how prioritised rebuilding principles could be practically implemented, allowing for barriers to be identified and enabling mechanisms to emerge.

The workshop participants were firstly identified via a Red Cross registration list for local CBOs. These were then supplemented through contacts via a local organisation and desk-based research. We cannot claim that the list is exhaustive or representative. However, over 40 local organisations were contacted and the lengthy process to identify relevant organisations – no overarching organisations/umbrellas organisations emerged – is perhaps indicative of the disparate nature of civil society in Sint Maarten. This was borne out in the workshop itself where a lot of the organisations in the small island state did not know each other – even when working with the same client group; and where it became quickly evident it was a rare opportunity for local organisations to engage. See Appendix G for more information.

3.4.3 Local responders rebuilding principles

Four clear priority areas emerged from the workshop, which were seen as central to community resilience in Sint Maarten. The first two were emphasised by the majority as the most critical though there was comment that "without coordination you have nothing."

1. Vulnerability and social protection
2. Livelihoods support
3. Coordination (and communication) for the response
4. Psychosocial support/trauma

These four directly correlate to the principles that emerged from the LPRR project. The one area that was not directly referenced was "Allow and enable the community to co-run the response." Perhaps the small size of Sint Maarten – where the ruling administration is in the immediate vicinity, and for some part of the community – gives a 'direct link' to government and rise to the belief that it is 'accountable' and needs to fulfil its obligations in terms of the response. There is, however, an example of a community in the district of St. Peters taking the initiative in hurricane preparedness in the face of a non-functioning community council – they meet regularly; formulate preparedness plans; and are reaching out and sharing information with other communities. This desire for 'agency' is shared across all the case studies, including Sint Maarten.

The following tables (Table 3.7, Table 3.8, Table 3.9, and Table 3.10) detail the perspective of the CBOs who attended the workshop, plus the additional interviewee, see Appendix G. At the workshop we focused on highlighting, as CBOs, the needs and priorities for the response (Gaps); the challenges in effecting a response (Barriers); and, where possible, where policy could respond (Policy implications). The tables are arranged as per aforementioned priority area:

Table 3.7. Vulnerability and social protection

Gaps	**Barriers**	**Policy implications**
Elderly population/ poorer communities (migrants) struggling for basic needs i.e. food and reconstruction of dwellings.	- Pension not enough to cover both food and reconstruction costs post-Hurricane - Support from the Sint Maarten Government not timely/ adequate for roofing repairs - CBOs physical infrastructure damaged by the Hurricane. Need to rebuild – and secure properties – in order to re-start services for clients.	- More support for CBOs to provide foodstuffs and basic needs - Better coordination with International NGOs (INGOs) to ensure vulnerable populations prioritised in aid disbursement/ housing reconstruction - Emergency increase of pension in post-Hurricane environment.
Migrant communities live in sub-standard (wooden) houses i.e. for extreme weather events	- Support from Sint Maarten Government non-existent for roofing repairs - Only three post-disaster shelters on Sint Maarten	- Better coordination with INGOs to ensure vulnerable populations prioritised in aid disbursement/ housing reconstruction - Prioritise the building of post-disaster shelters.
Vulnerable groups struggle to access aid disbursement points. Some saw no aid for over two weeks post-Hurricane	- Lack of public transport ensures elderly/poorer sections of community have difficulty getting to aid points.	- Prioritise vulnerable sections of community in aid disbursement - Look at affordable public transport links.
Undocumented migrants won't speak out/ register for aid for fear of being deported.	- Trust in the government is low - Mistrust of aid registers – some INGOs ask very personal questions.	- Improve outreach/engagement with migrant communities, vis-à-vis government supporting CBOs and first responders.
Lack of knowledge of who/where most vulnerable are	- Language: 120 nationalities registered in Sint Maarten	- Improve outreach/engagement with migrant communities, vis-à-vis government supporting CBOs and first responders. Rather than

	- Ethnic groups, particularly Chinese and Indian communities, find it culturally challenging to ask for help.	government placing all emphasis on (largely dormant) community councils to do this, CBOs are well-placed (and active bodies) to perform this function.

Table 3.8. Livelihoods support

Gaps	**Barriers**	**Policy implications**
Women vulnerable to the closure of hotels post-Irma (worked as domestics etc.). A lot of women-headed households on Sint Maarten	- Focus post-Hurricane is on reconstruction, traditionally male roles in construction - Lack of skills to do other roles.	- Support local organisations who have been training women in new skills (e.g. I.T.) - Support and expand training given by INGOs to women in the construction industry
Unemployment across Sint Maarten – hotel industry/tourism has been particularly hit	- No social welfare safety net - Only jobs in construction available	- Local unions are a critical actor to advocate for workers' rights in the fluid post-Hurricane working environment. Support local unions to: i) Reach agreements with corporates who run hotels to employ workers in relevant 'roles' (e.g. maintenance; landscaping etc.) in their re-construction ii) Make agreements with companies to allow undocumented workers (who qualify via signing work contracts) and who left the island after Irma to able return back to work when possible.
Long term job security	- Six month contracts standard.	- Work with local unions to change current contracts practice.
Workers rights. Poor work culture – sexual harassment and bullying widespread.	- Contracts outsourced to third parties: impacts on workers' rights (no holiday or sick leave). - All major employers are off-island – no connection with workforce - Labour department not enforcing legislation - Workers not aware of their rights.	- Work with local unions to change current contracts practice and strengthen awareness of workers' rights - -Strengthen capacity of Labour department.

Table 3.9. Coordination (and communication) for the response

Gaps	Barriers	Policy implications
Aid not reaching survivors: i) No transparency: no formal information on aid disbursement but via 'rumour' ii) Communities unclear why others qualify but not themselves → community cohesion seen as not as strong compared to post-Hurricane Luis in 1995	- No effective coordination or clear communication from the government: i) The Hurricane Preparedness task group seen as ineffective ii) Survivors are on multiple lists which causes frustration and in some cases are not acted upon.	- Weekly coordination meetings between government and INGOs to manage 'lists' needs to be more effective - More capacity support needed for Sint Maarten Government to manage the crisis
First responders (CBOs) unclear how to support response: poor information-sharing culture	- No coordination/support from government: i) National disaster plans not shared ii) No information from official government/INGO group which meets weekly iii) Government information not coordinated – 'residing' in different departments.	- Post-Hurricane Luis in 1995 there were regular meetings between government and CBOs as a forum to share information and coordinate the response. Re-instate these regular meetings → *also helps strengthen and coordinate civil society as a sector* - Establish a central government department for the gathering and disbursement of data.
Poor levels of engagement between CBOs and the government	- Unstable Sint Maarten government makes it difficult for CBOs to engage with it - Government seen as very bureaucratic - No culture of 'partnership' in government: "if we worked with government we would be dictated to, we would have to work to their rules," local CBO - Civil society not coordinated or organised.	- Support CBOs to build robust networks, and offer training opportunities, so can be more effective coordinated body to engage with government - Strengthen government capacity.
Poor local governance mechanisms to facilitate the response (and to serve as a bridge between CBOs and government)	- Majority of local community councils seen as dormant and non-functioning.	- Engage local communities on the re-establishing of community councils → tap into initiatives (re. aforementioned St Peters district example) where there is strong enthusiasm to build local resilience - Establish funding pool where pop-up initiatives, such as in St.Peters, can bid for funds to support disaster preparedness. *See recommendations section below*

Table 3.10. Psycho-social support

Gaps	Barriers	Policy implications
Looting had severe effect on wellbeing: "it was worse than the hurricane. It was more scary," local CBO. Social fabric damaged.	- There was no security for two/three days post-Hurricane	- Better security planning and provision for post-disaster environment.
Large rise in domestic violence post-Hurricane	- Unemployment post-Hurricane major contributory factor	- Support populace to find new work opportunities - More support for victims of violence.
Hard to ascertain who is need of support	- Cultural sensitivities to admitting to mental health issues, across both migrant (Indian/Chinese) and Caribbean communities	- Support/involve CBOs outreach in identifying those in need of mental health support.

3.4.4 Comparison with RRCA, stakeholder meetings and household survey

The RRCA and stakeholder meetings with officials and the household survey corroborate and contrast a number of areas in line with the detailed first responders' rebuilding principles. These include, from the RRCA analysis, poor government capacity to coordinate the response (Table 3.5), which is corroborated in meetings with government officials – there was admission that there were too many actors, with no clear roles or responsibilities, involved. This ineffective coordination was highlighted by CBOs as the principle barrier to effecting a comprehensive post-Irma process. As an example the RRCA details government efforts to coordinate housing repairs with their international partners (Table 3.5). However, CBOs have relayed that this has to date proved ineffective as survivors are on multiple lists, which in some cases are not acted upon.

It was also evident from the workshop that CBOs see the Government of Sint Maarten as the principle mechanism to protect from and respond to Hurricane Irma. "We need a government with vision and planning;" "Government needs to take responsibility." This is echoed in the household survey where most respondents consider government to be the principle actor to 'take actions to prevent losses during a hurricane'; and where 'more than 60% of the interviewees responded that the Government should take the blame' for the destruction in general and not planning and preparing for the hurricane. Such perspectives align with government thinking, where there was recognition that the formal action groups involved in the disaster response need to be better prepared and have a clear understanding of their task.

There is also alignment between CBOs and government on the need to strengthen shelter provision. For CBOs this translated into increasing the number of shelters as a matter of urgency. Government have evidently been looking closely at this issue and now have plans to build eight new multifunctional buildings, which can function as shelters. However, participants in the household survey evidently did not see the shelters as a viable disaster mechanism during, immediately post-Irma, or further into the future. Reasons given for not evacuating to them included that they were 'not strong enough' and they wanted to protect their homes from looting. Interestingly none of these

concerns – or reticence to use the shelters – was highlighted by the CBOs. This perhaps belies the ‘gap’ between any ‘responding organisation’ who are focusing on the macro disaster response, and homeowners whose focus is on the micro.

Finally, CBOs and local organisations also share the government’s priority of re-starting the economy (i.e. the tourist industry) as quickly as possible (Table 3.4). However, they want a number of safeguards as part of the process. For instance, local unions have been advocating that the fluid post-Irma working environment defends SXM livelihoods and that vulnerable workers are protected (particularly migrants and women).

4 Hurricane Irma Risk Assessment

In this section, we focus on the vulnerability and hazard related only to Hurricane Irma. The vulnerabilities are assessed based on the field observations and the PEARL Vulnerability Index (PeVI). The hazards discussed are wave, wind and storm surge hazards related to Hurricane Irma. As Irma did not bring enough rainfall to cause flooding, we do not discuss inland flooding in this section.

4.1 Vulnerability assessment from the field observation

Even though Irma brought extremely strong winds, the socioeconomic, demographic and governance characteristics on the island played a role on the level of destruction witnessed. The main source of physical vulnerability in Sint Maarten is related to “poor housings”. Many houses in Sint Maarten were not build to withstand category 5 hurricanes. It was mentioned by the household interviewees that, in reference to their experiences with Hurricane Luis, they rebuilt their houses to endure a maximum of a category 4 hurricane. The poor housings are attributed to poor construction methods due to empirical constructors in the island and poor construction materials used in the houses (ECLAC, 2017). The most predominant roof material in the Dutch part of the island is zinc (or metallic sheet). Houses with zinc roof sustained high level of destruction throughout the island. In addition, houses with pitched zinc roof, a flatter roof construction method, suffered the highest (Figure 4.1a and b).

The effect of the poor housings is two folds. First, they can easily be destroyed by hurricanes like Irma, leaving the owners homeless. A striking scene during the field visit was to observe houses completely destroyed except their toilets (in many cases) intact (Figure 4.1c). The “tradition” for those who does not afford to build full concrete houses is that they build concrete toilets that serve as shelter during hurricanes. Second, destroyed poor housings in neighborhoods can be a source of flying debris during hurricanes creating a snowball effect of destruction. In Sint Maarten, owners of damaged concrete houses mentioned that their houses were damaged because flying roofs from neighboring poor houses hit theirs (Figure 4.1d and e).

The other source of physical vulnerability is related lack of proper house maintenance. As the island is hit by hurricanes regularly, even the category 1 and 2 hurricanes may weaken the structure of houses. Owners usually maintain their houses if a noticeable or major destruction happens to the house. Over decades, those shaken houses, sustain structural damages that make them vulnerable to extreme events like Irma (Figure 4.1f). Further, during the household survey, residents expressed confidence to not evacuate because they felt their houses were strong enough. That assumption was based on previous experiences with hurricanes in which their houses suffer minor or no apparent damage. That belief leads to some residents not to evacuate or find a strong place, and had to seek for shelter during Hurricane Irma when their compromised houses were destroyed.

Buildings such as hotels and warehouses, which appears to be strong structures, were also destroyed by Irma (Figure 4.1g and h). Most of the hotels that are destroyed by Irma were mainly made of plywood. This material is proved to be not a proper material of construction in a high-risk hurricane zone as Sint Maarten, especially, their geographical location and proximity to the sea made them directly exposed to high waves and strong winds.

(a)

(b)

(c)

(d)

(e)

(f)

(g)

(h)

Figure 4.1. Sample photos showing Irma's destruction in Sint Maarten. (a) and (b) pitched roof houses damaged by Irma; (c) a house fully destroyed except the toilet in Middle Region; (d) a hurricane shutter and roof hit by a flying debris (e) a column damaged by an apparent hit of a flying object (f) concrete houses destroyed by Irma in Middle Region; (g) Sonesta Maho Beach resort in Maho; (h) a warehouse in Pointe Blanche. Source: the photos were taken during the field visit in Sint Maarten by the PEARL team in February 2018.

4.2 PEARL Vulnerability Index (PeVI) – Sint Maarten Case Study

One of the PEARL project product is a new methodology to assess vulnerability to floods, named PEARL vulnerability index (PeVI). The method was initially presented as part of Milestone 25-Completion of two case study analysis and vulnerability assessments as part of the work package 1 (WP1). The milestone report was created between partners of WP1 (Institute of Spatial and Environmental Planning - IREUS and King's Collage London - KCL) and IHE Delft. In addition, the method is described in Sorg et al (2018). This work is the basis to prepare the work for the vulnerability assessment for Sint Maarten.

The PeVI is a transparent and comprehensive indicator-based approach which is flexible in terms of data availability and is not tied to a specific case study site. The PeVI is used to perform socioeconomic vulnerability assessment and it takes into account susceptibility, coping and adaptation as the main elements of a modular hierarchical structure to capture the societal sphere of vulnerability. The modular approach allowed the team to use information that is available and relevant, in order to capture the main components or driver of vulnerability for the local conditions of Sint Maarten. Table 4.1 presents the subcomponents of each dimension of the PeVI. In the following subsections, we present the computation of the three components of vulnerability as well as the final vulnerability assessment

Table 4.1. Components of the PEARL Vulnerability Assessment in Sint Maarten

Susceptibility (S)	Lack of Coping Capacities (C)	Lack of Adaptation Capacities (A)
S.1 - Demography S1.1 Vulnerable Age **S.2 - Poverty** S.2.1 Dependency Ratio S.2.2 Unemployment Ratio **S.3 - Housing** S.3.1 Decade of Construction of the building S.3.2 Building Material S.3.2.1 Walls S.3.2.1 Roof **S.4 - Infrastructure** S.4.1 Type of Electricity Supply S.4.2 Building Damage Estimate S.4.3 Roads Assessment S.4.3.1 Slope S.4.3.2 Distance to Shelters S.4.3.3 Physical Condition S.4.3.4 Road Material S.4.3.5 Road Type	**C.1 Social Network** C.1.1 Household Size C.1.2 Migration **C.2 Immediate Action** C.2.1 Multi-Storey Building C.2.2 Car Ownership **C.3 Government** C.3.1 Trust in Institutions C.3.2 Performance Perception C.3.3 Emergency Infrastructure **C.4 Economic Coverage** C.4.1 Insurance C.4.2 Economic Status C.4.3 House ownership **C.5 Information** C.5.1 Time of Early Warning C.5.2 Access to Information C.5.3 Knowledge Evacuation place **C.6 Awareness** C.6.1 Risk Knowledge C.6.2 Risk Perception C.6.3 Frequency of Information	**A.1 Education** A.1.1 Education Level **A.2 Gender Equity** A.2.1 Gender Parity Ratio **A.3 Investments** A.3.1 Recovery Speed from Irma **A.4 Infrastructure** A.4.1 Vulnerability of Critical Infrastructure

4.2.1 Susceptibility

The first element of PeVI is *susceptibility*, which is defined as the current status of a society and its likelihood to be harmed. It refers to the condition of exposed citizens and infrastructure to a certain hazard (Sorg et al, 2018). The susceptibility component for PeVI in the case of Sint Maarten is defined by four major components: demography, poverty, housing and infrastructure (see Table 4.1) and the results are summarized in the map presented in Figure 4.2.

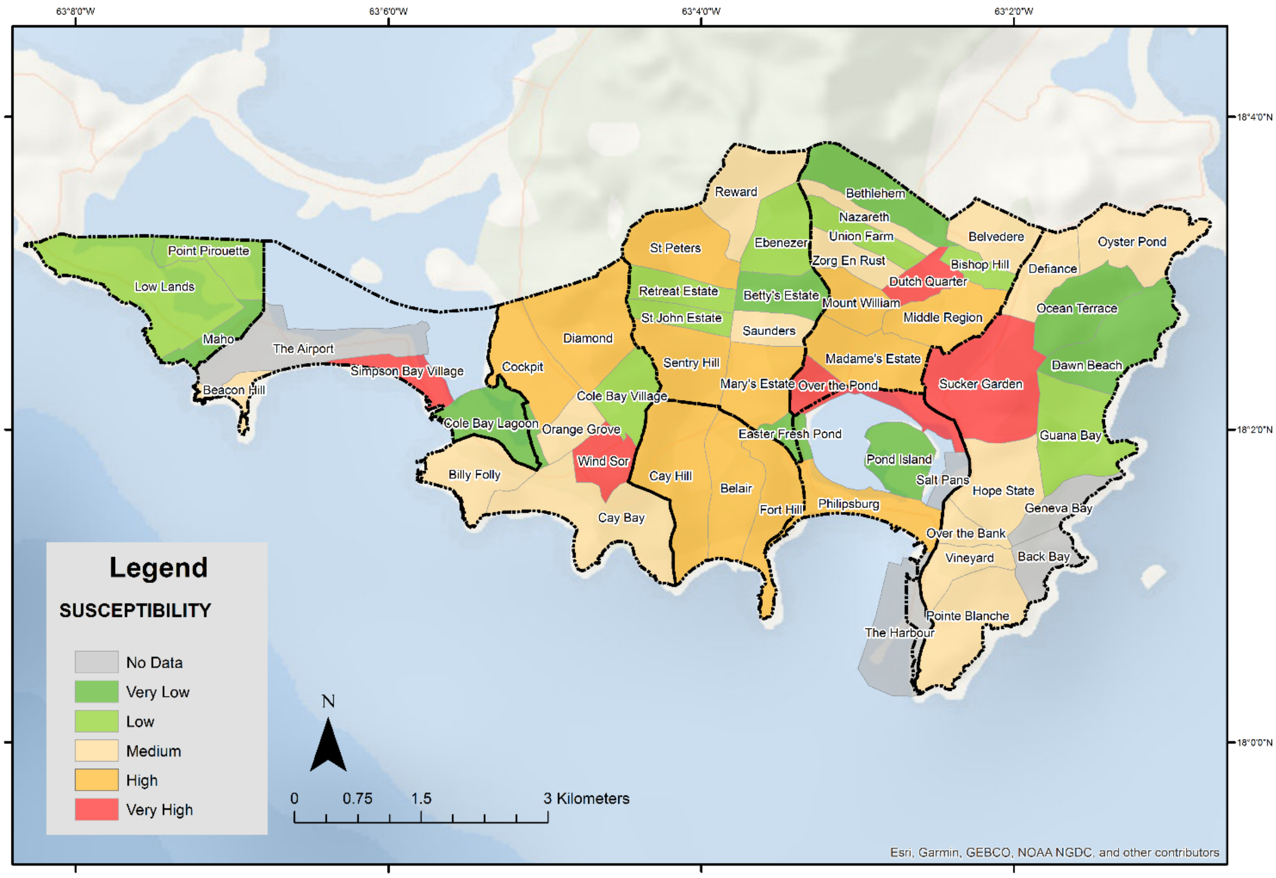


Figure 4.2. PeVI - Susceptibility component

As can be observed in the Susceptibility map the most critical areas regarding this components are Dutch Quarter, Wind Sor, Over the Pond, Sucker Garden and Simpson Bay Village. A closer look into this components reflects that the main drivers of susceptibility in these neighbourhoods are housing and infrastructure (Figure 4.3). To reduce vulnerability through the susceptibility component the government of Sint Maarten should focus the efforts on a stronger and resilient infrastructure in the island, for instance, improve the road infrastructure, electricity underground all over the island and monitor closely the material used for reconstruction at the household level.

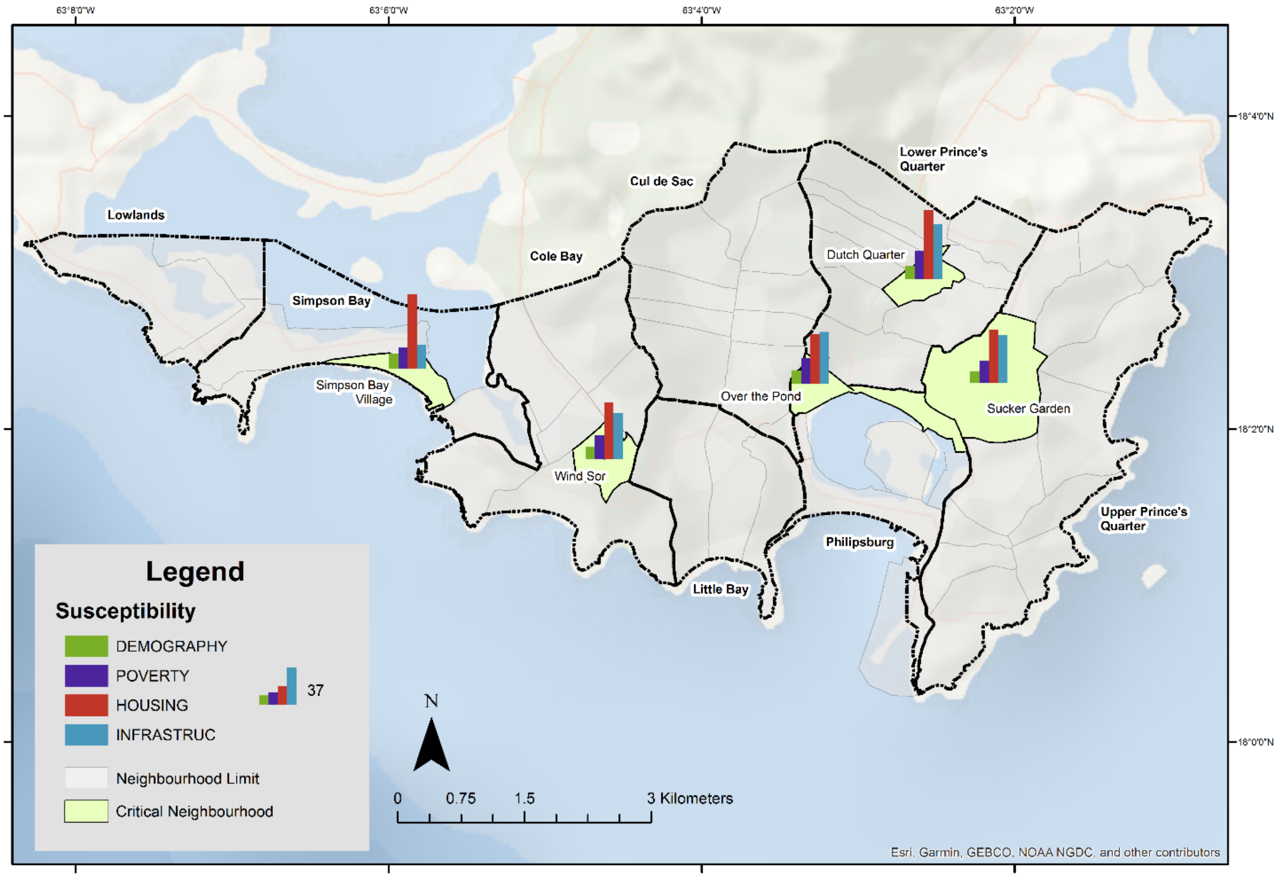


Figure 4.3. Critical neighbourhoods for the PeVI - susceptibility component

4.2.2 Lack of Coping Capacity

The second element used in the computation of the index is *coping*, which is evaluated by strengths and resources for direct actions which lead to a reduction in the consequences of a hazardous event (Birkmann and Welle, 2015). This not only implies knowledge about local natural hazards and resources but also the ability to react immediately when a disaster strikes to minimize harming impacts. In this context coping includes the following six elements: social network, immediate action, government and authorities, economic coverage, information and awareness/preparedness (see Table 4.1) and the results are shown in Figure 4.4. In terms of lack of coping capacities the five most critical neighbourhoods are Bishop Hill, Mount William, Over the Bank, Over the Pond and Philipsburg.

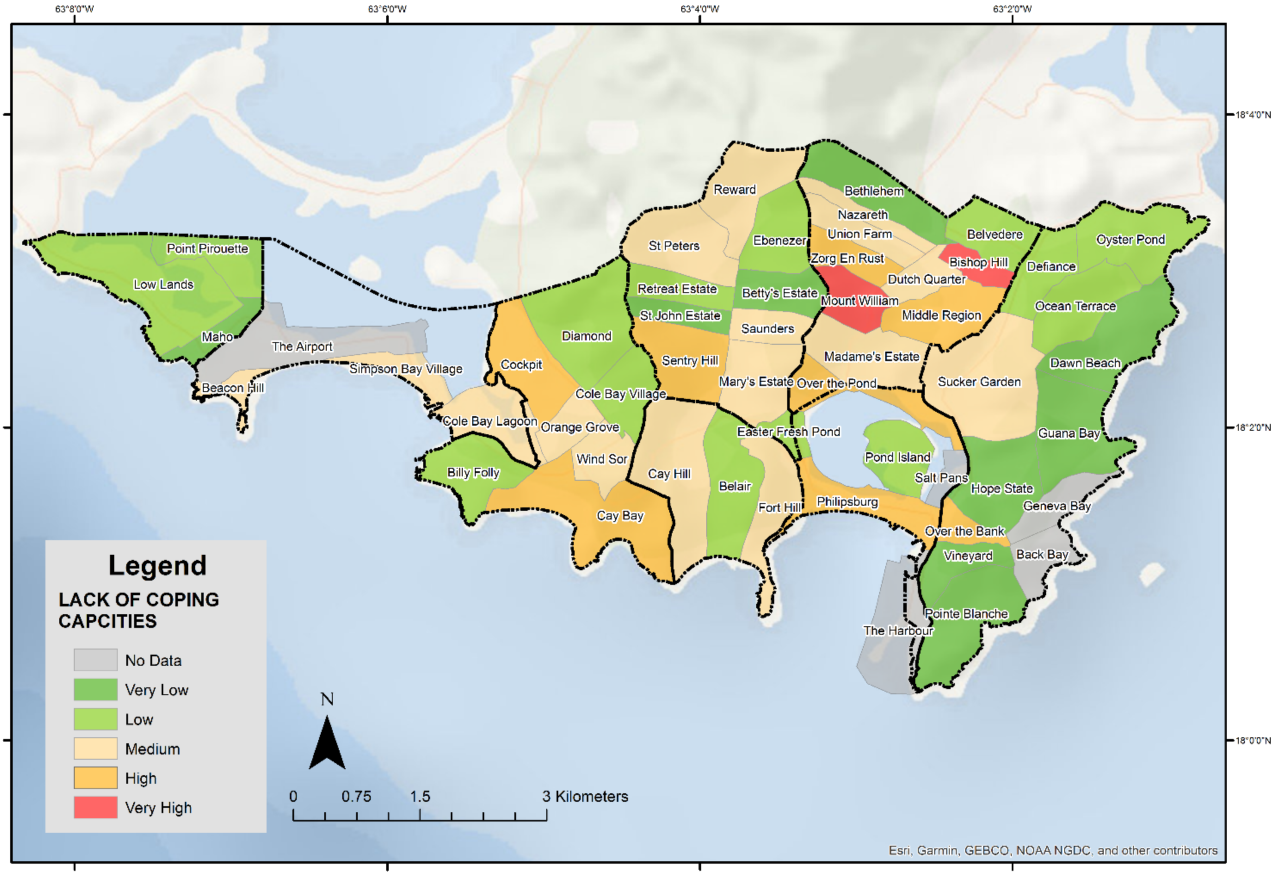


Figure 4.4. PeVI – Lack of coping capacities component

Analysing the individual components of the lack of coping capacities it is clear that the more critical components in this dimension of vulnerability are: economic coverage, immediate action and social network (Figure 4.5). The economic component can be addressed by creating a more social justice in the island and closing the gap between reach and poor. In addition, increasing and promoting the insurance coverage will reduce the vulnerability as well. Immediate action refers in this analysis as having multi-storey buildings and car ownership, a high value in this parameter reinforce the needs to have a good preparation on time before an extreme wheatear event such hurricane or floods since the island has shown a low capacity to have a fast response. In terms of social network, the high number of immigration in the island creates a highly disperse population with few social links, hence increasing the value of the vulnerability. This factor is critical if people who do not have a strong social network to rely on in times of evacuation more if it is analysed in combination with the fact that in Sint Maarten the use of the shelter infrastructure is projected to be used only after the hurricanes.

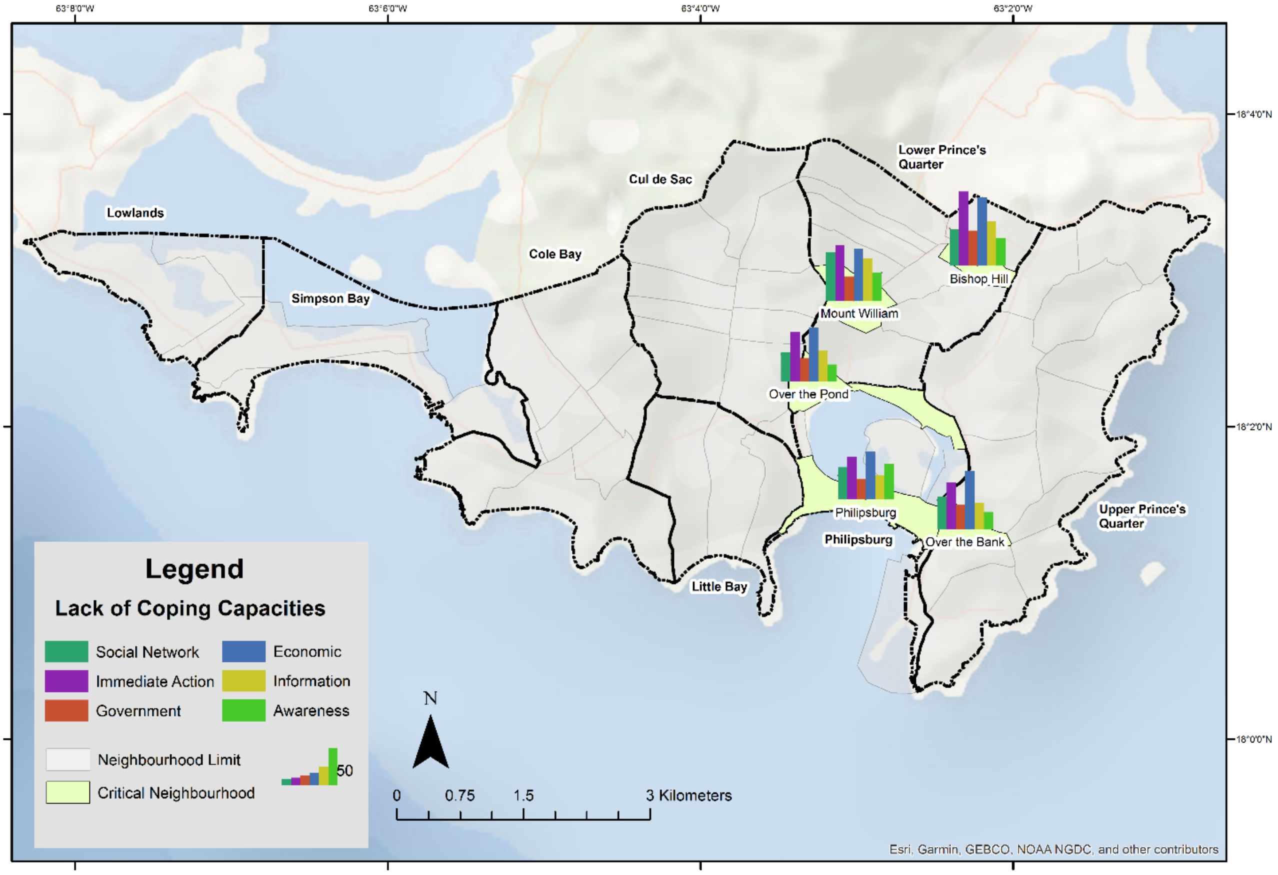


Figure 4.5. Critical neighbourhoods for the PeVI – Lack of coping capacities component

4.2.3 Lack of Adaptation Capacities

The third and final element of the PeVI represents *adaptive capacities* of a community. Adaptation in contrast to coping, which is linked to the impacts, is closer related to change (Birkmann 2011). In order to deal with negative impacts of future disasters, adaptive capacities enable societies to transform. Therefore, adaptive capacities include medium to long-term changes and a future-oriented view (Birkmann and Welle 2015). The following four categories were used to represent adaptation for the PeVI: education and research, gender equity, investments and infrastructure (see Table 4.1). The results Figure 4.6 show that in terms of lack of coping capacities, the five most critical neighbourhoods are Dutch Quarter, Maho, Vineyard, Over the Bank and Ocean Terrace.

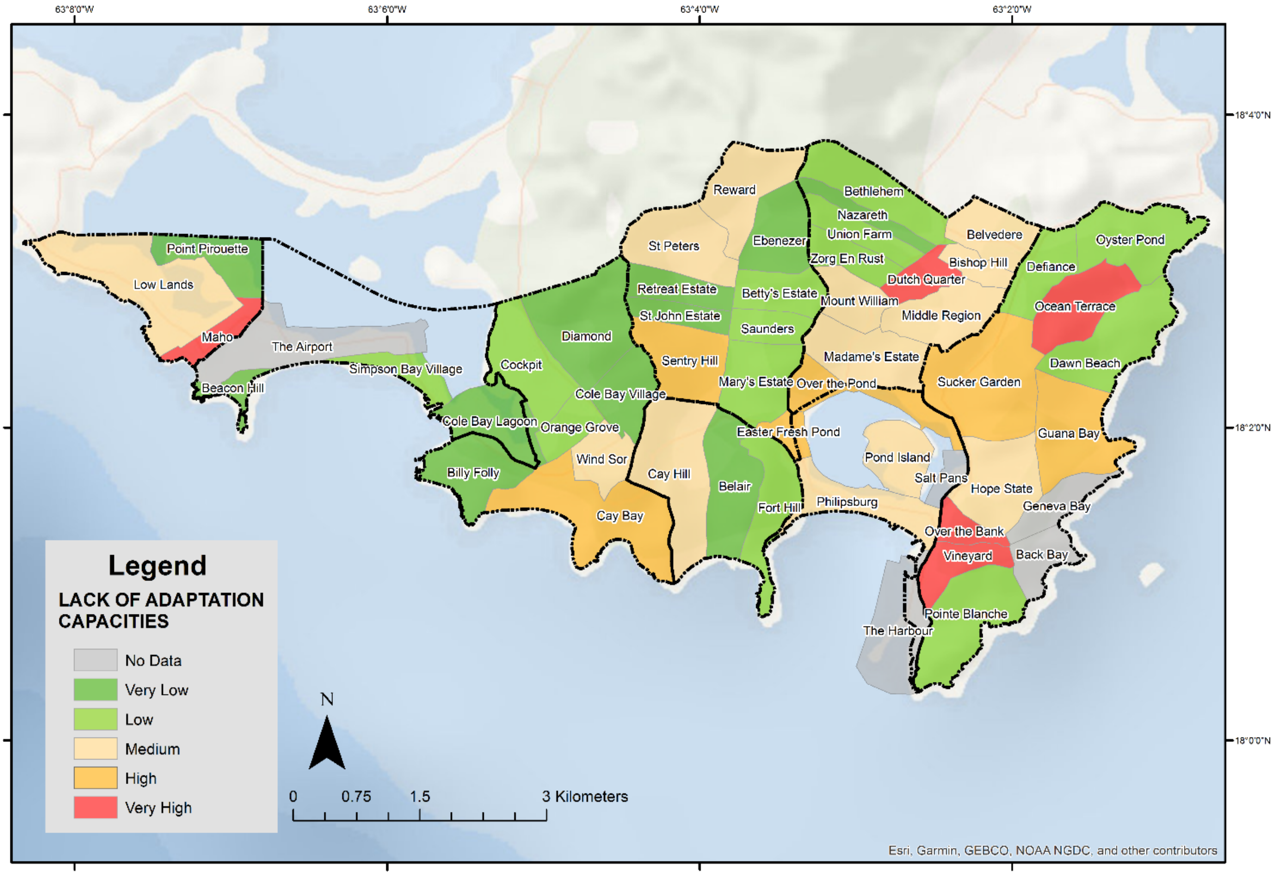


Figure 4.6. PeVI – Lack of adaptation capacities component

The lack of adaptation is critical in Sint Maarten in the ability or speed to recover after the devastation of Hurricane Irma, which was evaluated qualitatively in the field mission in the different neighbours of the island. It calls the attention of the team that some of the wealthiest areas are presenting a slower recovery rate. One of the main reasons for this can be attributed to houses fully covered by insurance and the claim process is under revision. It can also be attributed to the fact that in the more high-income areas people could just leave the island to another house in another country and return when the island is fully recovered in the aftermath of Irma, unfortunately, there is no census of people leaving the island after Hurricane Irma.

Education plays another important role in the high values on the lack of adaptation capacities (Figure 4.7). It was assumed that the better educated a person is, the more adaptation capacities will have to recover after the hurricane, for example, it will be easier to find a job. The research also shows that the higher the education the more resilient the household can be in terms of funding and strategies. Hence, neighbourhoods with low or no education will have a lower capacity to adapt to future extreme events.

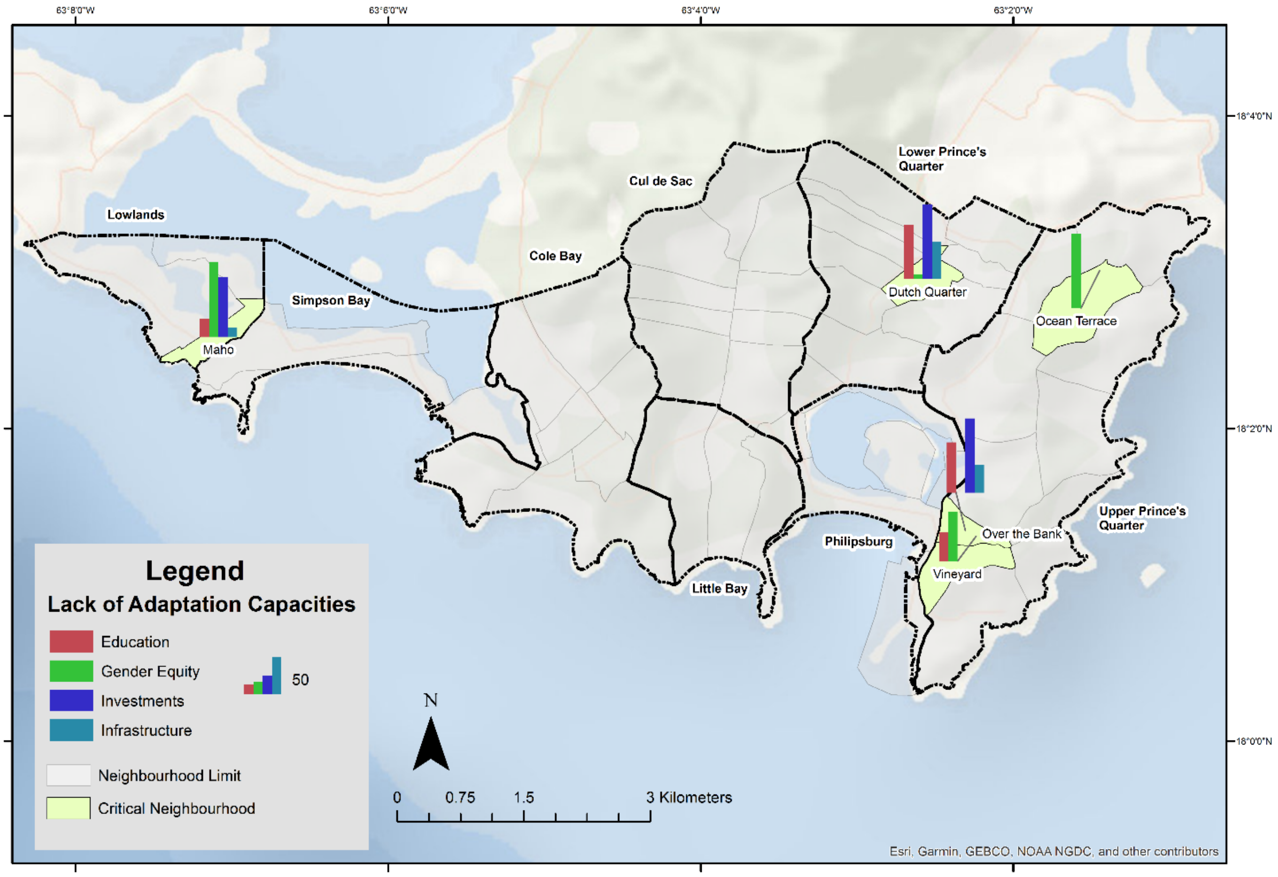


Figure 4.7. Critical Neighbourhoods for the PeVI – Lack of Adaptation component

4.2.4 Sint Maarten Hurricane Irma vulnerability

The PEARL vulnerability assessment has the purpose to display the composition of relative vulnerability in a specific case study area. Hence, all calculated indicators consist either of ratios, or are normalized between 0 and 100, and can only be seen with regard to the respective spatial entity. For the purpose of this assessment, all three components were weighted as equally important in the final computation. It displays the vulnerability of the different neighbourhoods in five categories from very low to very high vulnerability. This information and maps can be used as a tool for the reconstruction process in the aftermath of Hurricane Irma. It will allow the government to tackle the highly vulnerable areas (shown in red in Figure 4.8) as the more critical ones. In terms of vulnerability, the most critical neighbourhoods in Sint Maarten are Dutch Quarter, Over the Bank, Over the Pond, Mount William and Bishop Hill.

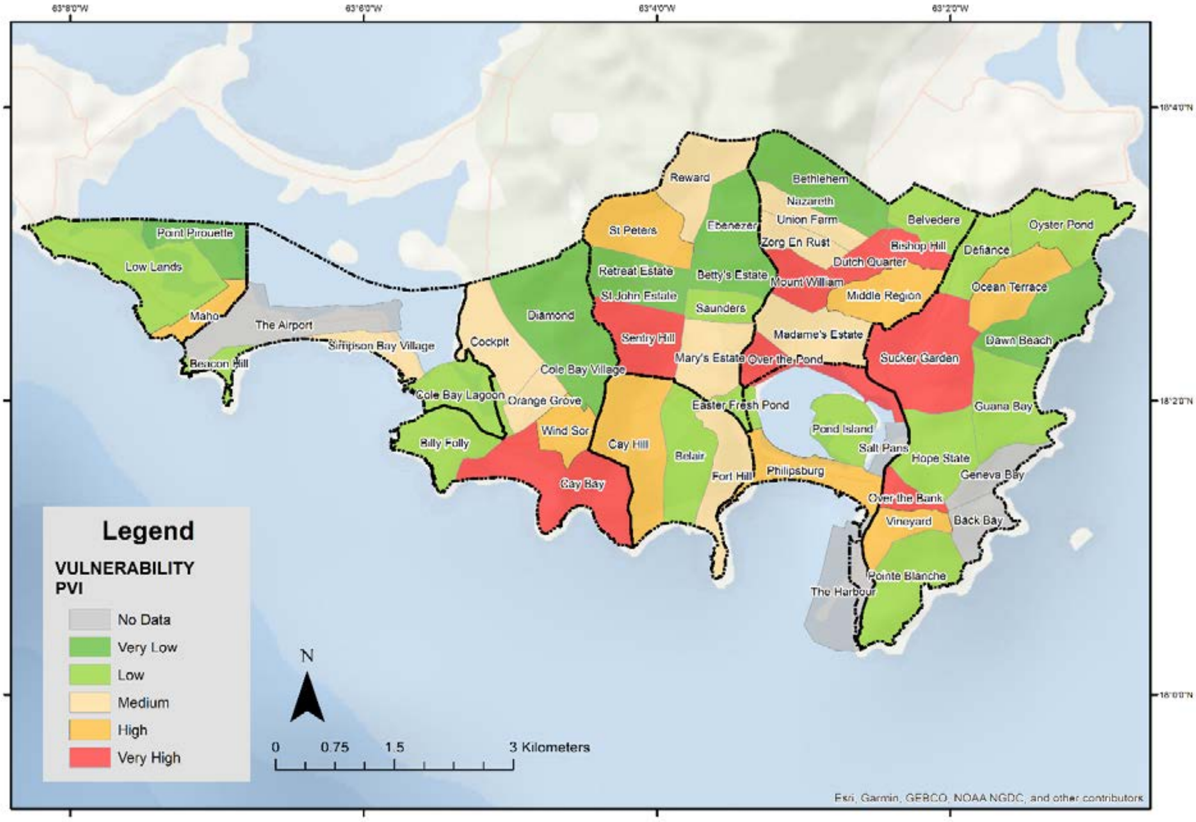


Figure 4.8. PeVI – Vulnerability Assessment

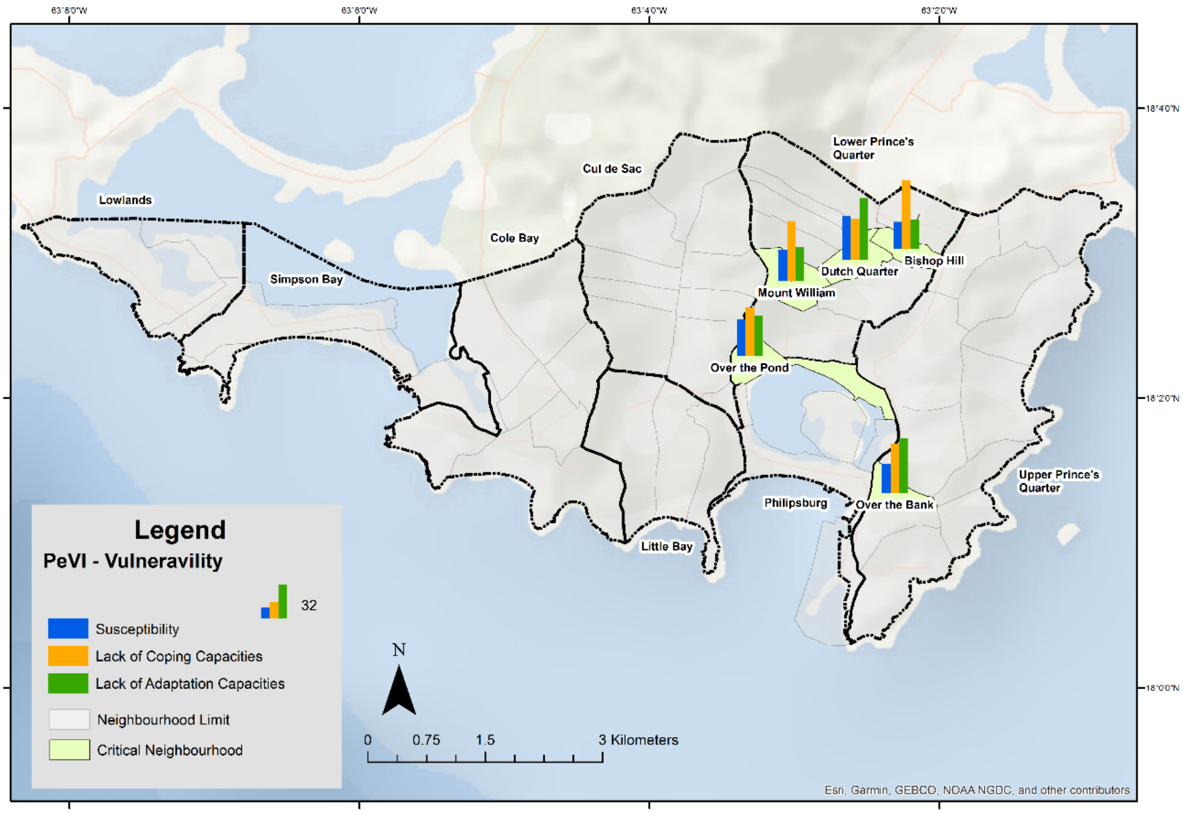


Figure 4.9. Critical Neighbourhoods for the PeVI – Vulnerability Assessment

A representation of the PeVI by component is presented in Figure 4.9 for the five most critical neighbourhoods and in Figure 4.10 for the entire island. The results show that Dutch Quarter is the most critical neighbourhood in terms of vulnerability, in which the lack of adaptation is 57% and a susceptibility around 40%. For the second most critical neighbourhood, which is Over the Bank, the lack of adaptation capacities and coping capacities are the most critical components with values close to 51% and 46%, respectively. The other three neighbourhoods that are in the top five of critical vulnerability have in common the lack of coping capacities as the most critical component of vulnerability with values of 46 % for Over the Pond up to 64% for Bishop Hill.

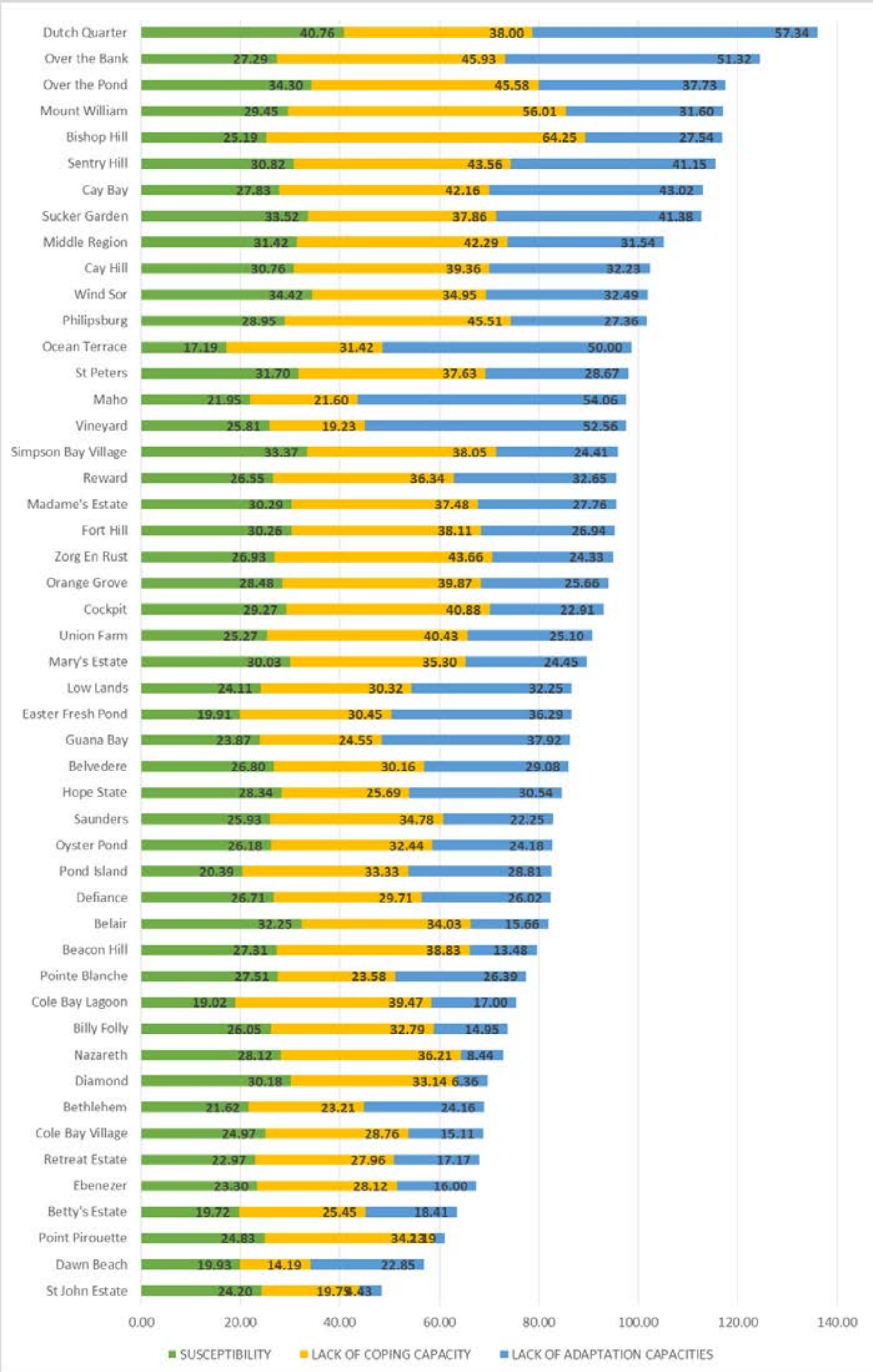


Figure 4.10. Aggregate PeVI – Vulnerability by components at neighbourhood level.

4.3 Hazard Assessment

4.3.1 Wave loads along the southern coast of Sint Maarten during Hurricane IRMA

To assess waves induced by Hurricane Irma on Sint Maarten, we developed a numerical wave model using the open source “Simulating Waves Nearshore” (SWAN) software[39]. The third generation, phase averaged spectral wave model SWAN was developed by TU Delft (Booij et al., 1999). The model accounts for the following main physics of the generation, propagation, interaction and dissipation of waves: (i) wave generation by wind (ii) wave propagation in time and space (iii) shallow water processes like shoaling, refraction due to current and depth (iv) tree- and four-wave interactions (v) frequency shifting due to currents and non-stationary depth and (vi) dissipation due to white-capping, depth-limited breaking, bottom friction, vegetation etc. The finite difference method is used for the discretization of the governing equations (e.g. spectral description of wind waves and the propagation of wave energy). The model is able to operate on a regular grid with Cartesian coordinate system or curvilinear grid or triangular mesh in spherical coordinate system. Non-stationary and stationary runs can be carried out on both linear and non-linear deep and shallow processes, respectively, can be included in the computations. Moreover, the model computes wind generated waves and is particularly useful for the modelling of waves in larger model domains and in shallow water regions. The model can be nested in other third generation phase averaged numerical models such as WAVEWATCH3 or WAM. Higher resolution information can be obtained within a smaller model domain by using spectral boundary conditions from the superior model as input for the inferior model (nesting approach).

4.3.1.1 Study area and model boundary

Sint Maarten borders on the northeast Caribbean Sea in the west and on the North Atlantic Ocean in the east (Figure 4.11). The topography of the surrounding sea floor is very complex due to its history of geological formation (Sint Maarten lies in the Lesser Antilles subduction zone of the South American Plate and the Caribbean Plate) and is characterized by steep submarine banks, troughs and ridges, that partly are raised up to 1000 m above the in general deep ocean depths.

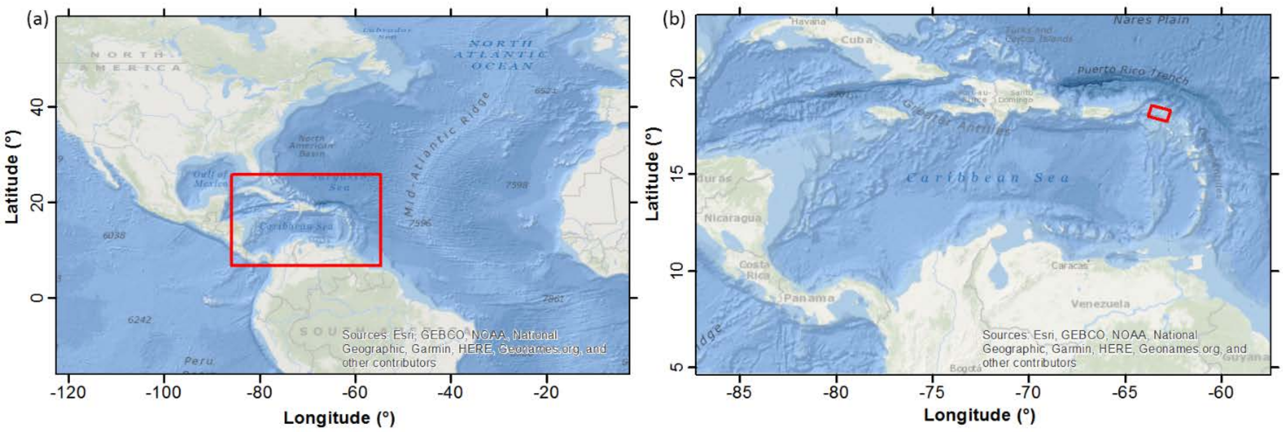


Figure 4.11. (a) Geographic locations of the Study Area and (b) Focus Area as indicated by the red boxes

39 http://swanmodel.sourceforge.net

The wave climate along the southern coast of Sint Maarten is characterized by swell and wind waves. Strong winds occur during the hurricane season from August to December. Swell waves enter the area from westerly directions over the Caribbean Sea. Wind waves depend in general on the wind speed, fetch (distance over which the wind is blowing) and the duration of the wind. In the shallow water areas another limiting factor for the development of the waves are the local water depths.

The model boundary should be far away from the area of interest to take into account the effects of combined wind waves and swell. Wave information from other regional or global wave models (e.g. from the operational phase averaged wave model WAVEWATCH3 from NCEP, NOAA) can be used to set-up a model for a smaller domain, using the wave information from the superior model as boundary conditions for the inferior model (i.e., nesting approach).

The inferior model domain is illustrated in Figure 4.12 and the boundaries of the model domain were selected in accordance with available wave information from NCEP's multigrid production hindcast[40] that consists of different global and regional nested grids, e.g. the NW Atlantic 10 min grid as shown in Figure 4.13.

The boundaries of the superior model domain (Figure 4.12) have been selected in accordance with available wind and wave information from a hindcast of the hurricane generated waves by IRMA on the basis of the ADCIRC storm surge and wave model (SWAN) using the official best track wind information from the NHC[41]. The system is operated by the ADCIRC storm surge model group at the University of North Carolina at Chapel Hill, the ADCIRC Surge Guidance System (ASGS) developed at Seahorse Coastal Consulting (NC), and the Coastal Emergency Risks Assessment (CERA) program at the Louisiana State University[42].

[40] http://polar.ncep.noaa.gov/waves/hindcasts/prod-multi_1.php
[41] https://cera.coastalrisk.live/?storm=11
[42] http://coastalemergency.org/

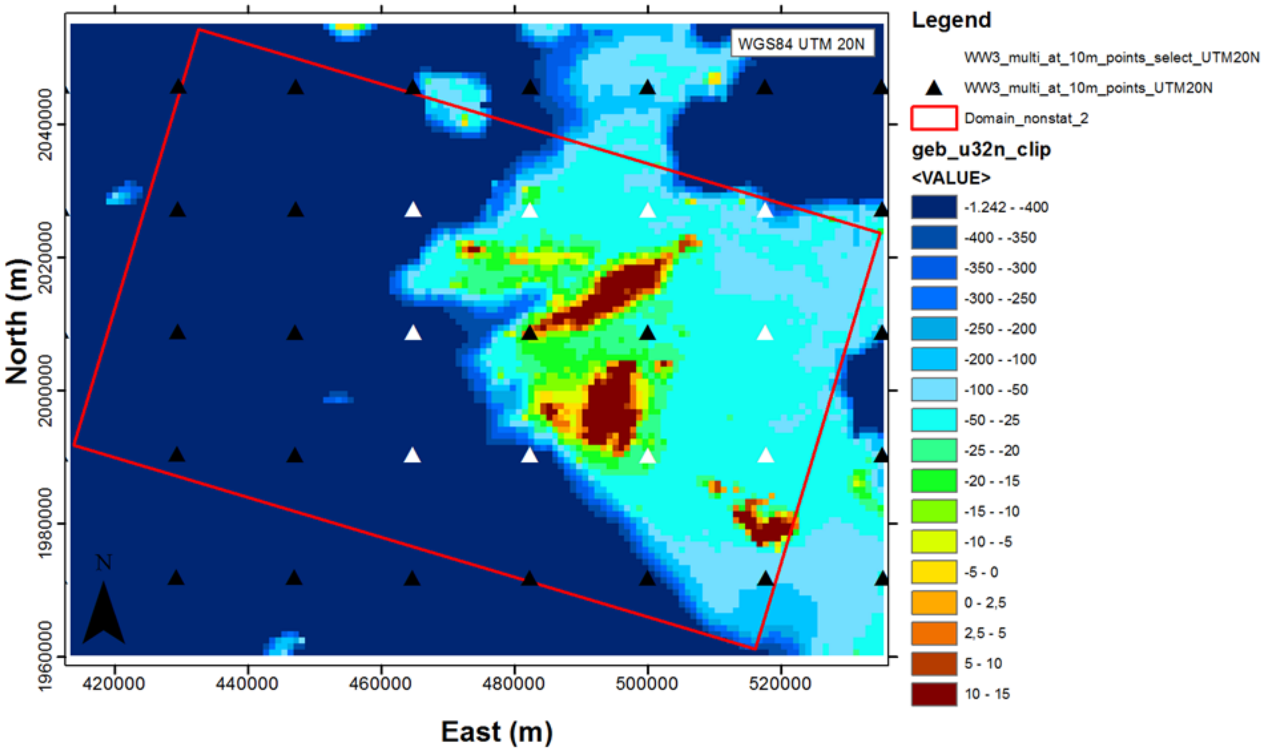


Figure 4.12. Bathymetry of the superior model (red box) based on the GEBCO_2014 Grid (version 20150318) and domain of the inferior model (white triangles). The black triangles denote the grid points of the regional NW Atlantic 10 minute nested grid from NCEP, NOAA.

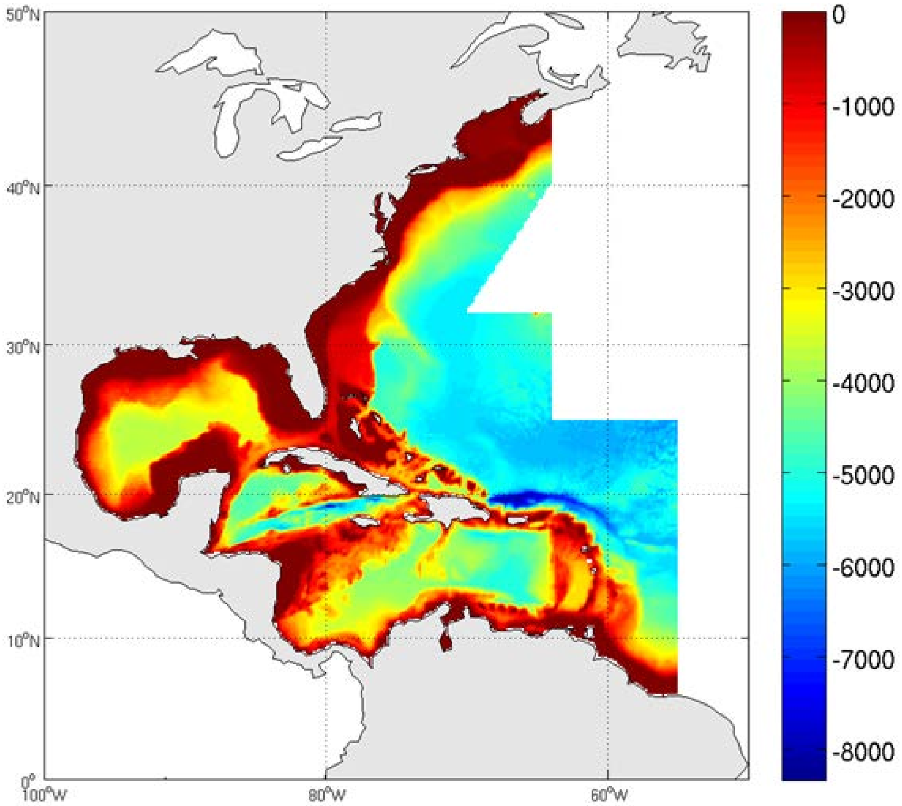
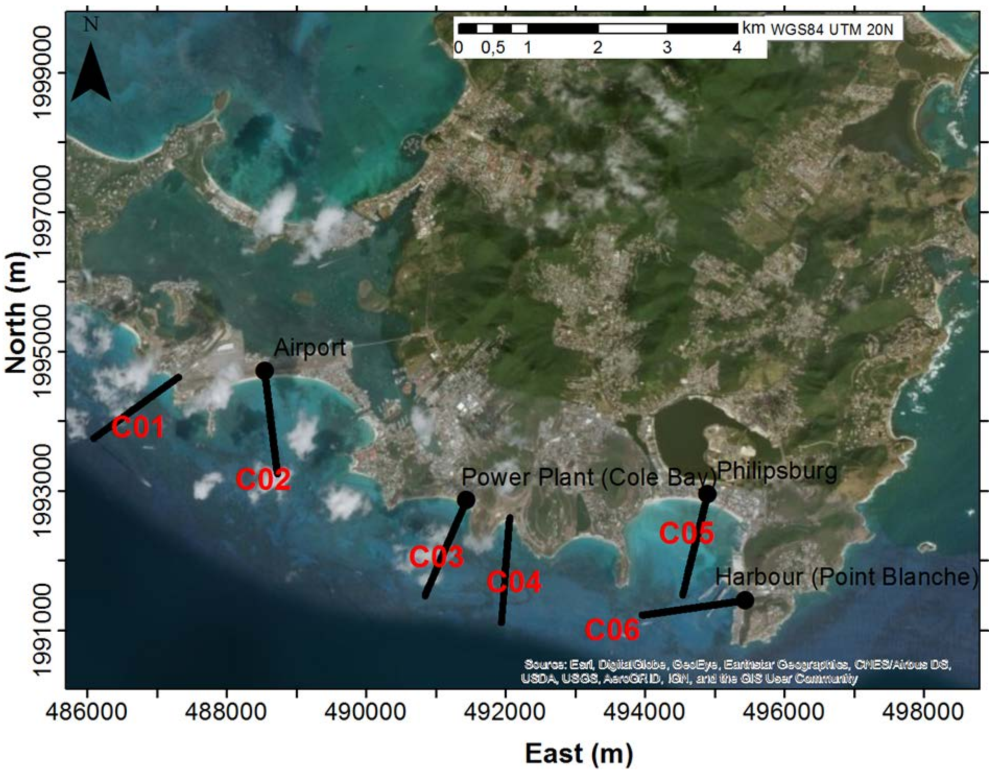


Figure 4.13. Bathymetry of the regional NW Atlantic 10 minute nested grid based on the ETOPO-1 bathymetry (Amante and Eakins, 2009); Source: NCEP, NOAA

4.3.1.2 Model domain discretization and Bathymetry

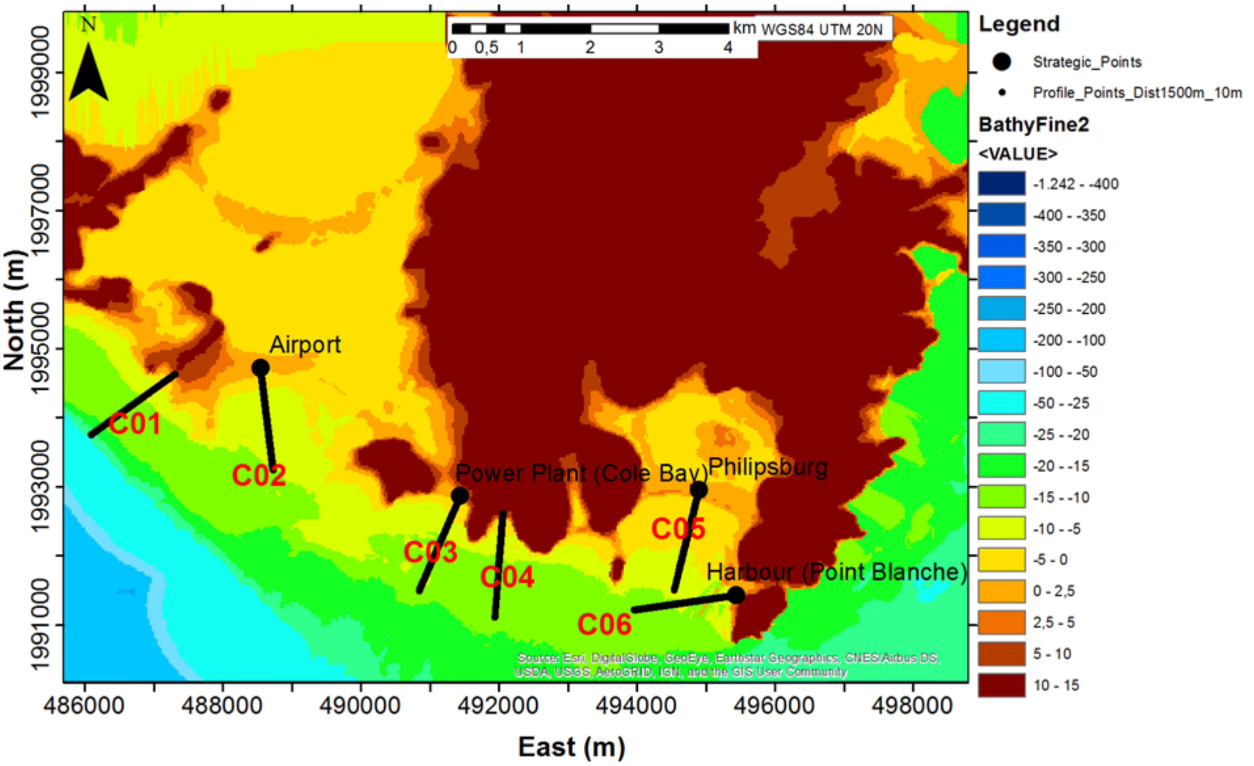
In SWAN, the finite difference method is applied for the discretization of the governing equations that describe the evolution and propagation of waves onto a computational mesh. A regular rectangular computational mesh was chosen for the superior model with a total number 8,496 mesh elements and a horizontal mesh resolution equal to the GEBCO2014_grid bathymetry (grid size of about 900 km). The length and width of the superior model domain are approximately 106 km and 65 km, respectively. Another regular rectangular computational mesh was chosen for the inferior model that covers the nearshore area. It contains 2,168,490 mesh elements to provide higher resolution information due to an available higher resolution bathymetric data set for the nearshore area.

On each point of the computational mesh, information about the topography of the seafloor (bathymetry) is needed. High resolution bathymetric data play an important role for the accuracy of the model results. Two sources of bathymetric data were available for this study. For the whole superior and partly inferior model domain, bathymetric information are obtained from the General Bathymetric Chart of the Oceans (GEBCO) as shown in Figure 4.12. In addition, a high resolution Digital Terrain Model (DTM) with a horizontal resolution of 30 m[43] was used for the inferior model domain. The topography of the higher resolution model is shown exemplarily within a section of the southern coast of Sint Maarten in Figure 4.14.



(a)

[43] The DTM is based on SONAR data from the Dutch Navy and IHE-Delft



(b)

Figure 4.14. Section of the southern coast of Sint Maarten with (a) output curves C01-C06 and (b) high resolution bathymetry

4.3.1.3 Model Parameters

The definition of the basic wave modelling parameters of the SWAN model has been done on the basis of experiences from previous costal engineering studies (e.g., Schlamkow and Fröhle (2009); Dreier and Fröhle (2015, 2016)). The calculated wave spectra are discretised within SWAN into 144 directional bins (2.5° width of the directional bin) and into 42 frequency bins (from 0.02 Hz to 1 Hz, 50 s to 1 s respectively). A local, projected coordinate system, WGS84-UTM20N, is used for all definitions of the model (e.g. computational grid, input and output fields etc.).

The number of iterations for the stationary computations (SWAN variable MXITST) was kept with its standard value of 50 iterations after test simulations. At the end of each simulation, different standard output is generated, e.g. along selected curves within the project site (Table 4.2 and Figure 4.14):

i) Output of water depth d and spectral wave parameter H_{m0} (significant wave height), T_{m01}, T_{m02}, $T_{m-1.0}$ (spectral wave period), T_p (peak period), θ_m (mean wave direction) and σ_θ (directional spreading) at every computational grid point in a binary NetCDF-format. Outputs of selected simulations are plotted in Appendix H (Figure H.4 and Figure H.5).

ii) Output of the above mentioned model parameter along selected curves with an output interval of 10 m in an ASCII format. The selected points are summarized in Table 4.2 and the locations are shown in Figure 4.14. The output along the selected curves are plotted for selected simulations in Appendix H (Figure H.1, Figure H.2 and Figure H.3).

Table 4.2. Definition of curve output, reference system WGS84-UTM20N

Curve	Begin North / East (m)	End North / East (m)	Length (m)	Location
C01	487303 / 1994631	486087 / 1993753	1500	Airport (Maho Bay)
C02	488545 / 1994725	488729 / 1993236	1500	Airport (Simson Bay)
C03	491442 / 1992866	490841 / 1991492	1500	Power Plant (Cole Bay)
C04	492062 / 1992611	491942 / 1991116	1500	Cay Bay
C05	494905 / 1992959	494542 / 1991503	1500	Philipsburg (Great Bay)
C06	495441 / 1991430	493957 / 1991216	1500	Harbour (Point Blanche)

4.3.1.4 *Hydrodynamic and meteorological boundary conditions (SWAN)*

Numerical offshore wave data near the project area are available from:

i) NCEP's multigrid production hindcast (WAVEWATCH3 for the NW Atlantic 10 min grid) based on the Global Forecast System (GFS) without data assimilation, time step = 3 h

ii) Coastal Emergency and Risks Assessment (CERA), hindcast of ADCIRC storm surge and wave model (SWAN) based on NHC's best track, time step = 1 h

Numerical wave data during Hurricane IRMA can be used as non-stationary or stationary boundary conditions for the SWAN wave simulations. After non-stationary test simulations with wave data from NCEP's multigrid production hindcast, it was decided to run stationary simulations with wave, wind and water level conditions derived from the CERA hindcast of IRMA. More information about the coupled forecast system of the ADCIRC coastal circulation and storm surge model with the SWAN wave model and the assessment of the forecast quality of hurricane generated waves (e.g. during the Hurricanes Irene, 2011; Isaac, 2012 and Arthur, 2014) are given, e.g., in Blanton et al. (2012), Dresback et al. (2013), Dietrich et al. (2013) and Cyriac et al. (2018).

The contour lines (i.e., isolines) of maximum significant wave height, wind speed 10 m above surface, water level and peak wave period from the CERA hindcast of IRMA have been used to derive the boundary conditions for the stationary wave simulations. The isolines of maximum significant wave height and wind speed respectively peak wave period and water level are shown in Figure 4.15 and Figure 4.16, respectively.

The following wave boundary conditions are compiled on the basis of the hindcast results and have been applied along the western and southern boundary of the superior model domain (Figure 4.15 and Figure 4.16, respectively):

West: H_{m0}~17.0 m, T_p~15.2 s, θ_p = 225° (SSW) with a spectral spreading factor of 2

South: H_{m0}~15.0 m, T_p~13.6 s, θ_p = 225° (SSW) with a spectral spreading factor of 2

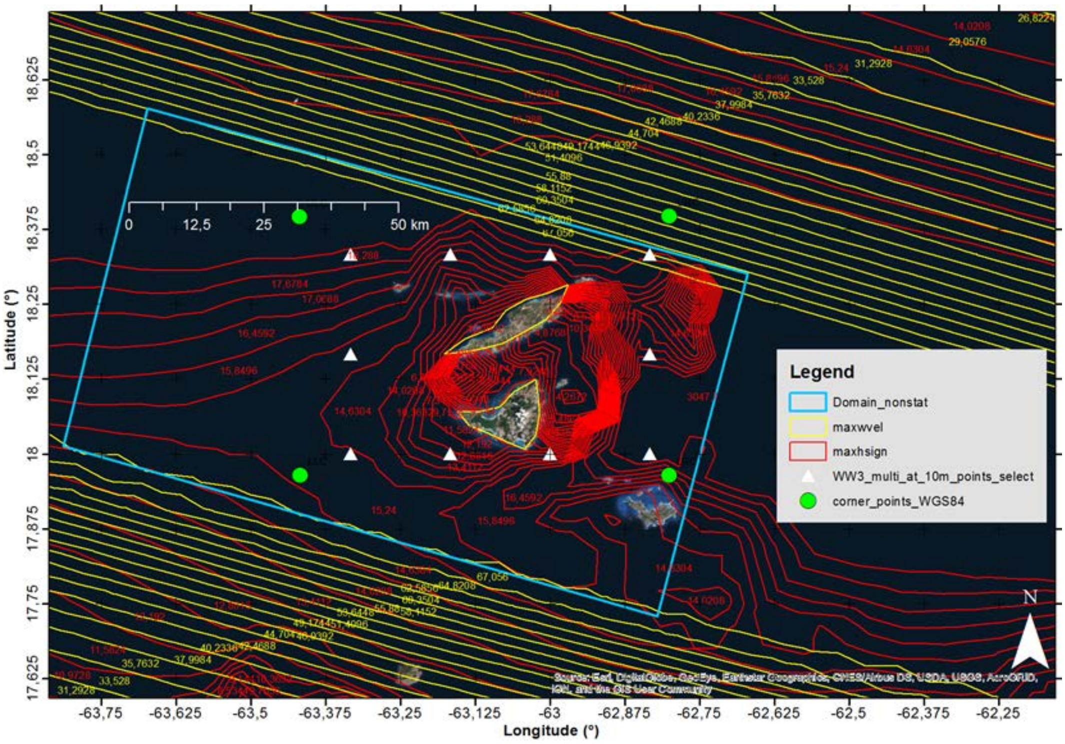


Figure 4.15. Isolines of maximum significant wave height (red) and wind speed 10 m above surface (yellow). Source: CERA hindcast of IRMA in the model domain (blue box)

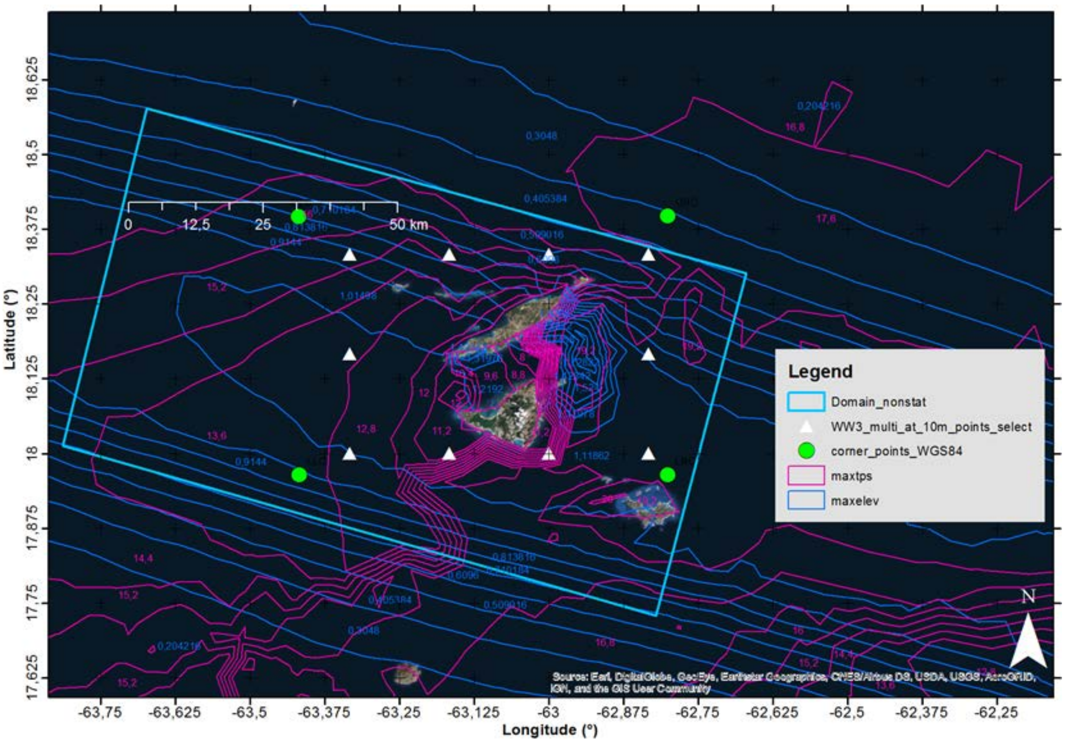


Figure 4.16. Isolines of maximum peak wave period (purple) and water level (blue). Source: CERA hindcast of IRMA in the model domain (blue box)

Numerical wind conditions that cover the area and time of interest are available from:

i) NCEP's multigrid production hindcast (WAVEWATCH3 for the NW Atlantic 10 min grid) based on the Global Forecast System (GFS) without data assimilation, time step = 3 h

ii) NCEP's Climate-Forecast System (CFS), 6-Hourly Surface and Radiative Fluxes from CFSv2 Operational Analysis runs with data assimilation, time step = 1 h

iii) CERA, hindcast of ADCIRC storm surge and wave model (SWAN) based on NHC's best track, time step = 1 h

The maximum calculated wind speed from the CERA hindcast of IRMA over the project area has been identified with U_{10}~67 m/s (yellow isolines in Figure 4.15). The maximum wind speed corresponds to the maximum forecasted wind speeds during IRMA from NCEP's multigrid production hindcast (Figure 4.17).

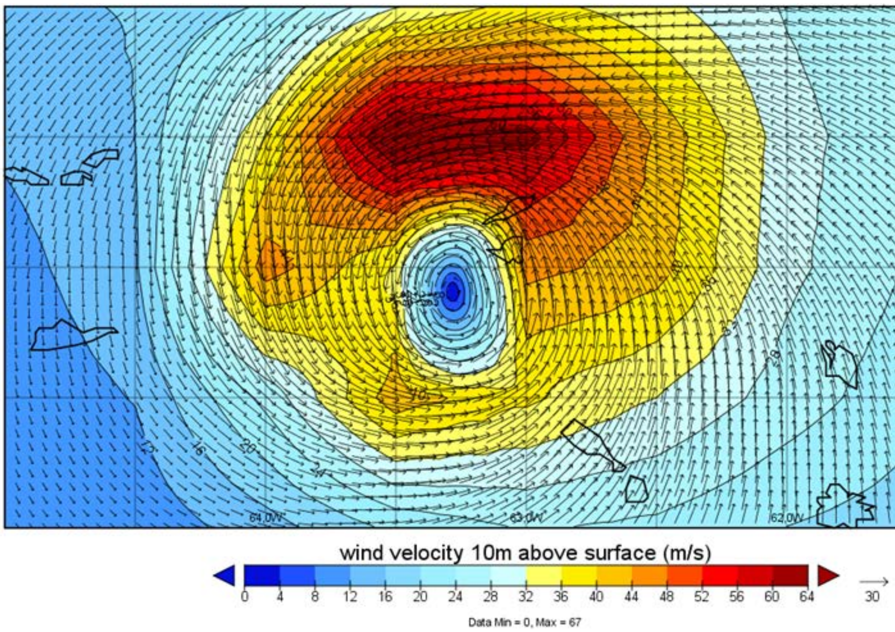


Figure 4.17. Wind field from NCEP's multigrid production hindcast (NW Atlantic 10 min grid) 1200 UTC on 6 September 2017

Records of maximum wind speed during IRMA are available e.g. from the tide gauge station "Barbuda" (17.591° N, 61.821° W) from the National Bouy Data Center (NBDC) of NOAA, on the Island of Barbuda. The station is located approximately 143 km to the southeast of Sint Maarten (Figure 4.17). Maximum average wind speeds up to 53 m/s and gusts up to 70 m/s were measured during IRMA (Figure 4.18) until an interruption of the measurement system at the time of the maximum wind speeds.

To account for the uncertainty of the numerical wind fields with respect to observations, three different wind speeds U_{10} = 67 m/s, 60 m/s and 55 m/s have been selected in combination with a constant unfavourable wind direction of θ_m = 225° (SSW). Moreover, three unfavourable wind directions θ_m = 225°, 212.5° and 237.5° have been selected in combination with a constant wind speed of U_{10} = 67 m/s. The wind conditions have been applied as spatially uniform (constant) values over the whole superior and inferior model domain within the numerical simulations.

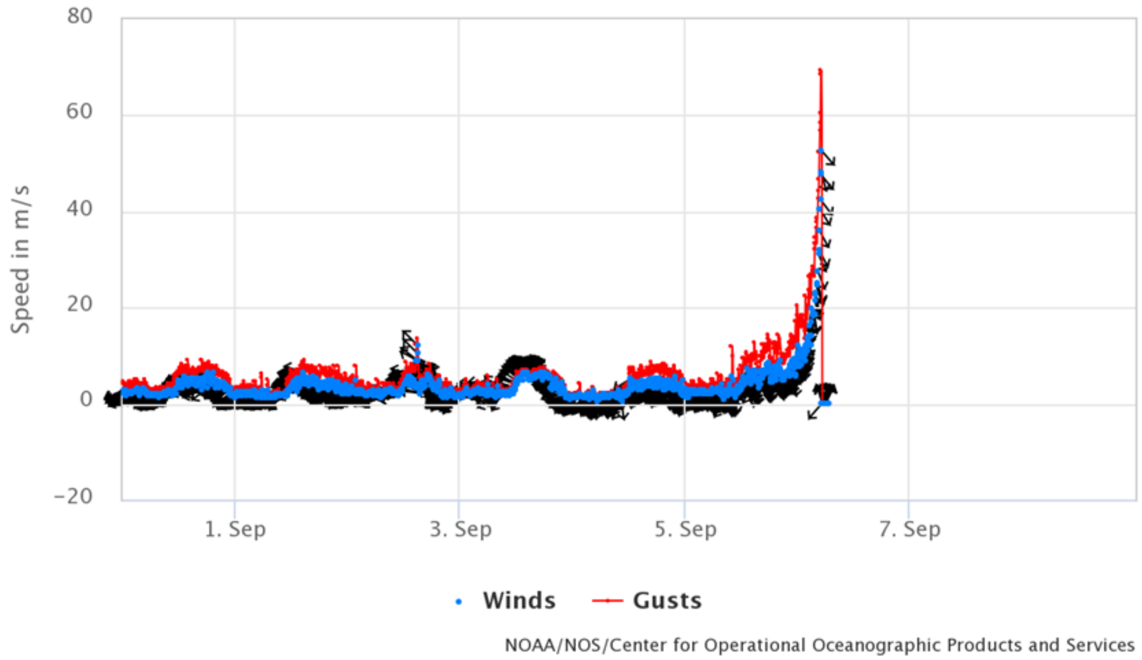


Figure 4.18. Winds at NBDC, NOAA's tide gauge station on the Island of Barbuda. Source: NOAA/NOS/Center for Operational Oceanographic Products and Services

Numerical data about the local water levels are available from:

i) NCEP's Climate-Forecast System (CFS), 6-Hourly 3-D Ocean Data from CFSv2 Operational Analysis runs with data assimilation, time step = 1 h

ii) Coastal Emergency and Risks Assessment (CERA), hindcast of ADCIRC storm surge and wave model (SWAN) based on NHC's best track, time step = 1 h

The maximum calculated water level from the CERA hindcast of IRMA in the project area was identified with *W*~MSL+1 m (Figure 4.16). At neighbouring tide gauge stations from NBDC, maximum water levels up to *W*~MSL+0.8 m at the tide gauge station "Arecibo", 18.480° N, 66.702° W at the coast of the Island of Puerto Rico were recorded. Other tide gauge stations show similar tendencies during the peak of the hurricane but lower magnitudes of maximum water levels. A distance averaged maximum water level of *W*~MSL+1.2 m is calculated on the basis of the observations from the five closest tide gauge stations with an average distance of 175 km. The maximum recorded water level during IRMA was found at the tide gauge station "Barbuda" with *W*~MSL+2.5 m (Figure 4.19). The latter is in correspondence with an observed significant barometric pressure drop during the time of the occurrence of the maximum water level as shown in Figure 4.20. The adjustment of the local water level to changes in barometric pressure is also known as the inverse barometric effect. A change of the barometric pressure of 1 hPa (1 mb) results in a change of the water level of 0.01 m[44]. During Hurricane IRMA a decrease of the barometric pressure of ca. 100 mb was noted (Figure 4.20) that theoretically results in an increase of the water level of ca. 1 m. If this effect is accompanied by wind set-up created by strong onshore winds, the water level can rise more than 1 m above MSL and cause coastal inundation for the low lying areas of Sint Maarten.

[44] http://glossary.ametsoc.org/wiki/Inverted_barometer_effect

As a results of the review of available measurements and simulation results three different water levels *W*=MSL+1 m, MSL+1.5 m and MSL+2 m have been selected for the numerical simulations. The water levels are regarded as spatially uniform (constant) values over the whole superior and inferior model domains.

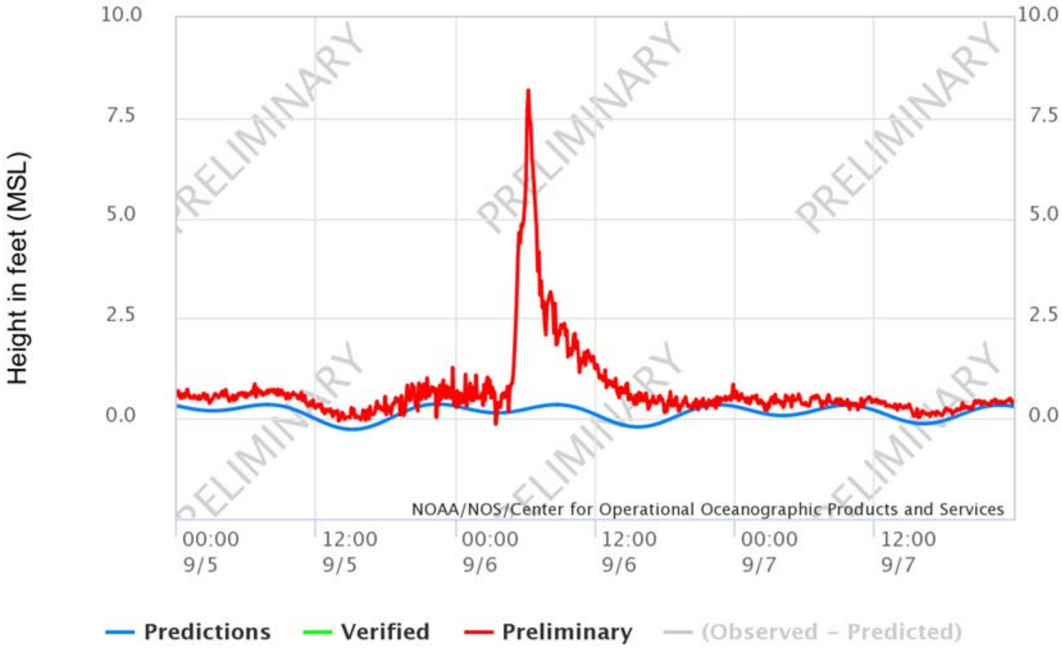


Figure 4.19. Observed water levels at NBDC, NOAA's tide gauge station on the Island of Barbuda. Source: NOAA/NOS/Center for Operational Oceanographic Products and Services

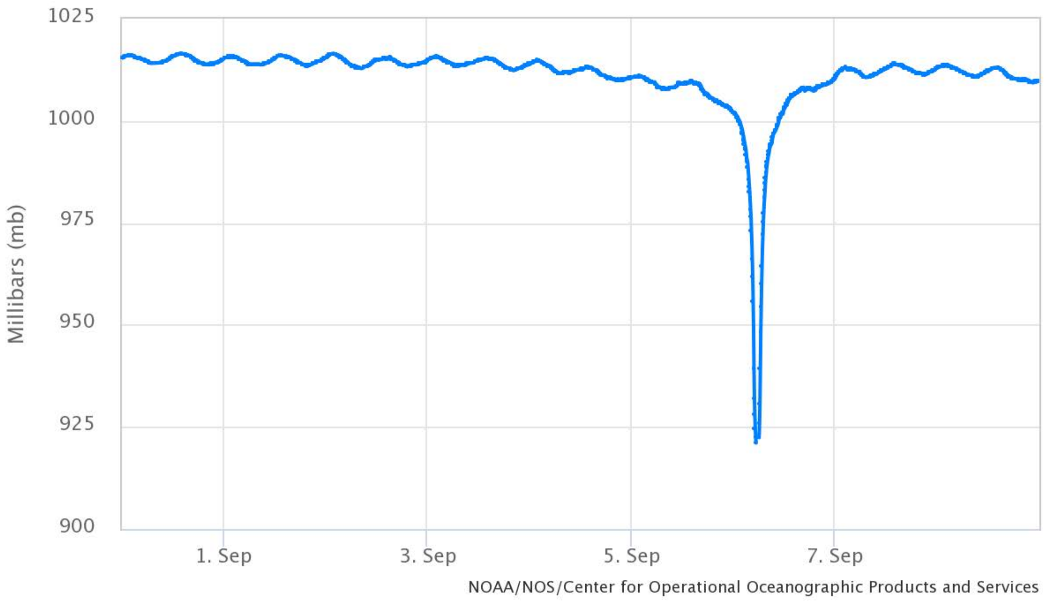


Figure 4.20. Observed barometric pressure at NBDC, NOAA's tide gauge station on the Island of Barbuda. Source: NOAA/NOS/Center for Operational Oceanographic Products and Services

4.3.1.5 Wave conditions

In total seven simulations have been carried out with varying hydrodynamic and meteorological boundary conditions. The simulation setups are summarized in Table 4.3. To assess the effects of

different boundary conditions on the local wave conditions, the influence of the local water levels and the local wind conditions have been analysed with the model. The reference simulation run is denoted as V0.

To assess the effect of varying water levels on the local wave conditions, different water levels have been used in the simulations V0, V1 and V2 while the wind conditions are kept constant. To assess the effects of varying wind speeds on the local wave conditions, different wind speeds have been chosen in the simulations V0, V3 and V4 while the wind directions are kept constant. Finally, to analyse the effects of varying wind directions on the local wave conditions, different wind directions are applied in the simulations V0, V4 and V5, while the wind speeds are kept constant. The wave boundary conditions are kept constant during all simulations.

Table 4.3. Numerical wave simulations setups

Sim. No.	Water level (m o. MSL)	$H_{m0,w}$ (m)	$T_{p,w}$ (m)	$\theta_{p,w}$ (°)	$H_{m0,s}$ (m)	$T_{p,s}$ (m)	$\theta_{p,s}$ (°)	U_{10} (m/s)	θ_w (°)	Remarks
V0	1.0	17.0	15.2	225°	15.0	13.6	225°	67	225°	reference run
V1	1.5	17.0	15.2	225°	15.0	13.6	225°	67	225°	effect of water levels
V2	2.0	17.0	15.2	225°	15.0	13.6	225°	67	225°	effect of water levels
V3	1.0	17.0	15.2	225°	15.0	13.6	225°	60	225°	effect of wind speeds
V4	1.0	17.0	15.2	225°	15.0	13.6	225°	55	225°	effect of wind speeds
V5	1.0	17.0	15.2	225°	15.0	13.6	225°	67	212.5°	effect of wind directions
V6	1.0	17.0	15.2	225°	15.0	13.6	225°	67	237.5°	effect of wind directions

The effect of varying water levels on the resulting wave conditions is related to the depth limited wave breaking. For the assessment of the effect of different water levels that were chosen in the previous chapter on the resulting wave conditions near the coast, the results from the simulations V0, V1 andV2 are compared. The depth induced wave breaking in the project area occurs in water depths below 25 to 20 m. This is exemplarily shown in Figure 4.21. The location of the output curve C01 is illustrated in Figure 4.14. If the water depths are higher than 20 to 25 m, no effect of the water levels are noted on the resulting significant wave heights (see bottom and top of Figure 4.21).

Due to the resolution of the computational mesh, which is equal to the resolution of the nearshore bathymetry (30 m), and the output interval of the wave parameter along the curves (10 m), the wave parameter are compared along each output curve at different distances between 10 m and 40 m seaward of the shoreline, which was assumed to be located at MSL+0 m. The results of the comparisons are summarized in Appendix H (Table H.1).

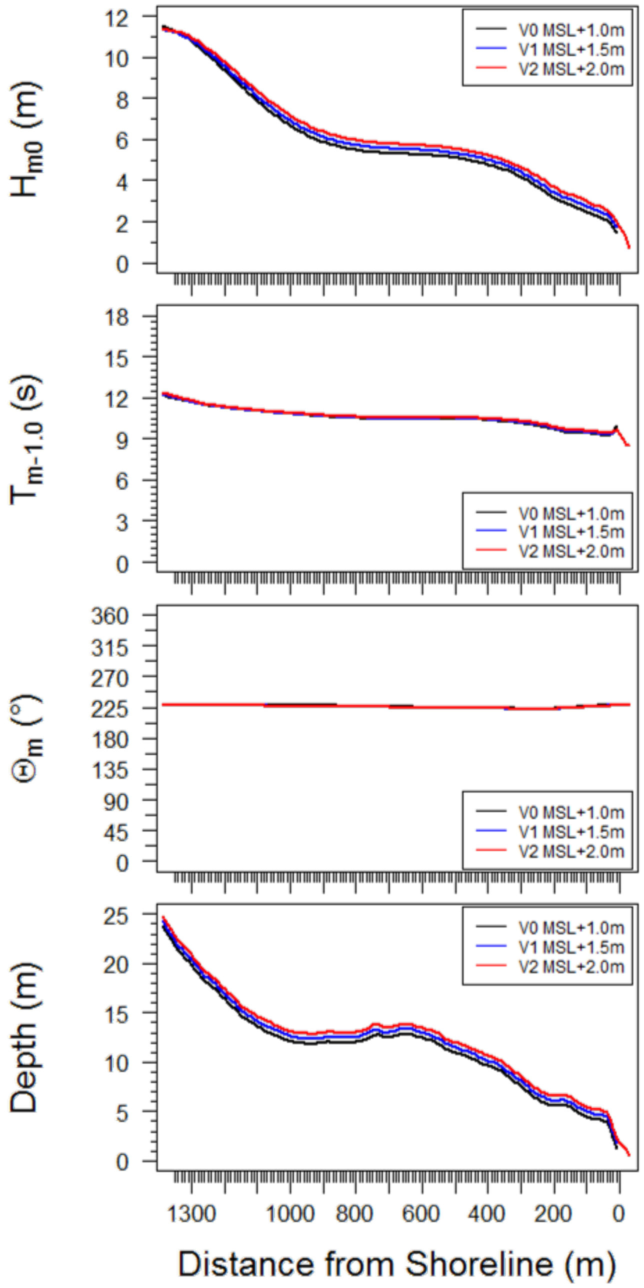


Figure 4.21. Wave conditions along output curve C01, numerical simulations V0, V1 and V2

For the assessment of the effect of different wind speeds and directions over the model domain that were chosen in the previous chapter on the resulting wave conditions near the coast, the results from the simulations V0 and V3 to V6 are compared. In the simulations V0, V3 and V4, the wind directions, wave boundary conditions and water levels are kept constant (Table 4.3). The results are summarized in Appendix H (Table H.2). From the results it can be concluded that the effect of increasing wind speeds from U_{10} = 55 m/s up to U_{10} = 67 m/s has no significant effect on the nearshore wave heights. Due to the relative shallow water depths near the shoreline, higher waves of the wave distribution that are caused by higher wind speeds will break due to the depth limited wave breaking.

In the simulations V0, V5 and V6, the wind speeds, wave boundary conditions and water levels are kept constant (Table 4.3). The results are summarized in Appendix H (Table H3). From the results it

can be concluded that the effect of changes in wind directions from θ_m = 212.5° (SSW) to 237.5° (WSW) has no significant effect on the nearshore wave heights, due to the relative short fetch lengths and the depth limited wave breaking.

In conclusion, maximum significant wave heights up to H_{m0}~11.5 m and spectral wave periods of $T_{m-1.0}$~12 s heading from SW (225°) have been identified 1350m offshore the shoreline and in water depths of ca. 25 m. The wave heights are continually decreasing towards the shoreline mainly due to the effect of the depth limited wave breaking. Changes of the wind speed and direction over the model domains are not significant for the nearshore wave conditions. The results of the numerical simulation V2 are selected as the design wave parameter for the recommendation of flood protection structures in the study area and the reduction of coastal flood hazards (see Section 5.2.5.2).

4.3.2 Wind and Storm surge

Since Irma had a landfall on Saint Martin as a category 5 hurricane, it brought extremely strong and dangerous winds. The winds caused substantial damage to residential, commercial and public buildings. As shown in Figure 4.22, the maximum wind was more than 70m/s (252km/hr). It did not bring a lot of rain. Hence inland flooding was not a major issue.

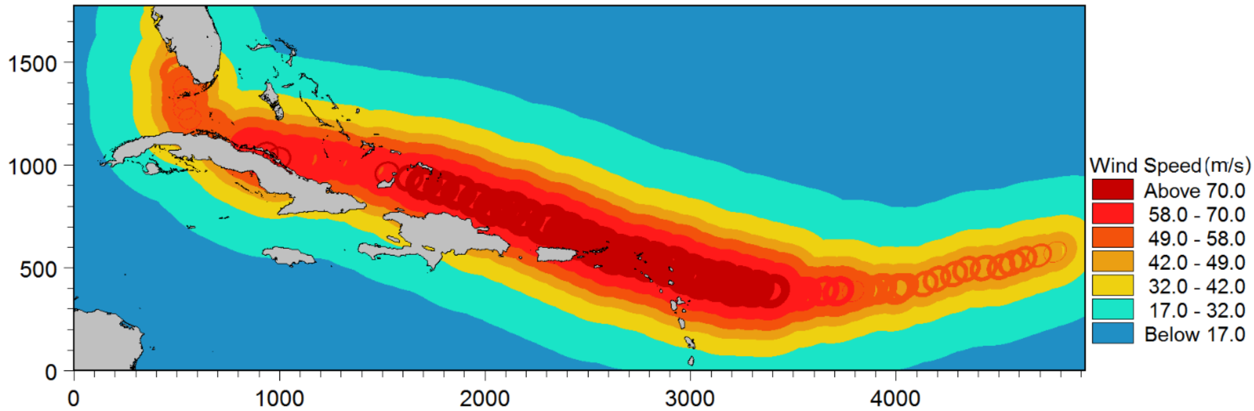


Figure 4.22. Maximum wind speed of Hurricane Irma

The strong winds and the low pressure of Irma also caused waves and storm surges. The French part registered extremely damaging waves, which many reported that it killed people and damaged properties especially in the French Quarter. The effect in Sint Maarten was milder, which damaged properties along the coast. Figure 4.23b shows MIKE21 flow model results of the storm surge hazard, flood extent and depth, which affected low-lying areas such as Princes Juliana Airport and Simpson Bay in Sint Maarten and Sandy Ground, Grand Case, Orient Bay and Oyster Bay in Saint-Martin.

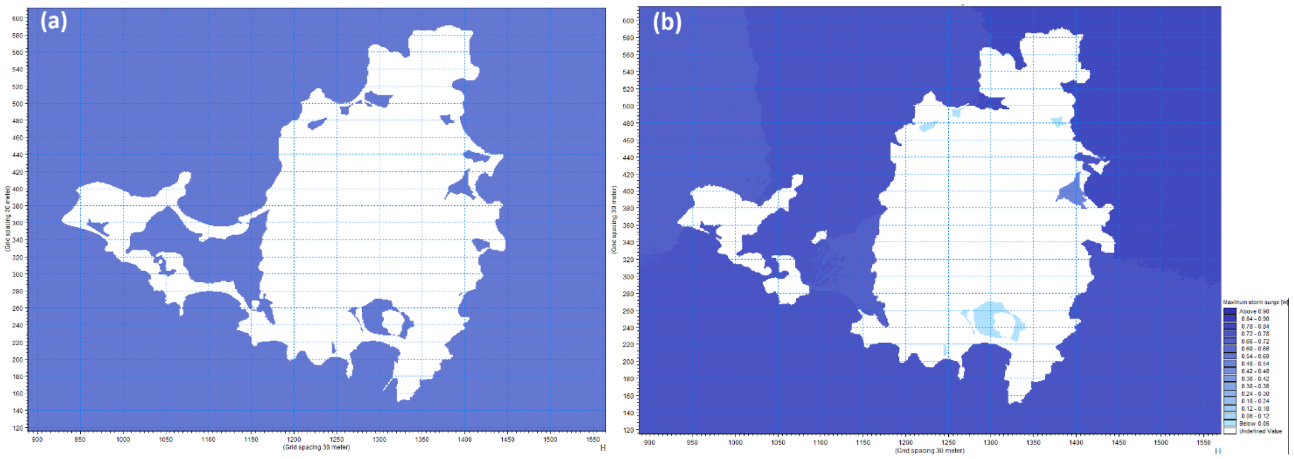


Figure 4.23. (a) Initial water level (without storm surge) and (b) model result showing maximum storm surge during Irma

5 Inputs for Reconstruction

In this section, we show modelling scenarios that are not directly related to Hurricane Irma but important to consider for the reconstruction process. These scenarios are related to inland and coastal floods, the potential impacts of tsunamis and the impacts of flood on road transport. The recommendations provided will be based on the fact finding mission analysis, the modelling work for Hurricane Irma and the modelling scenarios presented in this section. Hence, the recommendations will cover inputs that needs to be considered to reduce flood/hurricane hazard, vulnerability exposure and risk; to improve policy matters related to disaster management; to improve warning and evacuations; and to strengthen the work of first responders.

5.1 Scenario analysis of extreme weather event

5.1.1 Combined inland and coastal flooding

Due to its geographic location and topography, Sint Maarten is prone to flooding. The island experienced isolated heavy rainfalls which exceeded intensities of 150 mm/h. The storm water catchments and streams in Sint Maarten have several unique characteristics that contribute to the severity of flood related impacts. Urban environments are usually situated on low-lying areas, with little consideration for storm water drainage, and as such are subject to flash flooding (i.e. inland flooding) from surrounding hills or extreme rainfall events such as thunderstorms. The storm water channels or streams are often short, entering either the Salt and Fresh Ponds or the ocean as low or mid-order streams. They are typically inadequate to accommodate all the runoff due to the limited capacity, design/engineering issues (for example, channels with very flat bed gradient), obstructions and the morphological rising of the streambed. Those areas close to the sea, such as Philipsburg and Simpsons Bay, are also very vulnerable to inundation due to high water levels resulting from storm surges and waves. Typically, the localised flooding due to inadequate storm water drainage system happens almost every time it rains. In residential areas, the streets are usually narrow due to inadequate development control mechanisms and as such they represent a limiting factor for further enlargement of storm water channels.

During small rainfall events typical impacts would include temporary disruption to transportation systems and other inconveniences to life. During heavy rainfall events and storm surges, especially those caused by hurricanes, the large-scale flooding can cause a widespread damage to the residential and commercial areas and even loss of human lives. Other serious flood-related impacts such as unprecedented loss, personal pain, and social disruption must not be ignored.

To investigate the impact and risk of flooding, we build a coupled one-dimensional (1D) MIKE11 and two-dimensional (2D) MIKE21 hydrodynamic models that simulates inland and coastal flooding. The two modelling packages are integrated into a single, dynamically coupled modelling system through MIKE FLOOD[45]. The use of a coupled approach enables that best features of both 1D model and 2D model can be utilised, while at the same time avoiding many of the limitations of resolution and accuracy encountered when using MIKE11 or MIKE21 separately.

[45] MIKE11, MIKE21 and MIKE FLOOD are commercial products of DHI (https://www.mikepoweredbydhi.com/products)

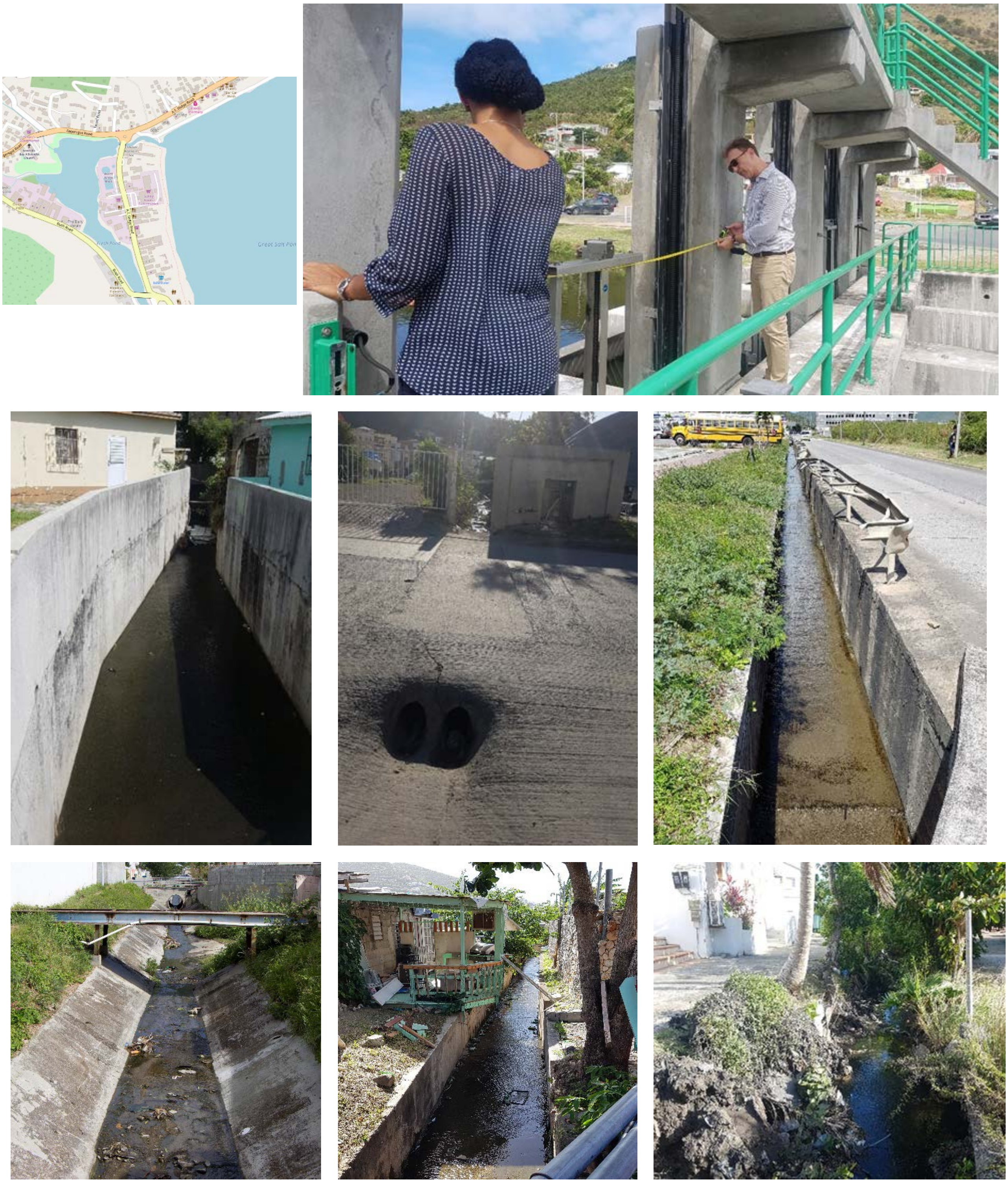


Figure 5.1. A flood gate and different channels in in Sint Maarten

The 1D MIKE11 model deals with the rainfall-runoff process and runoff routing along natural and man-made channels. The channel layout was defined from the contour maps and satellite photos of the island, and it has been adjusted from the field survey. One of the undertakings of the research team in the FFM was to assess and gather data related to the urban drainage infrastructure. IHE Delft has previously done flood related studies in Sint Maarten using drainage data collected a while

ago. Hence, the aim of the field mission was to measure new channels and drainage pipes and improved existing channels on the island. The work was done together with the Ministry of Public Housing, Spatial Planning, Environment and Infrastructure (VROMI) of the Government of Sint Maarten. We update the existing urban drainage models based on the recent data collected. Typical drainage channels and structures surveyed are shown in Figure 5.1.

The HD module of the 2D MIKE21 package was used to model flows in the floodplain. Apart from its use for coastal flooding and storm surge simulations, MIKE21 Flow Model can also be used to simulate inland flooding and overland flow modelling. The water levels and flows are resolved on a rectangular grid covering the area of interest when provided with the bathymetry, bed resistance coefficients, wind field and boundary conditions. The bathymetry for the MIKE21 simulation is a mosaic of digital terrain model develop from contour maps, sonar data measurements in the near shore and GEBCO bathymetry data for the deep waters. Figure 5.2 shows the coupled model setup within the MIKE FLOOD software environment.

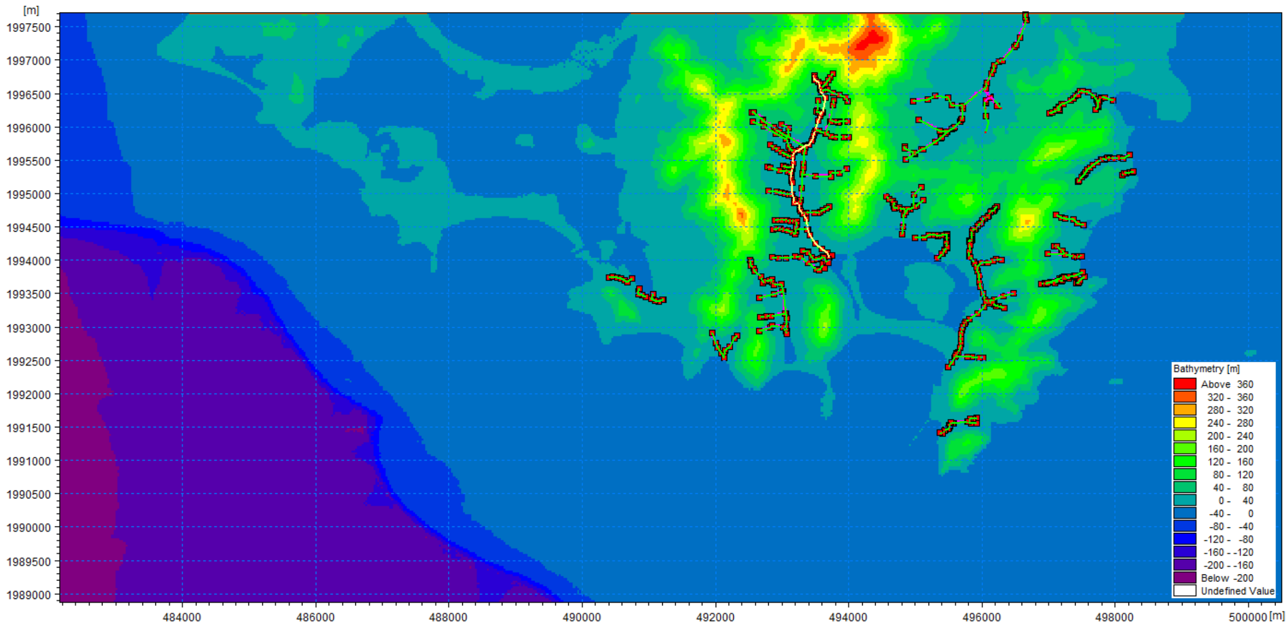


Figure 5.2. Coupled 1D-2D MIKE model setup showing open drainage channel layout and bathymetry

The coupled 1D-2D simulation is carried out for a rainfall of 100 year recurrence interval and a storm surge of 0.5 m. The boundary surge level is based on the surge simulation result shown in Figure 4.23. The simulation outputs, i.e., flood depth/extent and flow velocity, are illustrated in Figure 5.3 and Figure 5.4. The flooding in the Cul de Sac, Lower prince's Quarter, Little Bay and Madam's Estate is associated with the inland flooding whereas the flooding in Philipsburg, Cay Bay, Simpson Bay and Maho areas is mainly related to the coastal flooding.

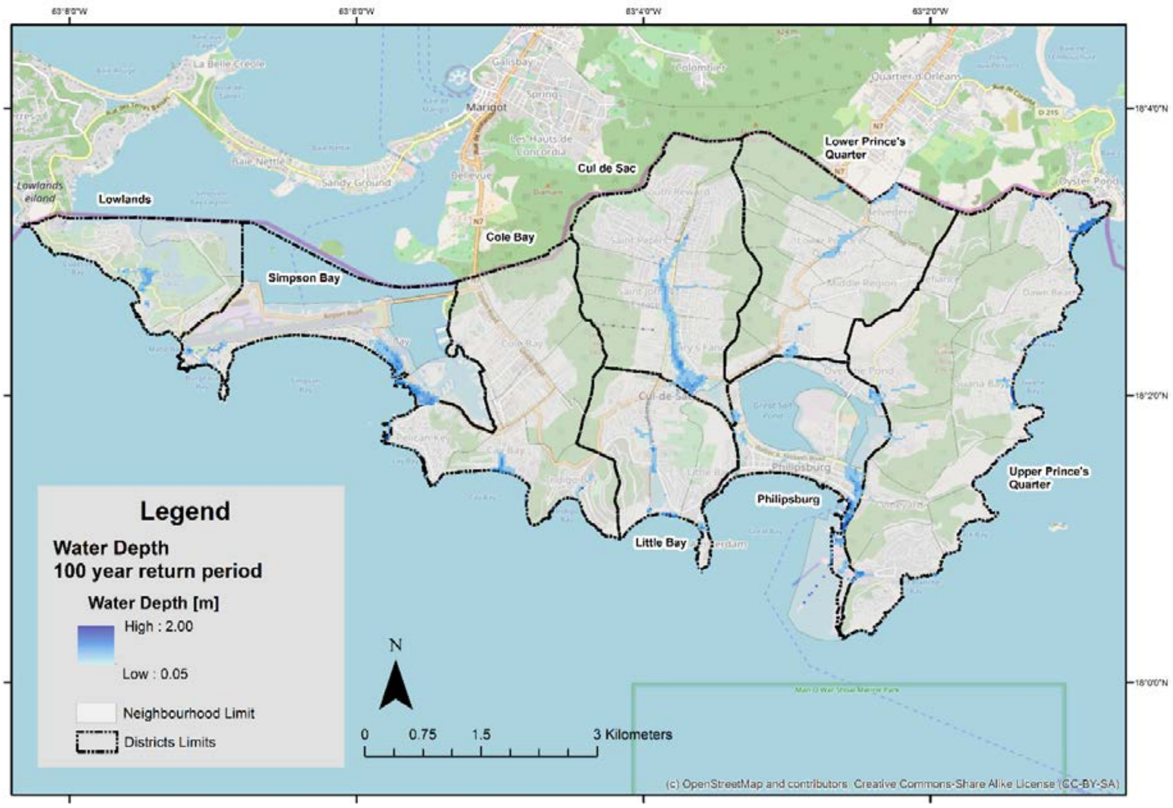


Figure 5.3. Maximum flood extent and depth map for a combined event of rainfall with 100 year recurrence interval and 0.5 m storm surge

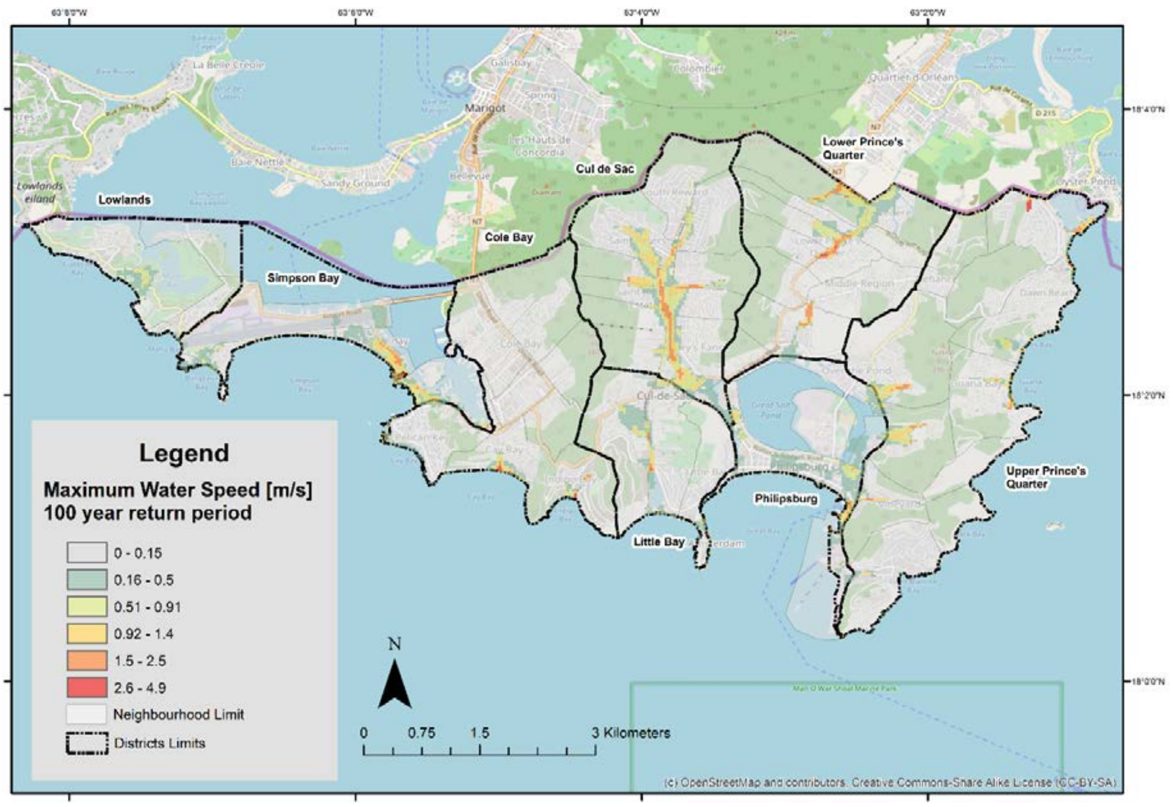


Figure 5.4. Maximum flood velocity map for a combined event of rainfall with 100 year recurrence interval and 0.5 m storm surge

5.1.2 Flood hazard

To compute the flood hazard, the two raster maps corresponding to water depth and water velocity (Figure 5.3 and Figure 5.4, respectively) are combined using the methodology presented by FLOODsite (2009). With this method, the hazard is computed by multiplying the flood depth with the flow speed and assign one hazard category given certain threshold based on the probability of getting injured or killed by the combined result of depth and speed of the water Table 5.1. The resulting hazard map using the threshold presented in Table 5.1 is shown in Figure 5.5.

Table 5.1. Flood hazards thresholds as a function of depth and velocity. Adopted from FLOODsite, 2009

Depth x Velocity (m^2/s)	**Hazard from flooding**	**Description**
Mid-range		
<0.25	Low	**Caution:** *"Flood zone with shallow flood water or deep standing water"*
0.25 to 0.50	Moderate	**Dangerous for some** (i.e. children and elderly) *"Danger: Flood zone with deep or fast flowing water"*
0.50 to 1.10	High	**Dangerous for most people** *"Danger: Flood zone with deep fast flowing water"*
> 1.10	Extreme	**Dangerous for all** *"Extreme danger: Flood zone with deep fast flowing water"*

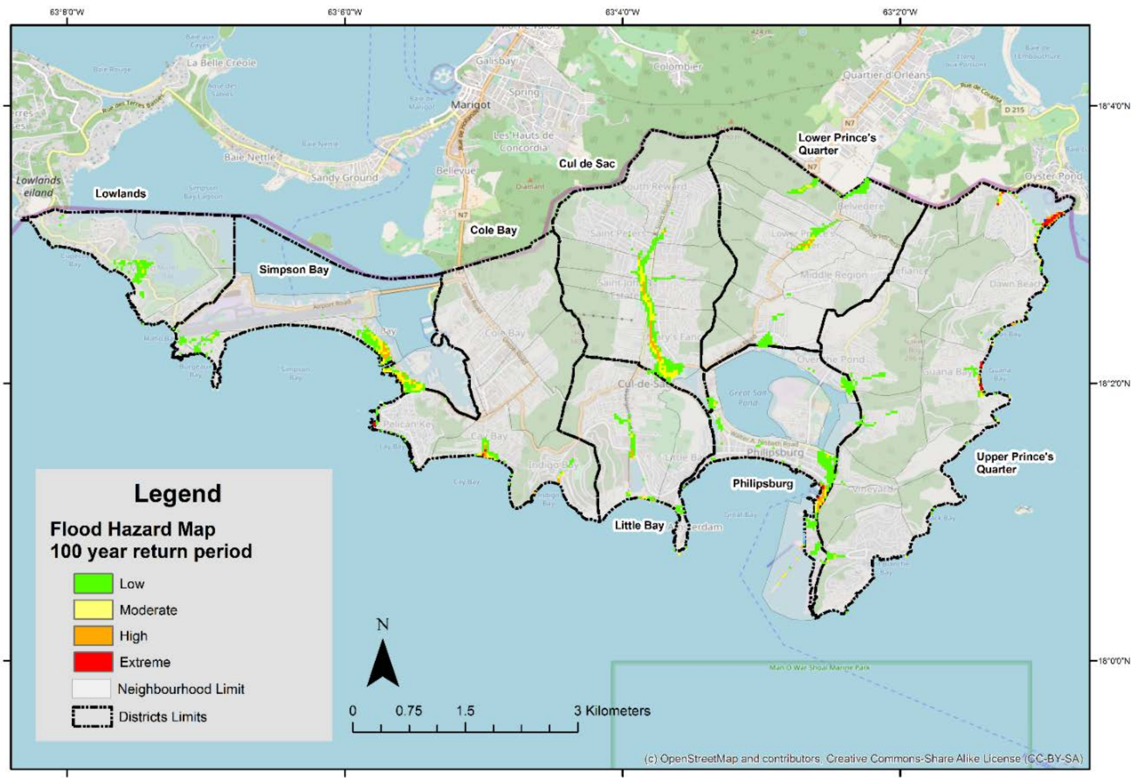


Figure 5.5. Flood Hazard map for a combined event of rainfall with 100 year recurrence interval and 0.5 m storm surge.

The most flood-prone areas exposed to high and extreme hazard are presented in Figure 5.6.

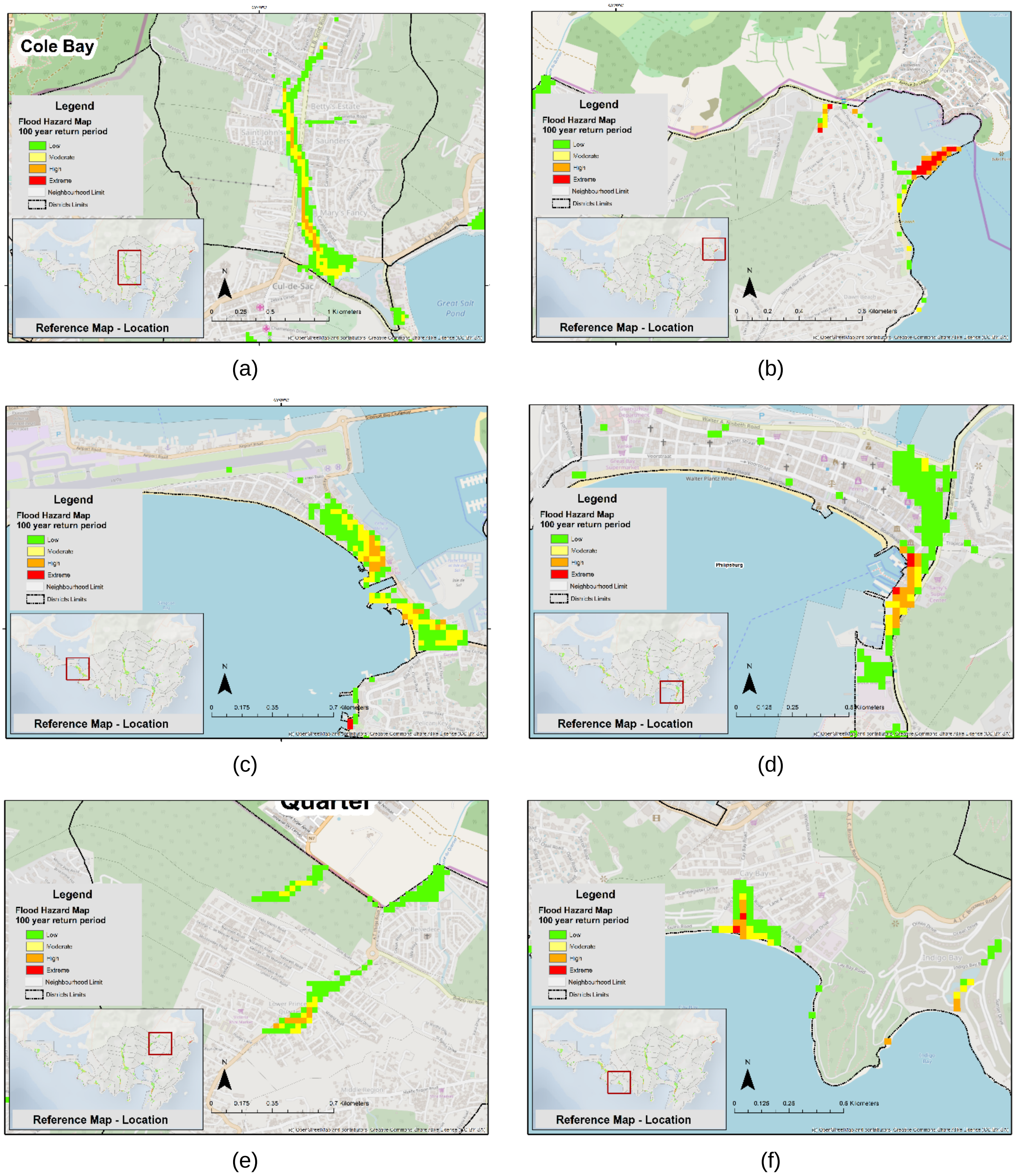


Figure 5.6. High and extreme hazards areas in (a) Cul de Sac district along the Zagersgut Canal, (b) Oyster Pond neighbourhood, (c) Simpson Bay along the Walfare and airport road, (d) Philipsburg area close to the Harbour area, (e) Dutch Quarter and (f) a region in Cay Bay in the proximity of GEBE power plant.

5.1.3 Flood risk assessment

The Intergovernmental Panel for Climate Change (IPCC 2014) defines flood risk as the potential for consequences where something of value is at stake and where the outcome is uncertain. Risk is

often represented as probability or likelihood of occurrence of hazardous events or trends multiplied by the impacts if these events or trends occur. In this report, risk is computed as the occurrence of hazards and vulnerability. Reclassified raster maps of the hazards and vulnerability maps (Figure 5.5 and Figure 4.8, respectively) are multiplied according to Table 5.2 and the product is the resulting risk for the island of Sint Maarten for a combined coastal and 100 years inland floods risk map shown in Figure 5.7.

Table 5.2. Hazard, vulnerability and risk reclassification values.

Hazards - H		**Vulnerability - V**		**H x V = Risk**	
Depth x Velocity (m^2/s)	Reclassified Value Hazard	Value	Reclassified Value Vulnerability	Value	
		16.13-24.26	Very Low = 1	0 – 2	Very Low = 1
<0.25	Low = 1	24.26 – 28.89	Low = 2	2 – 4	Low = 2
0.25 to 0.50	Moderate = 2	28.89 -31.94	Medium = 3	4 – 6	Medium = 3
0.50 to 1.10	High = 3	31.94 -35.08	High = 4	6 – 8	High = 4
> 1.10	Extreme =4	35.08 – 45.37	Extreme = 5	> 8	Extreme = 5

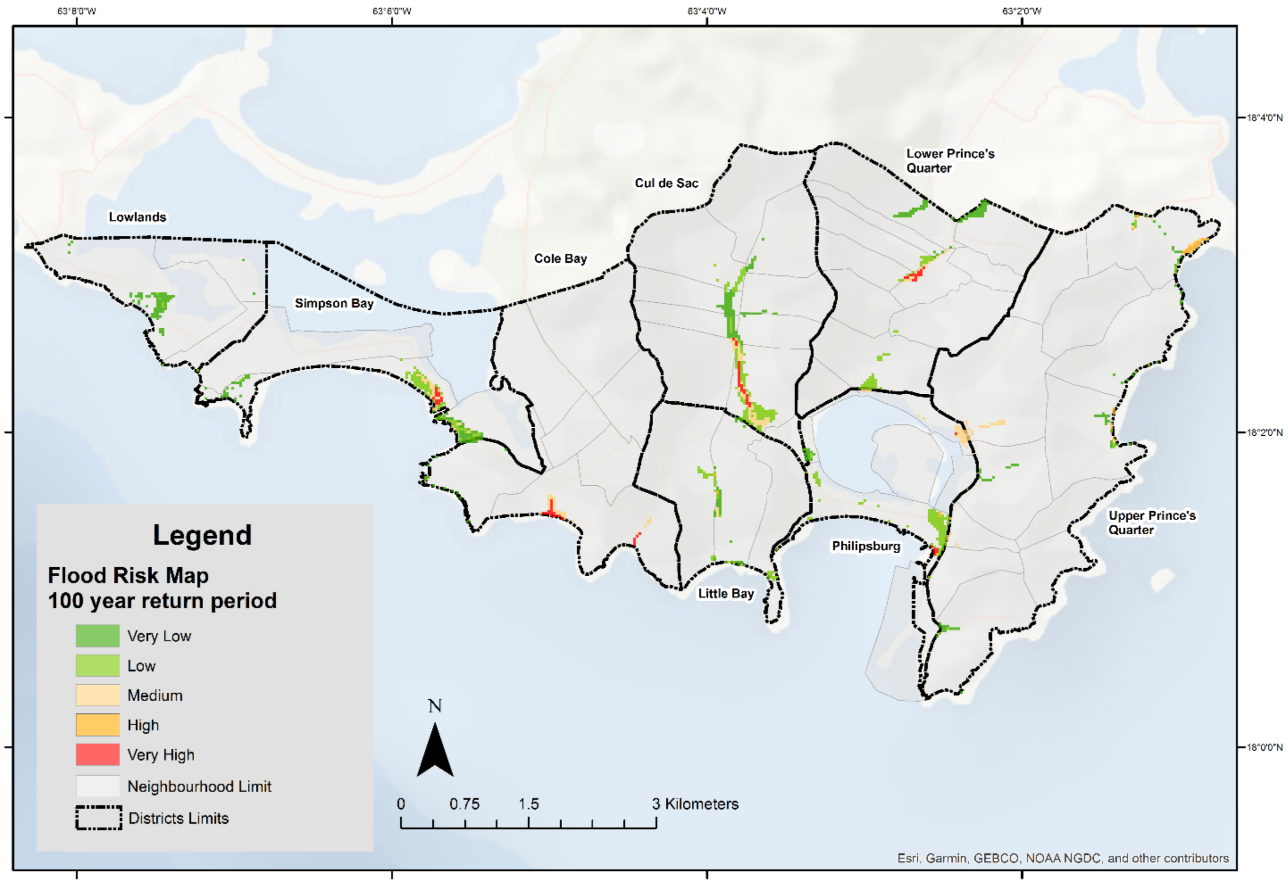


Figure 5.7. Flood Risk Map for a combined coastal and 100 years inland floods.

In addition, a closer look at areas with high and extreme flood risk is presented in Figure 5.8. In a similar way as presented with hazards the areas with high and extreme risk for this flood event

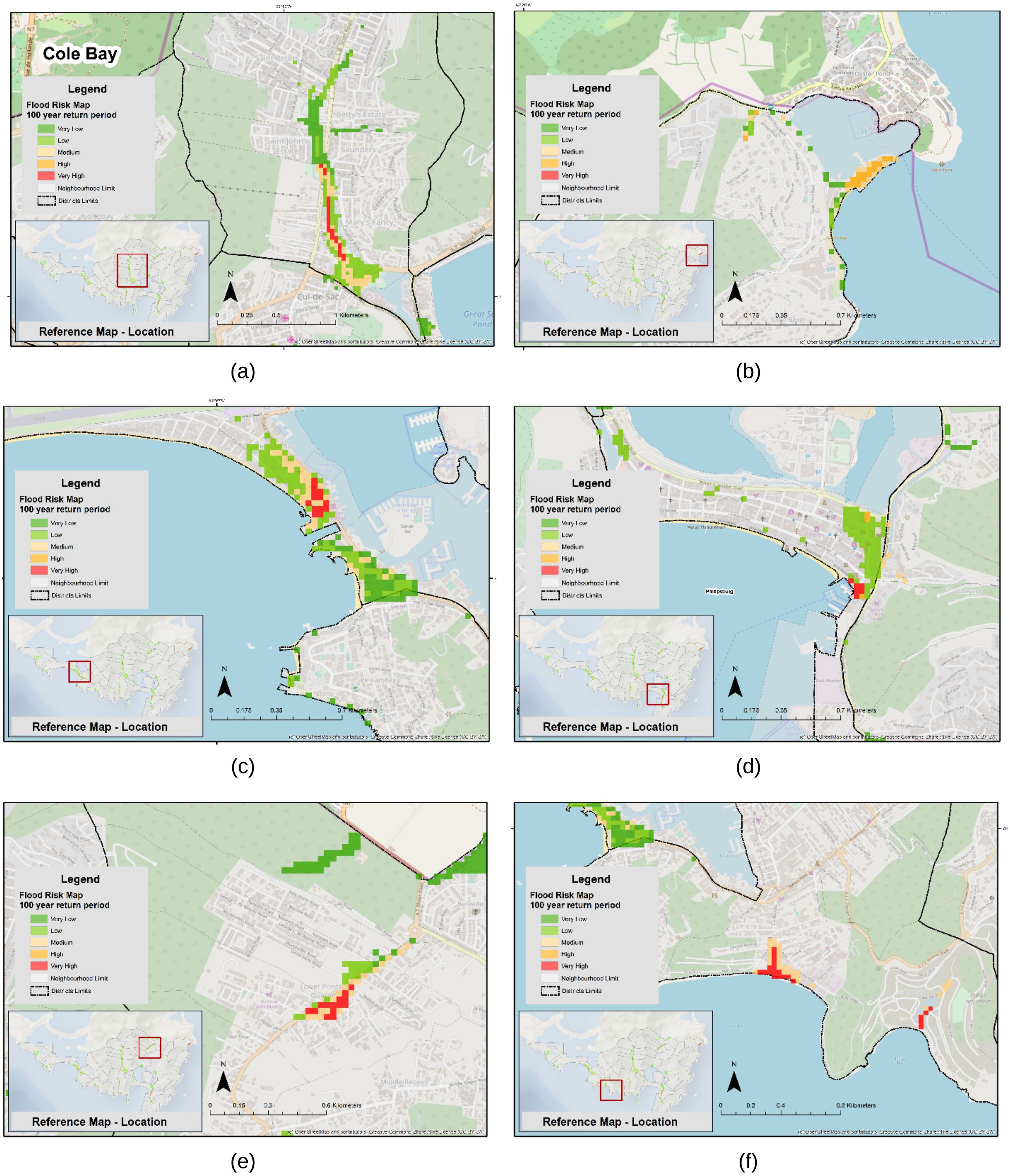


Figure 5.8. High and extreme flood risk areas. (a) Cul de Sac along the Zagersgut Canal, (b) Oyster Pond neighbourhood, (c) Walfare and airport road in Simpson Bay neighbourhood, (d) the east part of Philipsburg close to the Harbour area, (e) Dutch Quarter and (f) a region in Cay Bay in the proximity of GEBE power plant.

From this flood risk analysis, it is clear the need to have a holistic approach for the reconstruction of Sint Maarten after Hurricane Irma, where not only concern about high winds need to play a role in

the design of a resilient island, but floods need to be a high concern when projecting the investments in the reconstruction phase and prevent loss of life and structure from a more wet hurricane or heavy storm.

5.1.4 Potential impacts from tsunami

Tsunamis occurred in the Caribbean region in different periods of time. According to the Tsunami Research Center of the University of Southern California, the tsunamis fall into two categories[46]. The first ones are teletsunamis triggered by earthquakes along faults off the coast of Portugal. The two recorded teletsunamis striking the Caribbean region happened in 1755 and 1761. The tsunami of 1755, generated by large earthquakes centred near Lisbon, Portugal, produced a runup of 4.5 m at Saint Martin (affecting both the Dutch and French parts). The second categories are tsunamis generated by earthquakes along the faults of the Caribbean Plate boundaries. These resulted from seismic activity in the north-western portion of the Caribbean, near Puerto Rico and the Virgin Islands. The two most destructive events of this type are the Virgin Island tsunami of 1867, which killed 7 people in St Croix and 17 in St Thomas, and the 1918 Puerto Rico tsunami, which killed 140 people in Puerto Rico[47].

Hence, based on the historical evidence, there is a potential impact of tsunamis on the island of Saint Martin. Considering that, the IHE Delft team is developing a tsunami model. In the preliminary model, we assume a scenario of a magnitude 9 earthquake as a triggering factor. The assumed earthquake occurred about 115 km of the coast of Saint Martin, originated at 18.4°N, 62°W. We have used the GEBCO bathymetry in this model too. The preliminary result (Figure 5.9) shows that the coasts of Saint Martin can be subject to waves of up to 3.5 m. The tsunami model is under development and the result may change.

[46] http://cwis.usc.edu/dept/tsunamis/caribbean/webpages/index.html

[47] NGDC/WDS Global Historical Tsunami Database, 2100 BC to Present, NOAA (doi:10.7289/V5PN93H7)

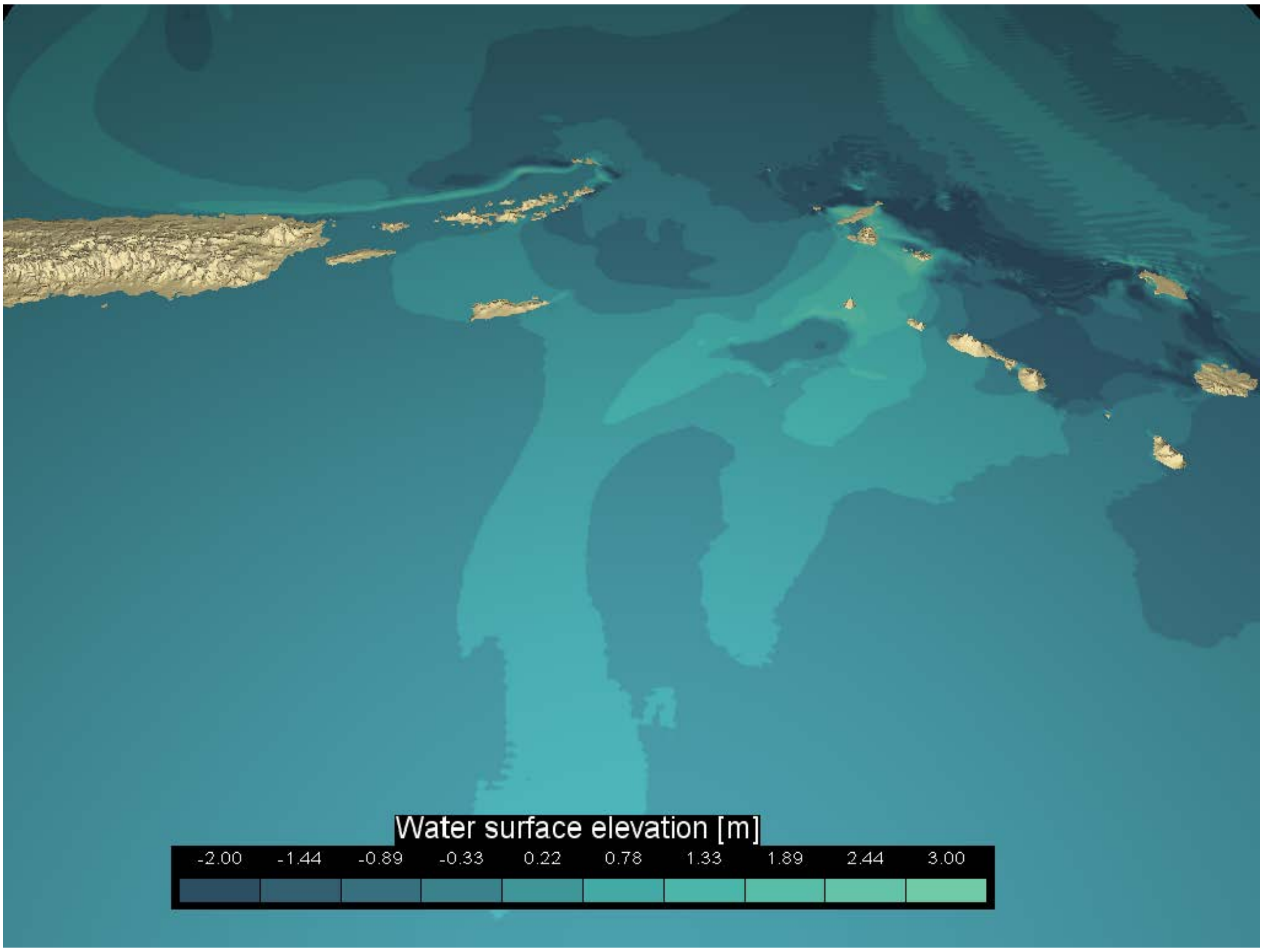


Figure 5.9. Preliminary tsunami model result showing the water levels

5.1.5 Flood impacts on road transportation

Sint Maarten's transportation system is already experiencing challenges due to a wide variety of reasons, mainly related to fast urbanization; the particularities of the terrain that limits network connectivity; and inadequate network capacity. On top of the delicate balance of the transportation system, the island is often exposed to hurricanes with immense impact. To assess the impact of flooding on road transportation, a microscopic traffic model has been integrated with time-varying flood modelling results. Due to the lack of traffic data in Sint Maarten, the model simulates randomized traffic demand to test the response of the network during dry and flood situations. Although the reliability of the traffic model may not be best, the traffic model is still able to capture some of the characteristics of the transportation system and the potential flood impact to the critical infrastructure (CI) on the island. This section explains the method of model integration and then discusses the knock-on effect of flooding on the traffic. As a recommendation, a mitigation measure was applied to the transportation model to investigate how this mitigation measure could alleviate the flood impact on the transportation CI in a crucial zone of Philipsburg.

Methodology

A novel framework for the integration of flood and transportation models has been produced within PEARL, which was described in (PEARL, 2017). The rationale is that flood conditions affect the

accessibility of particular roads so that vehicles would avoid driving into flooded waters. Therefore, vehicles that are originally passing through a flooded street are forced to choose an alternative route to reach their destinations. Consequently, these vehicles will experience longer travel times to complete their journeys. Because of the dynamic nature of transportation, the knock-on effect of events like that can expand further than the locations of the flooded areas and the durations of flood events. This rationale was applied in Marbella using two different approaches – static and dynamic. The static approach assigns a global duration of all the flooded locations in the city. It is very fast and straightforward, but it bears inherent problems related to the selection of that global flood duration value. The dynamic integration of the flood and the traffic models is more realistic because it captures the flood propagation over time by using time-varying flood maps as the input for the traffic model. The evolution of flooding is represented in the traffic model by closing the inundated streets for traffic. This is achieved by repeating the methodology multiple times for each time step. Within PEARL a special tool was developed to facilitate that dynamic interaction (PEARL, 2017).

Though, the dynamic integration still requires significant effort to ensure the models are properly coupled such that the approach was not feasible to apply in Sint Maarten because of the short duration of the project extension. On the other hand, the simple static integration is inefficient to represent the flood in the traffic model, because of the significant variation in the spatial distribution of the flood duration (up to 6 hours). As the flood model is run for the whole island of Sint Maarten including several catchments, which may react differently to a uniformly distributed rainfall. Moreover, the flood model also simulates coastal flooding, which has different drivers and durations from the inland flooding. Therefore, another approach was necessary to integrate the models in a more realistic manner, without compromising the temporal variation of the flood propagation. By applying a shift in the understanding of the methodology, a semi-dynamic approach has been developed especially for Sint Maarten (Figure 5.10).

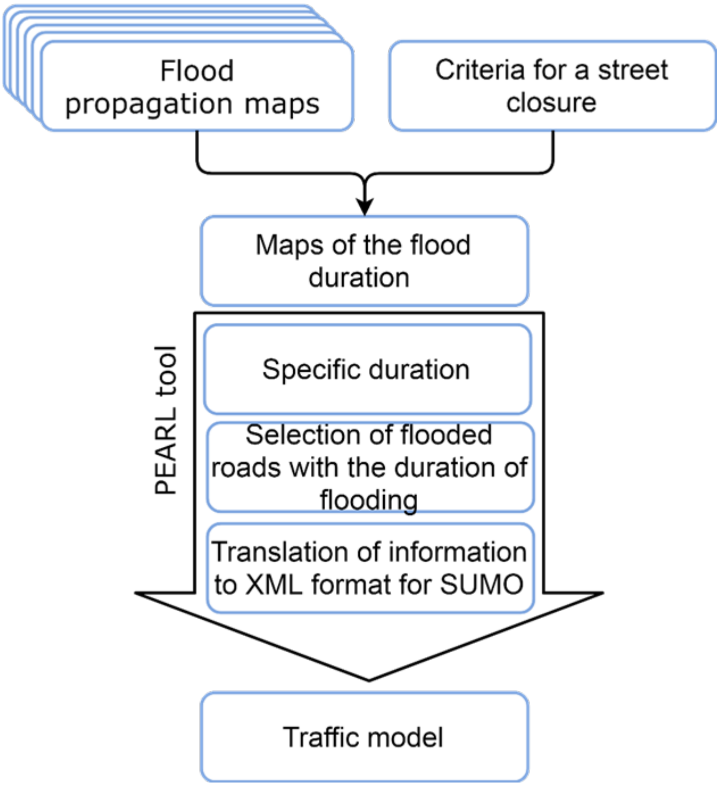


Figure 5.10. Methodology for a semi-dynamic integration of flood and transportation models

Instead of using a series of flood maps to capture the flood propagation, the new approach employs a pre-processing algorithm to analyse the duration of the flooding of each road. The flood duration is determined based on the period of flood water on a road that exceeds the criteria for street closure, assuming a road with flood deeper than 0.3 m is too dangerous for vehicles to pass through and will be closed for traffic (Shand et al., 2011; Martínez-Gomariz et al., 2017; Smith et al., 2017). That method practically eliminates the concept of shallow flooding that was previously applied to introduce speed reductions on the flooded roads with less than 0.3 m flood depth.

The output of the flood duration map is then further classified to the following categories: 0 – 10 min; 10 – 30 min; 30 – 60 min; 60 – 90 min; 90 – 120 min; 120 – 150 min; 150 – 180 min; 180 – 210 min; 210 – 240 min; 240 – 270 min; 270 – 300 min; 300 – 330 min; 330 – 350 min. Each category is regarded as a separate flood map and run with the PEARL tool to identify which streets will be closed for traffic. Although most of the categories have a range of 30 min, the first, the second and the last ones have respectively 10, 20 and 20 min duration. The first distinction was made shorter to accommodate very short-term flooding, whereas the highest value determined the maximum flood duration (350 min). Figure 5.11 depicts the flood duration map and it clearly differentiates the coastal flooding from inland flooding, because the coastal flooding has maximum duration.

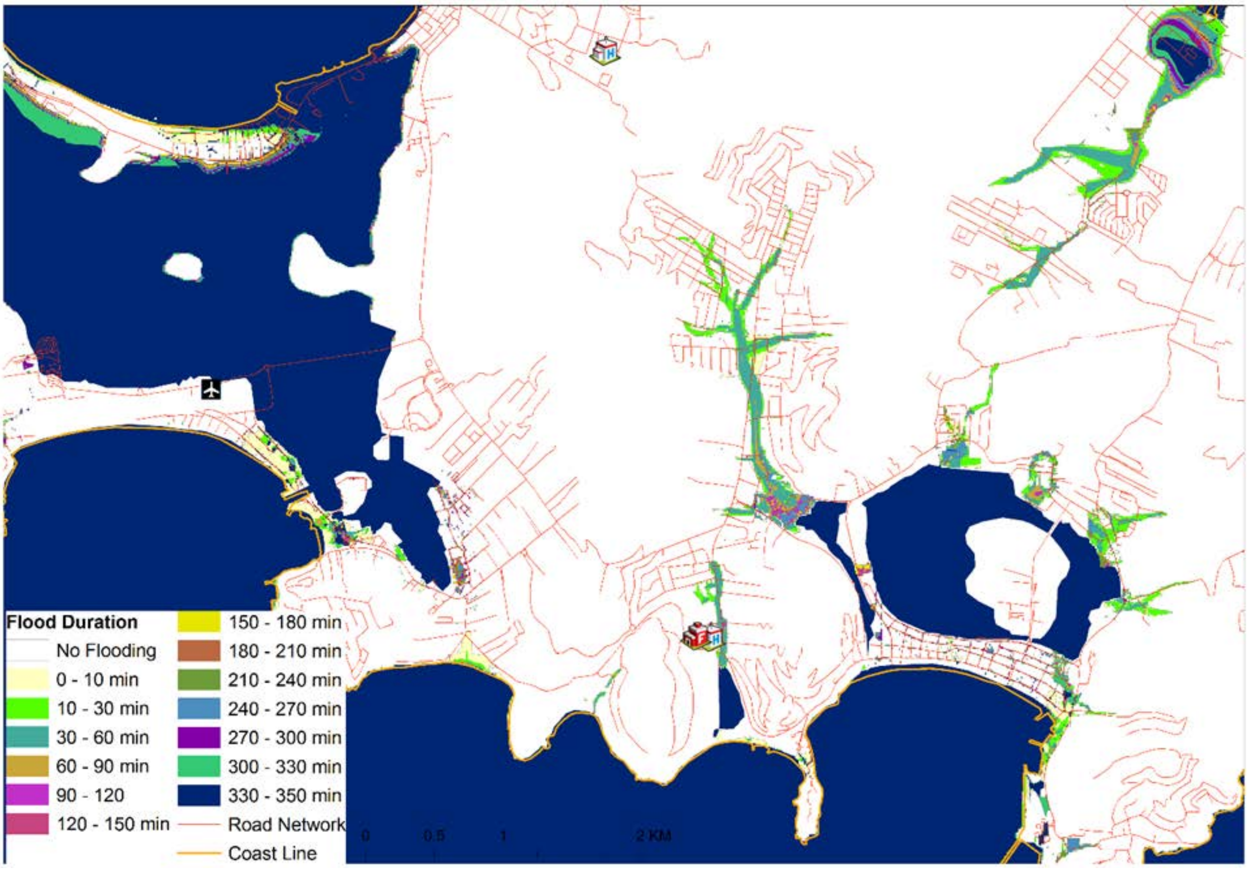


Figure 5.11. Flood map resulting from a rainfall with 100 year recurrence interval. Colours show flood duration classification.

As mentioned previously, the flood duration determines the period of the street closures in the traffic model. The street closures within one category require a single value which was considered to be the maximum value of the range. This assumption may lead to over-representing of the flood durations on the road but it was also reasonable to believe that a flooded road may not become

functional immediately after a flood has receded. This problem can be solved only with a dynamic integration between the flood and transport simulations, which was applied to the case study of Marbella within PEARL.

Another important assumption is related to the timing of the flood occurrences. The duration of the event does not provide any information when the flooding started and whether the areas with the same flood duration happened simultaneously. An observation of the flood propagation over time indicated that the rainfall-related events tend to start flooding almost simultaneously (with differences in the order of 5 min). Consequently, flooding with the same duration was assumed happening simultaneously from the beginning of the simulation.

The flood impact was estimated as a difference between transport conditions during dry weather and flooding conditions. Once the impact has been assessed, a mitigation measure was tested to assess how it potentially could alleviate congestion in critical areas of Philipsburg.

Traffic model set up

A microscopic traffic model was set up to simulate the mobility in the whole island of Sint Maarten. The model consisted of two main components: network capacity (supply) and demand models (Figure 5.12). The supply model represented the road network together with the rules to operate it, while the demand simulated the movement of people – when, from where and to where vehicles travel. The road network has been extracted from Open Street Map (OSM) and rigorously inspected and compared to Google Maps data, with special attention given to road classification and assigning correct speed limits. Due to the lack of traffic counts, the traffic demand modelling was based on a random trip generation. The route assignment method employs the shortest path by Dijkstra's algorithm. The randomized traffic simulation may not represent the actual road conditions accurately, but it was still capable of capturing trends and patterns. Most importantly, the microscopic traffic model has the ability to simulate knock-on effects of road closures on the whole transport system. As the flood duration was nearly 6 hours, the traffic simulation was set up to last for 8 hours traffic – one hour before and after the flooding.

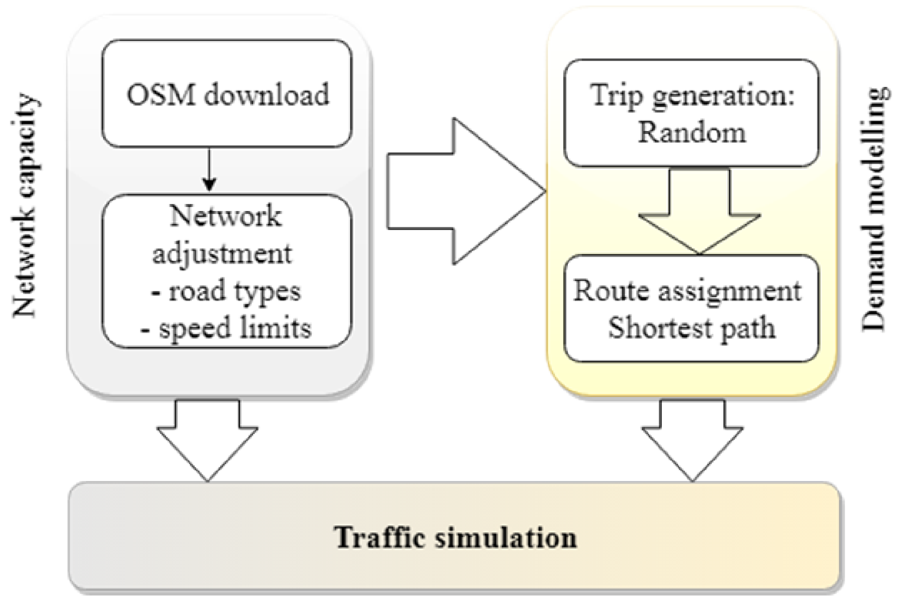


Figure 5.12. Flowchart of the implemented traffic model

Model results

The traffic model was run for both dry weather conditions and flood conditions. It was important to assess which of the roads suffer the knock-on impact of flooding. Maps for average vehicle speed per road per simulation hour were produced to visualize the speed changes when the two scenarios are compared. Due to the randomness of the simulations, some roads remained unused in the dry weather condition. Nevertheless, these roads can be used during the flooding conditions by vehicles that were forced to reroute. As these roads were originally empty, the rerouted vehicles would drive at a speed close to the maximum speed limit. The required output was meant to compare the used roads in both conditions and the not originally used roads were classified as a separate category. Once that assumption was set up, the road velocities were visualized in ArcGIS. Figure 5.13 depicts the speed changes between the flooded and the dry weather conditions between the 2nd and the 3rd hour of traffic simulation. That segment of time was selected because that is the period with the most significant flooding near the hospital and the fire brigade.

The largest speed reductions are registered on the main roads that creates a ring to connect Phillipsburg, Marigot and the north of the island where the airport of the French part is located (L'Espérance Airport). Because the main roads became blocked during the flood event (speed reductions 50 - 87 km/h), the flood impacts have propagated on the territory of the whole island and cannot be confined only in the vicinities of the flooded areas.

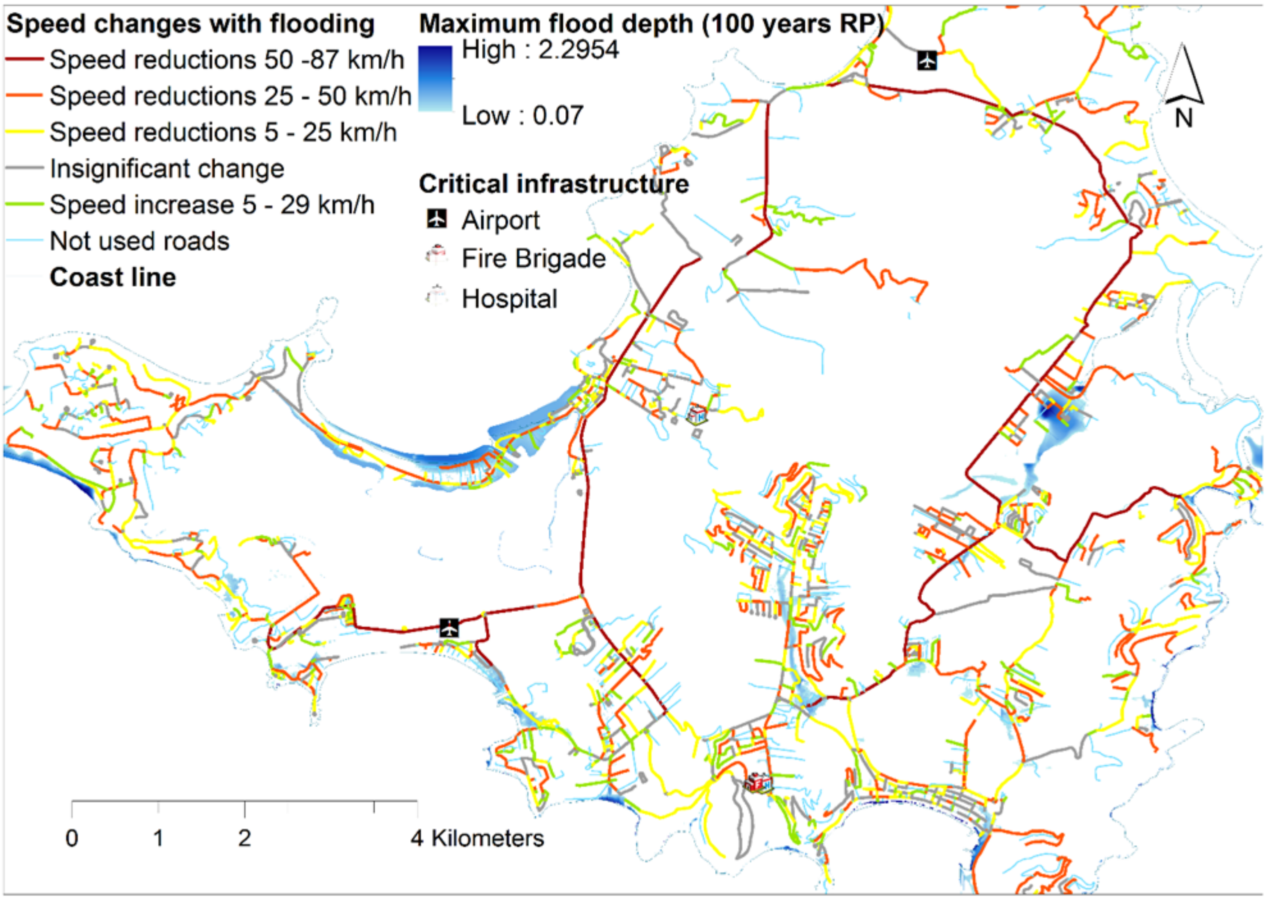


Figure 5.13. Speed changes per road between flood conditions and dry conditions

Figure 5.14 shows a histogram of the speed changes in the network which confirms that the flood impact is massive with 45% of all streets in the network experienced varying delays (speed reduction from 5 – 89 km/h). The speed increase during the flooding conditions is not negligible – 10% of all roads registers higher speeds than the normal conditions scenario. This can be explained by the routing mechanism used in the traffic model. The routes are based on shortest path, which may not always be the fastest route to reach a destination and in some cases when flooded, the rerouted vehicles may be prompted to travel on a less crowded road and thus partially alleviate congestion. However, the number of roads that have experienced certain conditions can hardly be representative of the traffic conditions. As seen in Figure 5.13 most roads that have experienced speed increase are short and usually located on the outskirts of the road network.

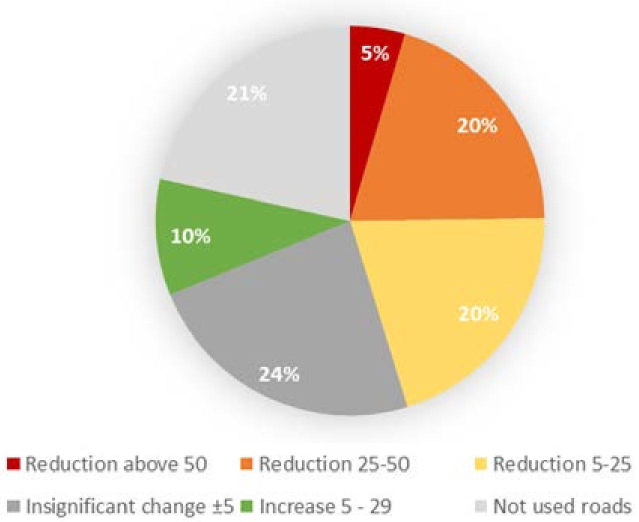


Figure 5.14. Histogram of the speed changes in the road network

5.2 Recommendations

5.2.1 Inputs to the recovery and reconstruction processes based on the RRCA analysis

Opportunities and challenges regarding land use and housing

Both sides: The pace of reconstruction efforts is creating concerns on both side and there is a trade-off between immediate and long-term risk management objectives. Long-term planning objectives and transformative visions are challenged by oncoming hurricane season. This time pressure creates concerns for long term safety regarding housing as in the meantime many self-repairs with little guidelines and scarce good quality material are taking place. Quick reconstruction efforts (often self-funded) raise questions about safety and equity. It is unclear whether vulnerable groups (e.g. government housing tenants) have access to appropriate support, not only financial but also technical as there is also a need to reconstruct taking into consideration the multi-hazard context of the island (i.e. earthquake, hurricanes, floods). Despite the existence of some form of social support on French side, there is on both sides a rise of social issues related to housing: rents have increased since Irma and triggered conflicts between renters and homeowners. The scarcity of housing and the pace of the reconstruction have also led people to share small spaces, creating concerns with regards to domestic violence and mental health.

Dutch side: Sint Maarten is currently attracting actors from the international community with experiences and, potentially transformative, knowledges from diverse places. However, alignment with government position may reduce discussions to technical aspects and processes, leaving discussions about alternative development pathways out. Opportunities for knowledge exchange in the short term (e.g. regarding housing and repair guidelines) and long-term (e.g. stronger regulation, structural changes) are bounded by tensions around local agency and politics. To date, there is little evidence of policy change with regards to housing and land-use. Moreover, while there is support to reinforce government capacity in the short term, this also challenges the coordination capacity of the government and raises questions regarding long-term capacities. Knowledge-exchange and capacity-building need to take place to ensure Sint Maarten government does not become dependent on external support - financially but also in terms of expertise.

French side: There is a quicker embedding of regulation and enforcement capacity to tackle unplanned urbanisation with a renewed dynamic in monitoring infringements and judicial action in this area, with cooperation between the COM and French State. However there is a need to strike balance between the State and local authorities and conflicting visions exist regarding what should be done for those living in risk areas (juridical uncertainty for 2 years). Regarding housing, the pace of the recovery has been affected by delays in insurance pay-out, with some heterogeneity between insurance companies. While on Dutch side insurances are more expensive (10% of house value) and less widespread, on French side insurances are compulsory for all people living in rented houses and in co-properties. Regarding house repairs, NGO expertise (e.g. Les Compagnons Batisseurs) has been used in some areas to ensure high standards and some guidelines are being drafted by the inter-ministerial delegation in collaboration with local actors and an expert centre in construction. It is unclear to which extent these will be used as time pressure is high and there is also a lack of supply for affordable, EU compliant, materials. The need to find a balance between local authorities and the State also limits knowledge exchange. For example in order to legitimate ideas coming from the State some compromise have to be made regarding which actors to mobilize.

Summary/Implications for recovery and reconstruction processes

Reconstruction processes taking place in Sint Maarten are both technical and political. The status of Saint-Martin and Sint Maarten determine who has the voice in reconstruction processes, how priorities are defined, and what the possibilities are. Questions over local autonomy and ownership vs. national concerns also affect the strategies used on both sides, creating both challenges and opportunities. On French side the State is developing a logic of partnership, working jointly with the Collectivite. The EU has a bigger regulatory influence and can drive priorities via funding attribution too. In Sint Maarten, the Netherlands are adopting a logic of mediation via the World Bank and creating a context which is attractive for the international development community. These differences open diverse spaces of opportunities with regards to funding, and to who gets funded, while rendering authoritative different forms of expertise.

However, in both cases the need to strike a balance between local autonomy and national sovereignty may encourage actors to reduce discussions to technicalities, leaving the politics out, therefore constraining ideas for alternative pathways and structural (transformative) change. This would be a missed opportunity, which has implications for long-term capacities, and narrows down how BBB is approached in practice. While Irma presents an opportunity to shift the development pathway of Saint-Martin and Sint Maarten, this can only be achieved if ideas regarding alternative sustainable pathways are discussed by key governance actors.

Recommendations

The 2018 Risk Root Cause Analysis for Sint Maarten is time-sensitive, and access to major partners such as the World Bank was not possible at the time of fieldwork. Our recommendations for the Sint Maarten government and its international partners at this stage are therefore contingent on current and perceived future trends, but also broadly based in earlier work from 2015 – 2016, which still provides a sound basis for understanding root causes post Irma. Current recovery-reconstruction responses have generated the opportunity for not only for substantial international finance into the island but also the provision of international expertise and knowledge on a scale unprecedented in Sint Maarten's post-Luis history. There is nevertheless a need to consider:

1. Whether underlying structural conditions that give rise to risks, and to periodic disaster losses and damages, are being addressed in a holistic manner. Risk Root Cause Analysis in PEARL can assist in identifying those structural pathways, but facilitating spaces for learning and reflection may also need to be supported to realise 'Building Back Better' in the full sense of the term.
2. Dutch Sint Maarten has yet to address underlying issues of land use and building regulation through comprehensive plans and policies, recognising the need for stronger monitoring and enforcement through strengthened capacities and political support, whilst protecting the most marginalised populations from expropriation and forced investment (asset loss) from enforced regulation. This should include supporting the value of ecosystems to disaster risk reduction.
3. How to address the trade-offs between short-responses to the impending hurricane season – already hindered by labour and materials shortages – and the need for built-in regulation as well as to reduce exposure.
4. How to embrace the potential for knowledge exchange whilst ensuring government capacities are strengthened in the long-term, and local autonomy and ownership enhanced.
5. How to improve the capacity, transparency and accountability of the Sint Maarten Government (identified through the root cause analysis as a root cause driver), whilst addressing local needs for restarting the economy and livelihoods which are also vital to development and social welfare.
6. How to address broader governance conditions, such as democratic accountability, without which there is a missed opportunity to tackle underlying governance risk drivers on the island. While little data exists regarding how the most vulnerable are coping with Irma, the risk is that the lack of representation of social groups in politics widens existing inequalities between different parts of the population.
7. The implications of "self-recovery" – particularly given the lack of widespread insurance coverage and lack of public social assistance – for long-run equity and vulnerability to future risks.
8. The possibility for greater Dutch-French co-operation to lead to locally-appropriate knowledge sharing, given common contextual conditions. Efforts should be made to ensure this dialogue is not only a reaction to Irma but is a sustained response that will be maintained over the long term. Aid given on the basis of Dutch-French co-operation, however, needs to recognise the historic constraints to co-operation, including language and administration structure, and support efforts to overcome these.

5.2.2 Reducing Vulnerability/increasing resilience

One of the most common phrases that the team constantly heard during the fieldwork was: “hope for the best, plan for the worst”. This should be a slogan put to practice every year during hurricane season for both government officials and inhabitants. Nothing should be left to chance. Proper annual maintenance of houses, roofs, windows and shutters; hurricane provision kit and cleaning up of streets and open spaces on the island needs to be done before the hurricane season starts.

The Government of Sint Maarten should look the aftermath of Irma not only as a challenging time but as an opportunity to build a more resilient future for the island. The government and inhabitants need to prioritise investment that adapts better to extreme weather events in the region together with disaster risk reduction measures. To reduce vulnerabilities and increase resilience of inhabitants and the government, the following recommendations are given.

- In addition to better building codes mentioned before, the government needs to improve the inspection and enforcement of the codes. The PEARL research team has witnessed that after Irma reconstruction of houses was underway by inhabitants without the permit and inspection of the government body (i.e., VROMI).
- Control the quality of construction materials that enter the island.
- Review and improve vulnerability and risk zoning to floods and hurricanes in the different neighbourhoods of the island
- Review the land lease strategies implemented by private landlords to allow the construction of concrete houses
- Improve the evacuation of elderly people: The Government of Sint Maarten, in close cooperation with the White and Yellow Cross Foundation, should have a complete census of the exact location of elderly people and put in place an evacuation plan for this vulnerable group when a hurricane or storm is forecasted to hit the island. This plan should contemplate provision of shelter and transportation.
- Support the role of religious groups: Religion in Sint Maarten plays an important role in everyday life of the society. After Hurricane Irma, the importance of religious organizations is vital in the recovery and mental/physical support of the most vulnerable communities. The Sint Maarten Government should create proper mechanisms to support the role of these groups in the island.
- Improve the insurance culture and promote better insurance coverage: Inhabitants of the island are aware of the financial impacts of hurricanes and the relevance of house insurance protection. However, one of the main reasons for citizens of Sint Maarten for not having a house insurance is the difficulties to receive a proper and fast payout in the aftermath of a hurricane. During the household survey, interviewees mentioned that they stopped their insurance after Hurricane Luis as they had bad experience with payouts. To increase the insurance coverage, the Sint Maarten Government may need to intervene as an intermediary to help the claims process. However, to get proper payout, policyholders should inform the insurance company any expansion works done and renegotiate the premiums.
- It was mentioned by several respondents during the household survey that the Sint Maarten Government should have a hurricane fund and add financial resources to the fund every year from the taxation to be used in disasters like the one caused by Hurricane Irma. This will allow the independent island state to finance the reconstruction with less dependency on the Dutch government or other external financial organizations or donors.

- Adopt better construction techniques: The metallic roof that shows better resistant based on empirical observations in the fieldwork was the hipped type of roof (**Figure 5.15**) compared with the pitched rood (Figure 4.1a and b). This is consistent with previous studies on damage assessment after a hurricane (ECLAC 2017, Red Cross, 2017). It is recommended to those using zinc to adopt the hipped roof technique.

Figure 5.15. Houses in Sint Maarten with hipped type zinc roof undamaged during Hurricane Irma. Source: Own photo during field work in February 2018.

- Diversify the economy: An almost 100% economic dependence on tourism probe to be one of the biggest challenges for the island in the aftermath of an extreme weather event such as Irma. The income of almost all of the residents of Sint Maarten depends on tourism and as such at risk due to the lack of job opportunities with a hotel industry almost destroyed and making some of the jobs redundant or in the best of cases salaries and jobs being put on reduced wages.
- Invest in disaster risk reduction: The consequences of the 2017 Hurricane season in the Sint Maarten stress the importance of investing in disaster risk reduction in the island. And it has been proved that the disaster in Sint Maarten are not only for high winds, but the reconstruction should also take into account other hazards such as floods. This should be incorporated in the recovery and reconstruction works. The reconstruction period should be seen as an opportunity to rebuild the country as a climate resilience island. This resilience approach should include not only the impacts of high winds such as those of Hurricane Irma but need also to include impacts of floods. Impacts on the island could be even more disastrous if the hurricane brings huge amounts of rain as in the case of Hurricane Harvey in Texas USA, in late August 2017. The effort in the reconstruction of the island should include reinforced and/or construction of drainage infrastructure in the flood-prone areas.
- Improve security after hurricanes: Based on the remarks of interviewees, after major hurricanes, lootings are common experiences on the island. Strict curfews are needed to prevent the looting, which for a large number of interviewees was the most damaging to the economy and what really slow down the recovery of the island. The security can be improved by deploying adequate number of Dutch Marines immediately after the hurricane has passed. Furthermore, looting presents considerable impact to the economy of Sint Maarten and it has significant social impact that is recognized for most of the inhabitants, as observed during the household surveys. Hence, it is recommended that future assessments of impacts and losses such as the one conducted by ECLAC (2017) should include the impacts of looting as an indirect impact of hurricanes.

- Improve communication all over the island regarding curfews, cleanings, food and water distributions which was one of the weakest points in the perception of the inhabitants of Sint Maarten.
- Improve inhabitants' after-hurricane health condition: Few or nothing could be found regarding emotional impact assessment of residents after the disaster they face in the 2017 hurricane season. A proper record of people attending hospitals with stress, depression or anxiety as well the creation of a program to assist people in need in the aftermath of a hurricane should be put in place on the island. It is suggested to include a specific role in this regard within the organizational structure of the disaster management of Sint Maarten. ESF6 under the Department of Public Health (VSA) may take the lead of this work.
- Build strong shelters: The 2017 hurricane season, classified as extremely active with 17 named storms of which 10 become hurricanes including six major ones[48], is a clear evidence that Sint Maarten needs to build strong shelters to be able to warranty a safe roof for those in need. After Hurricane Irma smashed the island and left thousands of residents without roof they needed to seek a safe place. If Sint Maarten would have been hit by one of the hurricanes that were formed in the Caribbean after Irma such as Jose or Maria, the catastrophe would have been immeasurable in terms of fatalities and losses due to the lack of a proper roof for many of the residents in the island.
- Looking in hindsight, after the pass of Hurricane Irma over Sint Maarten, it ended up being an acceptable decision not to open the public shelters before the hurricane, because they are not designed to withstand category 5 hurricanes, as it was probed with the collapse of part of the roof of Sister Marie-Laurence and the New Testament Baptist Church. But is important to highlight that some residents needed the shelters to be open before the hurricane since their housing conditions were not strong enough and their social links (family or friends) were not good or did not exist at all, for example, as in the case of some undocumented immigrants.
- Install all power lines underground: One of the main impacts of Hurricane Luis in 1995 in Sint Maarten was on the power lines. At that time, most of the lines were installed above ground and the impact was an island without electricity for 4 to 6 months. After that disaster, the island started the installation of the power grid underground that lead to a very fast recovery after Hurricane Irma smashed the island with some neighbours having the power back just after two weeks. The lesson of Luis should be put into practice once more and the island should install the whole grid underground.
- The installation method used for the water meters in Sint Maarten was one of the most vulnerable elements to hurricanes that the team found during the fieldwork. As shown in Figure 5.16a, the water meters and pipes are completely exposed to the winds and flying objects during a hurricane. On the other hand, Figure 5.16b shows an example of how the electric meters are installed in the island protected by concrete walls. Therefore, it is recommended to follow a similar approach to protect the water meters.

[48] http://www.noaa.gov/media-release/extremely-active-2017-atlantic-hurricane-season-finally-ends

(a) (b)

Figure 5.16. (a) Water meters installation and (b) electric meters installations in Sint Maarten

5.2.3 Improving CBO's participation

CBOs matter to the response process in Sint Maarten. They are a crucial bridge to local communities and can help ensure that the response is 'joined-up', inclusive and leaves no section of the community behind. It is, therefore, very important that this constituent is protected, valued and is an integral part of the response. Recent humanitarian directives – such as the Charter for Change[49] and the World Humanitarian Summit's Grand Bargain[50] – explicitly recognise and demand that international aid actors value local agents and ensure they can access a larger proportion of aid funding. This is particularly relevant for Sint Maarten, where there is a high prevalence of international government partners for the post-Irma response. From the CBOs workshop there were instances of local organisations collaborating with INGOs, however this was not systematic or widespread.

Evidence from the LPRR project – and wider Community-Led Response (CLR) initiatives – shows that to support first responders they need access to unrestricted funds. This ensures that they can prioritise spend in-line with community needs – and has the benefit of building their capacity in disaster preparedness and response. Community initiatives in Sint Maarten such as in the St. Peter's district, where volunteers are leading hurricane preparedness activities in the face of a non-functioning community council, could potentially be enhanced by access to direct funding. Such access would support and encourage citizen agency in Sint Maarten.

Specific Recommendations are:

1. Ensure that government and its international partners support and involve CBOs in the response, by:
    - Sharing information on all aid mechanisms (and how to access and engage with them)
    - Coordinate with CBOs to ensure a 'joined-up' response, which leaves no-one behind. Regular meetings between government and CBOs – as was the case post-Hurricane Luis – are key to this.
2. Support and strengthen civil society to be a more effective body for the response and partner for government – capacity building of CBOs is key.

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[49] https://charter4change.org/

[50] https://www.agendaforhumanity.org/initiatives/3861

3. Recognise and partner with local unions in order to support the valuable role they are playing in the very fluid post-disaster employment sector
4. Prioritise re-construction of homes – particularly roofing – for the most vulnerable (elderly; migrant communities). Clear communication and coordination by implementing agencies is crucial for this.
5. Consider CBOs and encourage community pop-up groups to (temporarily) replace community councils as the pre-eminent district-level hurricane preparedness and response mechanism. Community councils in Sint Maarten are largely dormant and non-functioning – there is an urgent need to fill this gap with the annual storm season approaching. “Government used to organise with community organisations … we have to start doing it ourselves now. We need to get the community centres going,” local CBO.

From discussions with local CBOs in Sint Maarten other suggestions included Sint Maarten Government establishing a central data collection/disbursement office that could be easily accessed by CBOs in order to strengthen the information environment for the response; investment in public transport links to ensure poorer/vulnerable sections of the community were catered for; and a revision of post-disaster security provision to counter looting – the latter greatly damaged the social fabric in Sint Maarten.

5.2.4 Improving warning and evacuation

To improve the warning and evacuation in Sint Maarten, the following recommendations are forwarded based on the household and semi-structured survey analysis.

- Meteorological office bulletins contain very technical information. Even though the Met Office used standard warning terminologies, there should also be a mechanism to communicate with inhabitants using simple/plain language. For example, the location of the hurricane can better be communicated with the public in reference to distance (in km) from Sint Marten or any other Caribbean island instead of coordinates. It may also be advisable to use previous major hurricanes that impacted the island as a reference to inform the strength of a coming hurricane.
- It is recommended that the Met Office cross-checks more models in their analysis and forecasting not only for the track but also for the intensity of an upcoming storm in future hurricane seasons. This will allow to reduce uncertainty and have a more informed decision whether or not a hurricane will pose a threat to the island as well as how severe the impact could be. Regarding Hurricane Irma, the model that showed better performance to forecast the track of the hurricane was the European Centre for Medium-Range Weather Forecasts model (EMXI). The NOAA HFIP Corrected Consensus Approach (HCCA) model and the Florida State Super ensemble (FSSE) also performed very well for the prediction of the path of Irma (Cangialosi et al., 2018). Regarding the intensity, the Hurricane Weather Research and Forecast System (HWFI), Hurricanes in a Multi-scale Ocean-coupled Non-hydrostatic model (HMNI), and the Coupled Ocean/Atmosphere Mesoscale Prediction System Tropical Cyclone model (CTCI) had similar or slightly lower errors than the NHC official forecasts (Cangialosi et al., 2018).
- Hurricane Irma will bring more awareness for hurricane prevention and people of the island will remember the effects of this hurricanes for many years to come as it already happened with previous major hurricanes that hit the island (e.g., Hurricane Luis). Reaction and

preparation from the inhabitants are expected to be high in the coming hurricane seasons but this is an effect that is expected to fade through time. Therefore, regular hurricane awareness campaigns must take place in the coming years. It is important that parents pass their experience/knowledge of Irma to the next generations as it was observed that younger generations of Sint Maarten did not know what a “real” hurricane can do to the island.

- Radio, internet and television are the preferred methods to get the latest information during a hurricane in Sint Maarten. Authorities should consider reinforcing their ability to officially use these channels to properly communicate warning and evacuation instructions before and in the aftermath of a hurricane. Due to the multicultural background of the inhabitants of the island, warning and evacuation messages should be transmitted at least in the three main languages spoken in the island: English, Spanish and French. It was identified that many of the Spanish and French speakers in the island do not have a proper knowledge of English.
- Radio is the most important source of information on the Island, even more than internet. But, the fact that social media platforms such as WhatsApp and Facebook were also broadly used during and after the pass of Hurricane Irma is showing the shift on technologies and the important role of mobile applications for disaster management. Even officials from the government use those platforms to communicate and plan actions before, during and after Irma. The Sint Maarten Government should utilize this opportunity and invest in developing specific applications to communicate the latest and official news in one centralizaed place and campaing so that residents and tourist to use them.
- The government should force the closure of schools, government offices that are not directly connected with disaster management, hotels, businesses and industry at least two or three days prior the potential landfall of a hurricane to allow enough time for residents to properly prepare their homes for the hurricane.
- Tourist should have been evacuated from the island before Irma’s landfall. Evacuating tourists after the hurricane passed took valuable and scare resources that could have been used to help those residents in more need in the aftermath of Irma. The government should evaluate and perform a cost-benefit analysis of a mandatory evacuation of tourist for future hurricane seasons.
- Before major hurricanes hit the island, the Sint Maarten Government should arrange with airlines and cruise ships to increase the number of available seats for those residents and tourists who want to leave the island. This proved to be a limiting factor during Hurricane Irma where many tourists and residents could not travel due to the shortage of available means of transport.
- Prior the start of the hurricane season, the disaster management team and ESFs should be evaluated if ESF members are clear on the functions and to detect possible wrong doings and be able to correct them in case of need.
- Due to the tragedy of Irma and due to people’s perception on the poor management of the government during this disaster there is a big chance for the government to be tempted to ask for massive evacuations during a possible threat in the next hurricane seasons. It is advisable to the government to not react based on fear but to be really informed using several sources as mentioned before in this report to have a proper forecast and communicate it properly to the residents of the island. Creation of panic should be avoided at all times.
- One of the key aspect during a hurricane is the ability to have constant access to communication and also to be able to communicate as soon as possible with family members and relatives to report safety. Nowadays, internet is a very reliable and fast way of

communication. During Irma, DSL internet provider managed to maintain the internet service running. A closer look on the infrastructure of its provider should serve as a guide in the reconstruction process for the other providers.

- Sint Maarten government lost a lot of credibility in regards to disaster management, warning and evacuation communication. It is advisable to have several awareness campaigns before the next hurricane season starts to regain the trust of the inhabitants and be able to properly communicate the possible threats the island may face in the near future.
- Sint Maarten needs strong shelters that could sustain a category 5 hurricane. Building a dedicated shelter might be considered as wasting resources as major hurricanes may not happen very frequently. However, the Government of Sint Maarten should invest on the schools and community centres used as public shelters to be hurricane category 5 resistant. Only in this way, people will start considering evacuation to public shelters as real option, rather than staying at home.

5.2.5 Reducing flood risk

5.2.5.1 Reducing inland flood hazard

Even if flooding was not the major problem during Hurricane Irma, it is a common issue in Sint Maarten and has been strongly associated to hurricanes in the past. As a result, we propose and describe below structural measures for inland flood risk reduction.

Measures selection: A questionnaire has been developed and applied in this case to learn about local characteristics, issues and preferences. The questionnaire has been filled for people related with technical decision-making processes and people related to political decision-making processes. The questions answered cover issues as flood type, physical site characteristics, drainage system characteristics, land use and preferred co-benefits for the area under study.

From the answers obtained it is concluded that the main flood problem in the area is related to pluvial issues and has characteristics of flush floods. Several site characteristics are understood through the answers. For example, the soil has medium permeability and the water table, as well as the bedrock, have depth higher than one meter. The surface slope is higher than 5% and the sewer system is separate. However, there is also illegal combined sewer system. The area is already developed, and the main land use is residential with medium to low density. It is not possible to rise or relocate buildings and assets under risk in the area. The availability of public spaces is less than 25% of the area and there is low space availability along roads and sidewalks. Finally, combined sewer overflows are identified as an issue in the area. Regarding preferred co-benefits, liveability improvement and socio-cultural benefits are identified as the most important for the area. Water quality enhancement and environmental benefits are seen as second in importance in this case, and economic co-benefits are seen as the least important.

Finally, decision makers identify flood problems affecting buildings and generating high damages in the area as occurring every two years. Besides, they identify budget restrictions when investing on infrastructure for flood management. Lastly, they see the achievement of co-benefits as a medium to low importance objective for the area under study.

The answers to the questionnaire were introduced into a measures selection tool (Alves et al 2018). This tool uses multi criteria analysis to develop a ranking of possible infrastructural measures to be

applied in the area. The ranking obtained (Table 5.3) is not seen as a final solution, the measures best ranked are analysed and few of them are selected for further study.

Table 5.3. Ranking of selected measures

Measures	Final Score
Closed conduits / Pipes / Tubes/Tunnels	22.4
Multi-functional open detention basin	22.2
Retention ponds / Buffering ponds	20.9
Daylighting, de-culverting, opening watercourses	20.8
Open water channels and rills	20.8
Water / Blue Roofs	20.5
Rainwater disconnection	20.0
Green Roofs	19.9
Grassed channels / Vegetated ditches / Dry swales	19.8
Rainwater Harvesting / Rainwater tank	19.1
Wetland channel / Bio-swales	19.0
Rain gardens / Bio-retention area	18.6
Infiltration Trenches	17.5
Soakaways / Dry well / Infiltration boxes	17.5
Pervious Pavements	17.4

The result of measures selection process shows that the investment in closed conduits is a possible option to enhance conveyance capacity of the current open channel drainage system. Besides, the selection process establishes measures as daylighting water courses, open water channels, grassed channels and wetland channels as possible options for this case. This is in accordance with the practice of maintaining and improving the existent open channels in order to maintain and increase the existent capacity. The option of grassed and wetland channels can be selected for landscape enhancement and environmental benefits. Due to the increment of roughness caused by vegetation, this is applicable in areas where channels can be wide enough to maintain conveyance capacity.

Another preferred measure according to the selection process is open detention basins. This measure is chosen when the system is described as exclusively separate. If the system is considered mixed, with separate and combined sectors, then underground storages appear as preferred. In this case open channels are not a preferred option either. A similar option, also selected in this process, is retention ponds. Either open detentions basins or retention ponds can be applied, though retention ponds will need more space to have the storage capacity required. The advantage of open detention basins is the availability of multi-functional space during dry periods. While retention ponds contribute to landscape enhancement among other co-benefits such as water quality improvement and heat stress reduction.

Additionally, rainwater disconnection appears as a good option for runoff management at the surface. To achieve this, several of the measures selected could be applied, such as green and blue roofs, rainwater tanks and rain gardens. Since green roofs offer the possibility of green spaces increment and urban farming, this option if preferred in front of blue roofs. Rainwater tanks are also chosen because they offer the possibility of water reuse, this is interesting due to the high price of water in the island and the existence of water scarcity issues. Rain gardens are not chosen due to the low availability of public places and lack of data regarding space availability at private areas.

Besides, measures that allow the infiltration of runoff are recommended. Due to the low availability of public spaces, infiltration boxes are not seen as an easily applicable measure. Infiltration trenches are not also selected because of the low availability of linear spaces in roads and sidewalks. The infiltration option better applicable in this case are pervious pavements since the most paved area is located in the lower catchment where the slope is less than 5%.

The measures selected in this study for further analysis are closed pipes, open detention basins, green roofs, rainwater tanks and pervious pavements. These options are evaluated considering the current channels system working properly.

Optimal measures combination: The objective in this section is to evaluate the performance of selected measures with respect to different rainfall events. To achieve this, three options are designed and combined, and the results of each case are compared. The first option is the combination of three measures: green roofs, rainwater barrels and pervious pavements, the option is called here green infrastructure (GI). These measures are applied in the lower and more urbanised area of the catchment. The second option considers open detention basins or storages (St). The Cul de Sac catchment area is divided in 14 sub-catchments and this option considers one open storage for each sub-catchment. These measures are designed to collect the runoff generated in the upper and steeper part of each sub-catchment. The last option is closed pipes, applied in this case as a tunnel (Tu) to enhance the conveyance capacity of the existent drainage system. The pipe tunnel follows the layout of existing main channel. The pipe starts around the middle area of the catchment and ends at the same point where the outfall of the current drainage system is located.

These three options are combined and evaluated under five rainfall scenarios of 5, 10, 20, 50 and 100 years return periods. Every combination of measures is optimised for every rainfall scenario. To achieve this, more than 30000 design possibilities were represented in a hydrodynamic model and results were compared for the measures combination and for the rainfall scenario. Differences among the design possibilities are the surfaces of green roofs and pervious pavements, the number of rainwater barrels, the volume of open storages and different pipes diameters. After this comparison, the options which achieve least damages costs at the minimum investment cost are selected and presented in Pareto front curves (Figure 5.17).

Analysing the results obtained, it can be observed that options using open storages perform better for low return periods (dark blue, orange, green and yellow in Figure 5.17a and b). It means that those options achieve lower damages cost for the same level of investment or to achieve certain damage cost, these options will need lower investment. However, observing higher return periods, it is noticed that the options with better performance are the ones using the tunnel pipe (yellow, green and grey in Figure 5.17 d and e). From this analysis, it can be concluded that a combination of open detention basins (or storages) and pipes could be the best solution in this case. Further analysis is needed to achieve a proper design, stablishing location and size of these measures.

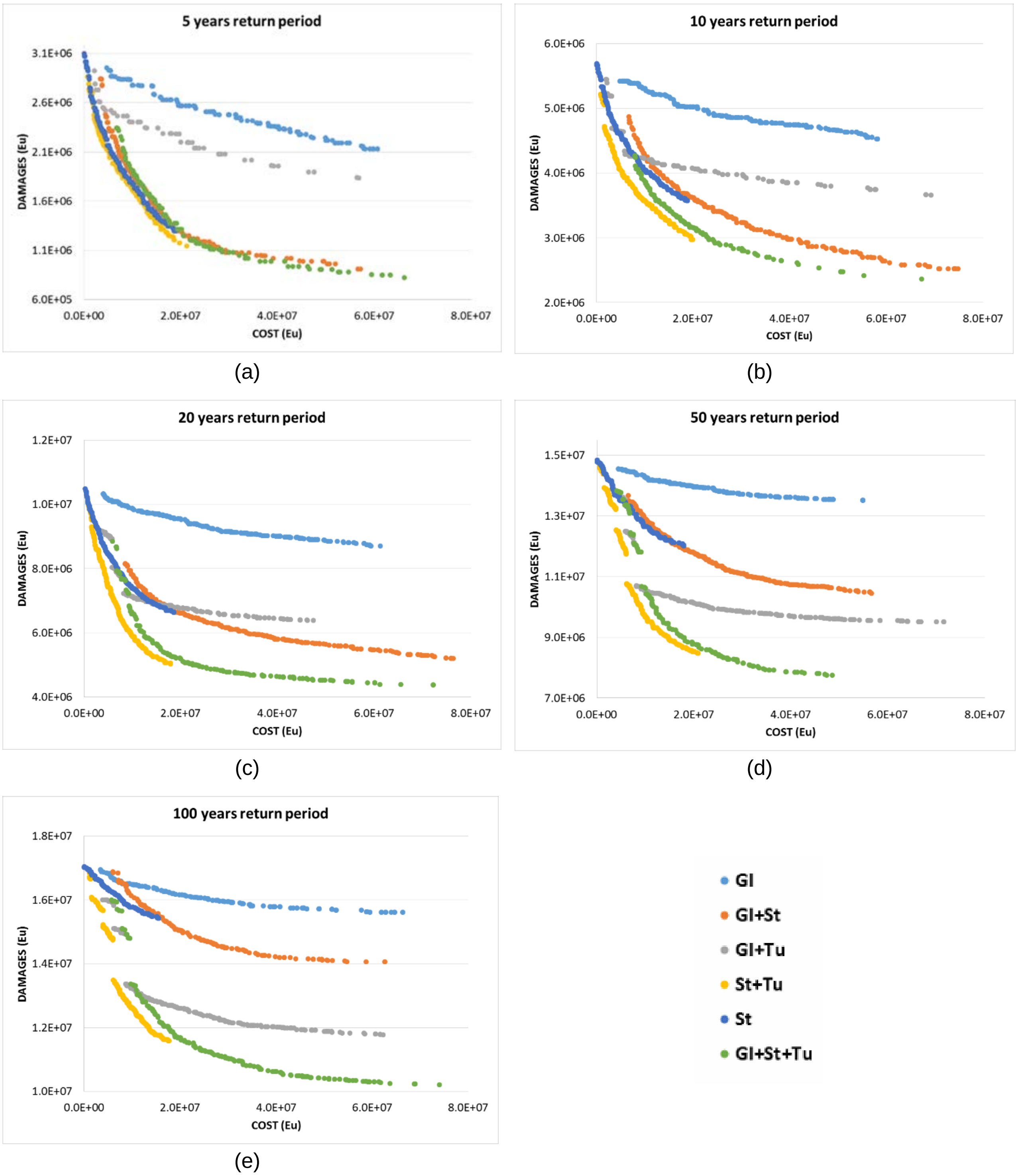


Figure 5.17. Optimal measures combinations for each rainfall scenario

Co-benefits analysis: The previous analysis suggests that green measures are not preferred to cope with extreme rainfall events. These measures do not reduce damages costs with low investment neither for high nor for low return period rainfall events. However, the low performance of green measures may change if co-benefits are considered. This is studied in this section through the addition of monetarised co-benefits to the previous analysis.

Co-benefits are seen here as benefits that can be achieved through the implementation of green measures, besides the reduction of damages. For instance, rainwater harvesting barrels allow the reuse of runoff for no-drinking proposes, while green roofs and pervious pavements contribute to heat stress reduction in urban spaces.

One of the co-benefits considered due to green roofs installation is air quality improvement as the increment of green surfaces aids the removal of air pollutants. Another co-benefit is the regulation of temperature in buildings, which contributes to energy savings that in this case is associated with savings in air conditioning. This co-benefit has two indirect benefits, because energy generation in the island is carbon based, savings in energy contribute to air quality improvements and carbon emission reduction. Finally, green roofs increment roofs longevity reducing replacement costs.

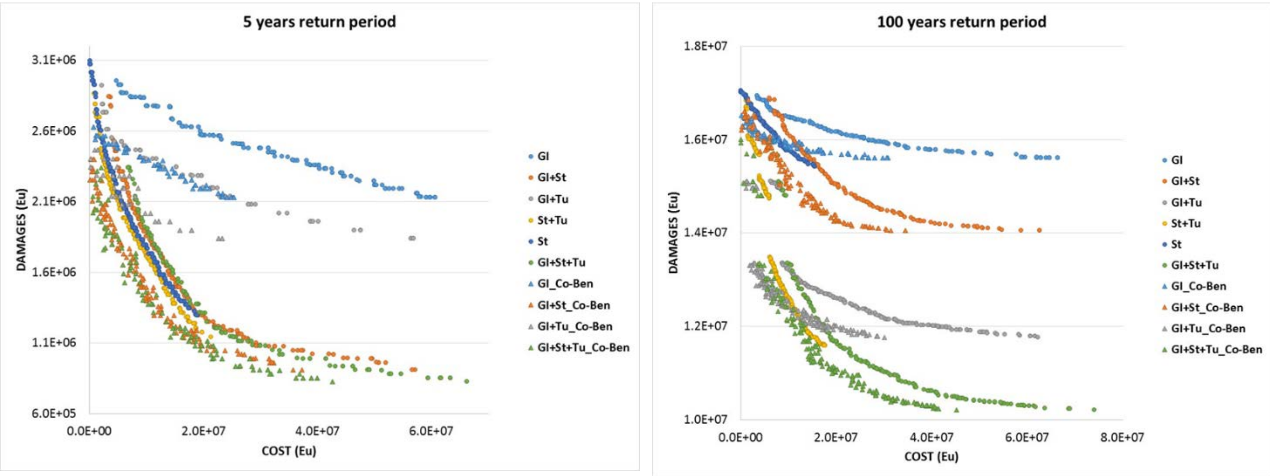
Regarding rainwater barrels, the main co-benefit considered in this study is water savings. Because water is generated through desalination in the island, which has high energy demand, the reduction in water consumption generates the benefit of energy savings. As in the case of green roofs, the reduction of energy demand has two indirect benefits associated – air quality improvement and carbon emission reduction. Another co-benefit also linked with the availability of water for reuse is the willingness to pay for freedom of water restrictions.

In the case of pervious pavements, the main co-benefits are related with its contribution to urban heat stress reduction. As a direct consequence less air conditioning is needed, then energy used for cooling can be saved. Again, indirect benefits of energy savings are air quality improvement and carbon emissions reduction. Finally, another benefit related with the reduction of heat stress is the willingness to pay for the service of cooling suburbs in summer.

The described co-benefits are monetarised and added to the analysis. These benefits are subtracted from the cost of measures. To calculate the costs, initial investment costs and the present value of maintenance costs for a period of 20 years are considered. To add co-benefits, the values of benefits for a period of 20 years are subtracted from the cost in each case. Figure 5.18 a and b shows the results of considering these benefits for rainfalls of 5 and 100 years return period respectively. In Figure 5.18, the solutions considering co-benefits are represented by triangles. For example, in the case of green infrastructure combined with pipes, the case without co-benefits is presented with grey circles and the case considering co-benefits is presented with grey triangles. It can be observed that for the same level of damages, the investment is much lower in the case that considers co-benefits.

If co-benefits are not considered, the combination of open detention basins and pipes (yellow circles) is the best option in both cases, 5 and 100 years return period. When co-benefits are considered, the combination of green infrastructure with open detention basins (orange triangles), or with open detention basins plus pipes (green triangles), appears as the best options in the case of 5 years return period rainfall. In the case of 100 years return period rainfall, the combination of green infrastructure with open detention basins and pipes (green triangles) is the best option to reduce flood damages.

As a conclusion, when co-benefits are considered, the combination of green infrastructure with open detention basins and pipes appears as the best option to reduce flooding in the case of different return period rainfalls. Consequently, green infrastructures are among the effective measures to reduce flood damages only when co-benefits are included into the analysis.



(a) (b)

Figure 5.18. Optimal measures combinations in the cases of 5 and 100 years return period rainfalls (a and b respectively), with and without consideration of co-benefits (triangles and circles respectively).

5.2.5.2 Reducing coastal flood hazard

On the basis of the results from the numerical simulations of waves during Hurricane IRMA (see Section 4.3.1), recommendations for future coastal and flood protection measures at selected locations along the southern coast of Sint Maarten are derived, assuming a protection level against a category 5 hurricane such as IRMA with high wind speeds up to 67 m/s from south-westerly directions and a medium to moderate surge water level MSL+2.0 m. Below, we describe sea dikes and vertical walls (seawalls) as recommended coastal flood protection measures for Sint Maarten.

Sea Dikes: Sea Dikes are typical flood protection structures along coasts and protect the low-lying coastal areas and hinterland against coastal flooding caused by storm surges and wave-induced wave run-up and wave overtopping on the dike. Dikes reduce the risk of flooding and protect both humans and economic respectively cultural values of urban areas close to the coast. The design of sea dikes is based on both constructional as well as functional aspects. From the constructional point of view, geotechnical information about the stability of the soil and the surface are relevant for the construction. A typical dike cross-section is shown in Figure 5.19.

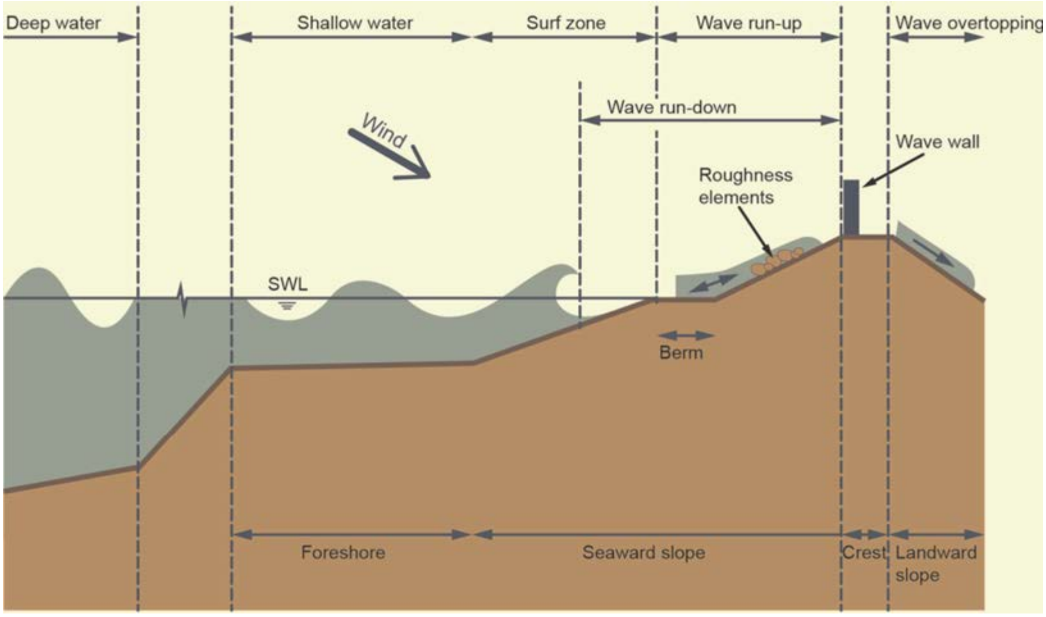


Figure 5.19. Typical cross-section for sea dikes and embankment seawalls with definition of wave run-up and overtopping. Source: EurOtop (2016), modified

For the design of a sea dike in general the following information are needed:

i) design water level (storm surge water level at a specific probability of occurrence)

ii) design wave run-up height (calculated on the basis of a design sea state)

iii) a safety sure-plus (taking into account effects of regional sea-level rise and climate change)

The design water level can be calculated on the basis of statistical methods (extreme value statistics), measurements (highest recorded storm surge water level) or the "single value method" (summation of mean tidal high water, the largest increase due to spring-tide and observed wind setup).

In the design and assessment approach of EurOtop (2016), the following equations are used for the calculation of the average wave run-up height $R_{u2\%}$ (the wave run-up height that is reached or exceeded by 2% of the incoming waves):

$$R_{u2\%} = H_s\, 1.75\, \gamma_b\, \gamma_f\, \gamma_\beta\, \xi_{m-1.0} \qquad \text{Eq. 5.1}$$

with a maximum of:

$$R_{u2\%,max} = H_s\, 1.07\, \gamma_f\, \gamma_\beta \left(4.0 - \frac{1.5}{\sqrt{\gamma_b \xi_{m-1,0}}}\right) \qquad \text{Eq. 5.2}$$

Where γ_b is the influence factor of a berm, γ_f is the influence factor of a roughness, γ_β is the influence factor of a wave obliquity. In this case, all γ_b, γ_f and γ_β are equal to 1. In the latter case, a frontal wave attack is assumed.

The design and assessment approach of EurOtop (2016) corresponds to the deterministic approach of EurOtop (2007).

The breaker parameter is given by:

$$\xi_{m-1.0} = \frac{\tan \alpha}{\sqrt{\frac{H_s}{L_{m-1.0}}}}$$ Eq. 5.3

Where α is the seaward slope (°) (tan α = 1/6), H_s is the significant wave height (H_{mo}) at dike toe (m) and $L_{m-1.0}$ is the deep water wave length (m).

The equations for the calculation of the average wave run-up height $R_{u2\%}$ of the design and assessment approach are illustrated in Figure 5.20 (grey line).

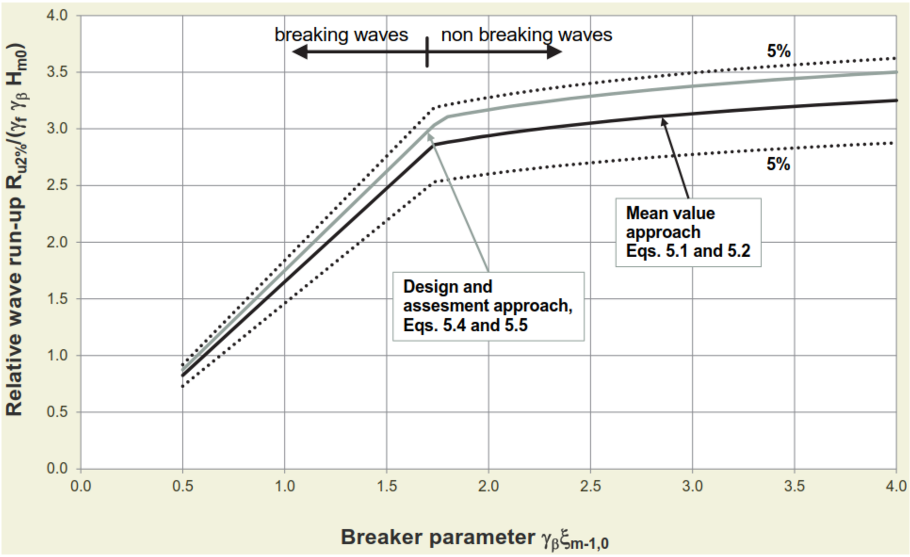


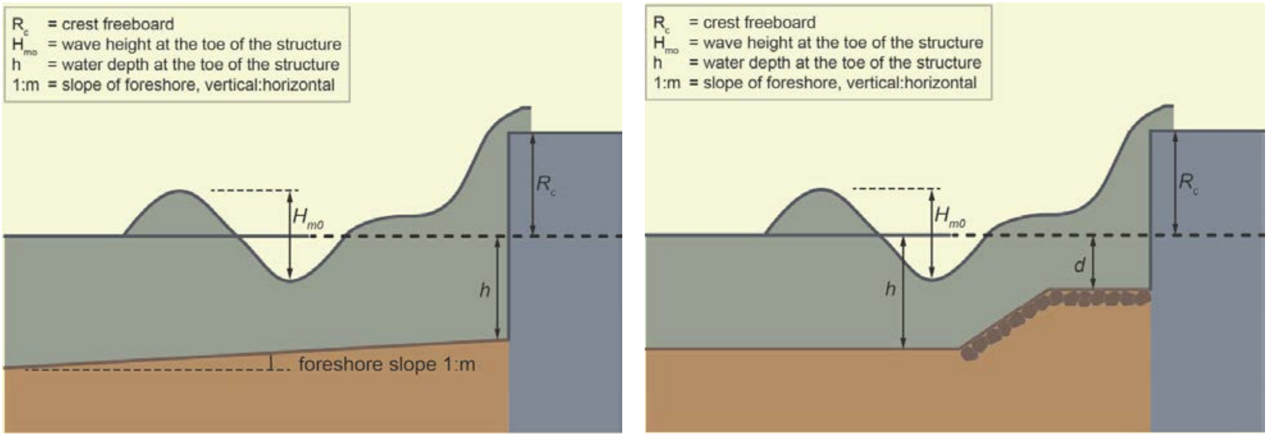
Figure 5.20. Relative 2%-wave run-up height $R_{u2\%}/H_{m0}$ for relatively gentle slopes. Source: Figure 5.5 in EurOtop (2016).

The deep water wave length $L_{m-1.0}$ is calculated from linear wave theory for deep water conditions and on the basis of the spectral wave period $T_{m-1.0}$ at the dike toe:

$$L_{m-1.0} = \frac{g}{2\,\pi}\, T_{m-1.0}^2$$ Eq. 5.4

Where g is the acceleration due to gravity (i.e., 9.81 m/s^2).

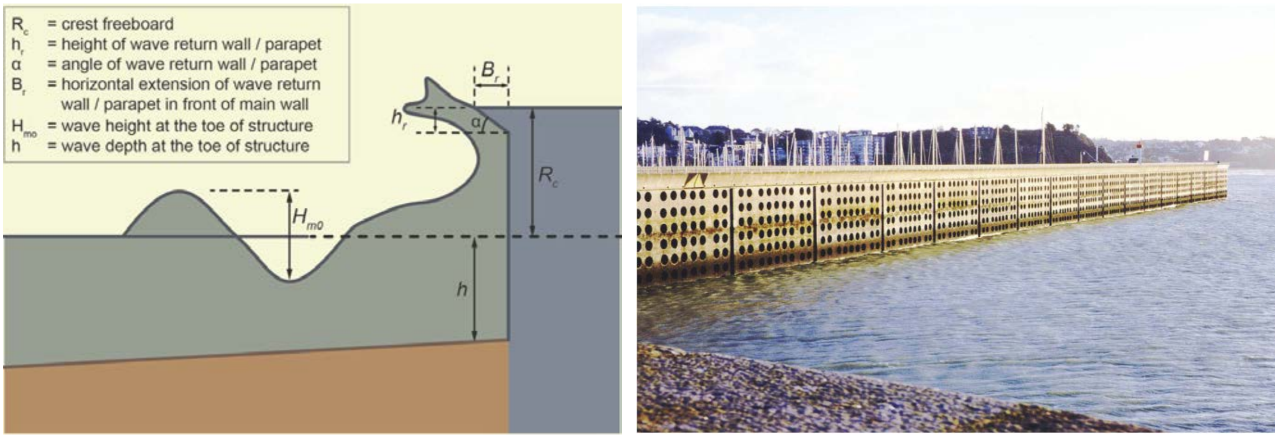
Vertical Walls (Seawalls): Along some sections of the coast, especially close to densely populated urban areas and ports, plain or composite vertical walls can be applied to protect the hinterland from coastal flooding. A typical cross section of a plain respectively composite vertical wall is shown in Figure 5.21.



(a) (b)

Figure 5.21. Principle cross-section for (a) plain and (b) composite vertical walls. Source: Figure 7.6 and Figure 7.14 in EurOtop (2016)

The wave run-up at vertical structures can be reduced by wave return walls / parapet or bull nose and perforated walls (see Figure 5.22).



(a) (b)

Figure 5.22. Reduction of wave run-up and overtopping at vertical walls, a: wave return wall, b: perforated caisson. Source: Figure 7.21 and Figure 7.24 in EurOtop (2016)

Vertical walls need special attention regarding the assessment of wave reflection and disturbance. Perforated vertical walls or caisson breakwaters can be applied to reduce wave reflection and overtopping (see Figure 5.22).

In the design and assessment approach of EurOtop (2016) the following equations are used for the calculation of the average wave run-up height $R_{u2\%}$ at plain vertical walls, excluding the influence of a foreshore:

$$R_{u2\%} = H_s\,(0.86\ \cot\alpha + 1.71) \qquad \text{Eq. 5.5}$$

Where α is the seaward slope (°), ($\cot\alpha$ = 0) and the maximum $R_{u2\%} = 1.91H_s$

The equations for the calculation of the average wave run-up height $R_{u2\%}$ of the design and assessment approach are illustrated in Figure 5.23 (grey line).

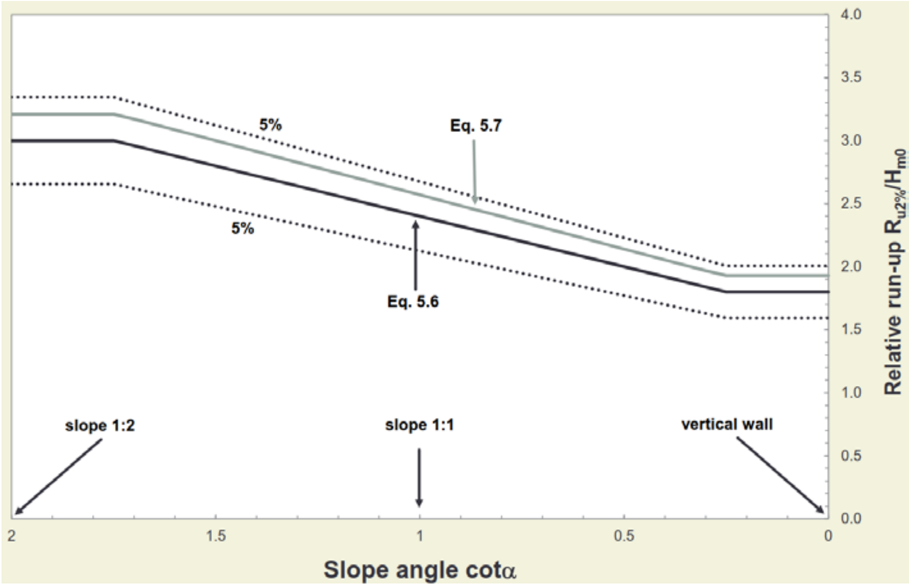


Figure 5.23. Relative 2%-wave run-up height $R_{u2\%}/H_{m0}$ for steep slopes and vertical walls. Source: Figure 5.9 in EurOtop (2016)

The wave and water level conditions of the numerical simulation V2 (Table 4.3) were used for the calculation of the average wave run-up heights at selected locations of the sections C01 to C06. The wave parameter at the dike toe has been used as input for the equations Eq 5.1 to Eq 5.4 and are summarized in Table 5.4.

For the design of the sea dikes at the coastal sections C01 to C05 a slope of 1:6 was assumed for the seaward slope of the dike and the height of the dike toe was assumed at MSL.

The results of the calculation are summarized in Table 5.5. The necessary height of the dike crest to prevent wave overtopping was calculated by summing up the average wave run-up heights, the height of the water level in the numerical simulation V2 (*W*=MSL+2 m) and an additional surplus of 0.5 m taking into account the effects of regional sea level rise and climate change. The design heights of the dike crest at the coastal sections C01 to C06 are summarized in the last column of Table 5.5. For the design of a coastal protection structure at the coastal section C01, both the crest heights of a sea dike and a vertical wall have been calculated (see the first two rows of Table 5.5).

Table 5.4. Wave parameter at the dike toe (numerical simulation V2)

Curve	Distance from Shore (m)	Depth (m)	H_s (m)	$T_{m-1.0}$ (s)	$L_{m-1.0}$ (m)
C01 (gentle slope)	10	2.3	2.0	9.7	146
C02 (gentle slope)		2.0	1.3	6.9	74
C03 (gentle slope)		2.2	1.7	9.5	142
C04 (gentle slope)	40	4.8	2.4	9.3	135
C05 (gentle slope)		4.4	1.6	8.0	100
C06 (vertical wall)		6.4	2.2	4.0	25

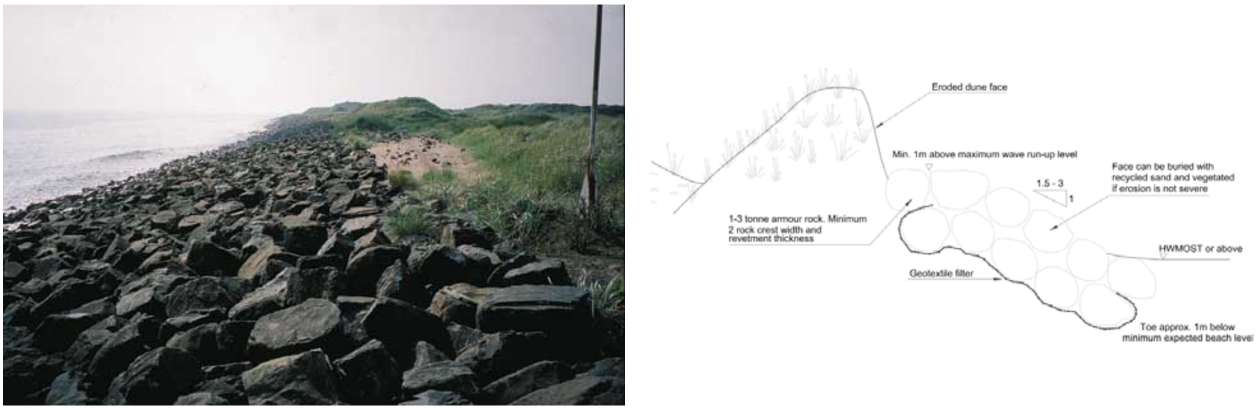
Table 5.5. Average wave run-up heights $R_{u2\%}$ and dike crest height (numerical simulation V2)

Curve (Structure)	H_s (m)	$L_{m-1,0}$ (m)	$\xi_{m-1,0}$ (-)	$R_{u2\%}$ (m)	Crest Height (m o. MSL)†
C01 (sea dike)	2.0	146	1.4	5.0	8.0
CO1 (vertical wall)	2.0	146	1.4	3.5	6.0
C02 (gentle slope)	1.3	74	1.3	2.8	5.0
C03 (gentle slope)	1.7	142	1.5	4.6	7.0
C04 (gentle slope)	2.4	135	1.3	5.2	8.0
C05 (gentle slope)	1.6	100	1.3	3.7	6.0
C06 (vertical wall)	2.2	25	0.6	3.7	6.0

† These values are rounded to the nearest integer value.

To conclude, a first assessment of the design of future coastal protection structures on the basis of the EurOtop (2016) approach and available hydrodynamic information from the case study of Hurricane IRMA has been carried out. The design crest heights of both sea dikes and vertical walls are summarized in Table 5.3.

The functional design of the coastal protection structures on the basis of the EurOtop (2016) approach can be improved in order to reduce the wave run-up and –overtopping and finally the design crest heights of the constructions. Measures for the reduction of wave run-up and –overtopping on sea dikes are e.g. the alignment of a berm, roughness elements and or wave walls. Measures for the reduction of wave run-up and –overtopping on vertical walls are e.g. wave return walls (bull nose), perforated caisson structures or the design of composite vertical walls. Moreover combined structures such as revetments (Figure 5.24) in combination with vertical walls can be considered. More information about revetments, beach nourishments etc. are given exemplarily in Brampton et al. (2000).



(a) (b)

Figure 5.24. (a) Rock armour revetment in front of a dune system and (b) cross-section. Source: Brampton et al. (2000)

Nevertheless, detailed information (e.g. shoreline profiles, wind and hydrodynamic information such as water levels and waves as well as information about the beach morphology and geology in the project area) are needed to improve the design of the coastal structures. This information can be derived from long-term terrestrial, nautical, wind and hydrodynamic measurements in the study area. Long-term numerical hindcast simulations of waves can be used for a detailed assessment of the

average and extreme hydrodynamic conditions and the wave induced effects on the long-shore sediment transport and beach morphology.

The recommended hard coastal protection measures need careful planning and design in order to reduce negative consequences such as enhanced coastal erosion in front and the lee of the structures. The structures (especially vertical walls as well as revetments) affect the long-shore sediment transport and finally the morphology of sandy beaches. Therefore, hard coastal protection measures should be accompanied by other coastal protection measures to encounter coastal erosion and for the stabilization of sandy beaches. For this purpose, different coastal protection measures such as soft protection measures (e.g. beach nourishments), groins and detached offshore breakwaters can be taken into consideration aiming at the overall goal of the development of a sustainable coastal management plan.

5.2.5.3 *Reducing flood impacts on road transportation*

The flood impact reduction measure is based on the findings in Section 5.1.5. To ensure the smooth functioning of CIs on the island, a mitigation measure was developed to improve the connectivity of the hospital and the fire brigade, which are located next to each other on a flooded road (Figure 5.25). When that road is flooded, the access to and from both CIs is very limited that will paralyse the emergency service and pose a greater risk to human life. Therefore, maintaining safe accessibility to the CIs is essential to minimise the cascading effect caused by transportation disruption. Assuming these roads leading to the CIs are well protected from flooding, the traffic model was examined to demonstrate the benefits.

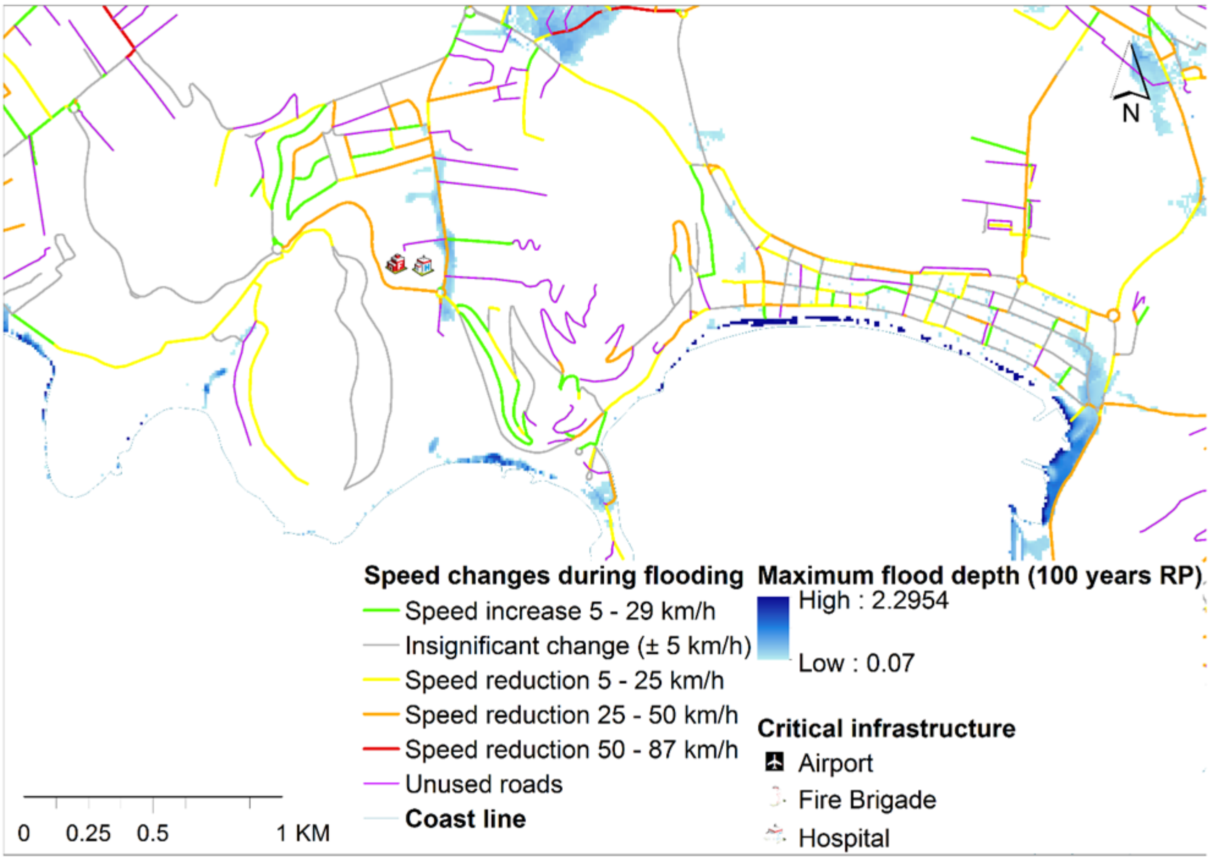


Figure 5.25. Flooded areas around the hospital and the fire brigade

After the mitigation measure was applied, a comparison was made between the roads speeds of the scenario of a normal flood and the scenario of a flood with a mitigation measure (Figure 5.26). The figure shows the differences in road speeds between the scenario with and without the mitigation measure during the same flood condition. Therefore, the higher the speed increase on the map, the better the performance of the mitigation measure. The results show a significant increase in the road speeds on the roads connecting the hospital and the fire brigade with the city of Philipsburg to the east and the airport to the west. The flooded roads were blocked for different durations under the normal flood conditions and because of that have maintained high downstream road speed. Once they have been open for use again, the downstream roads after the flood might experience some delays, but overall the connectivity with the critical infrastructure has been significantly improved.

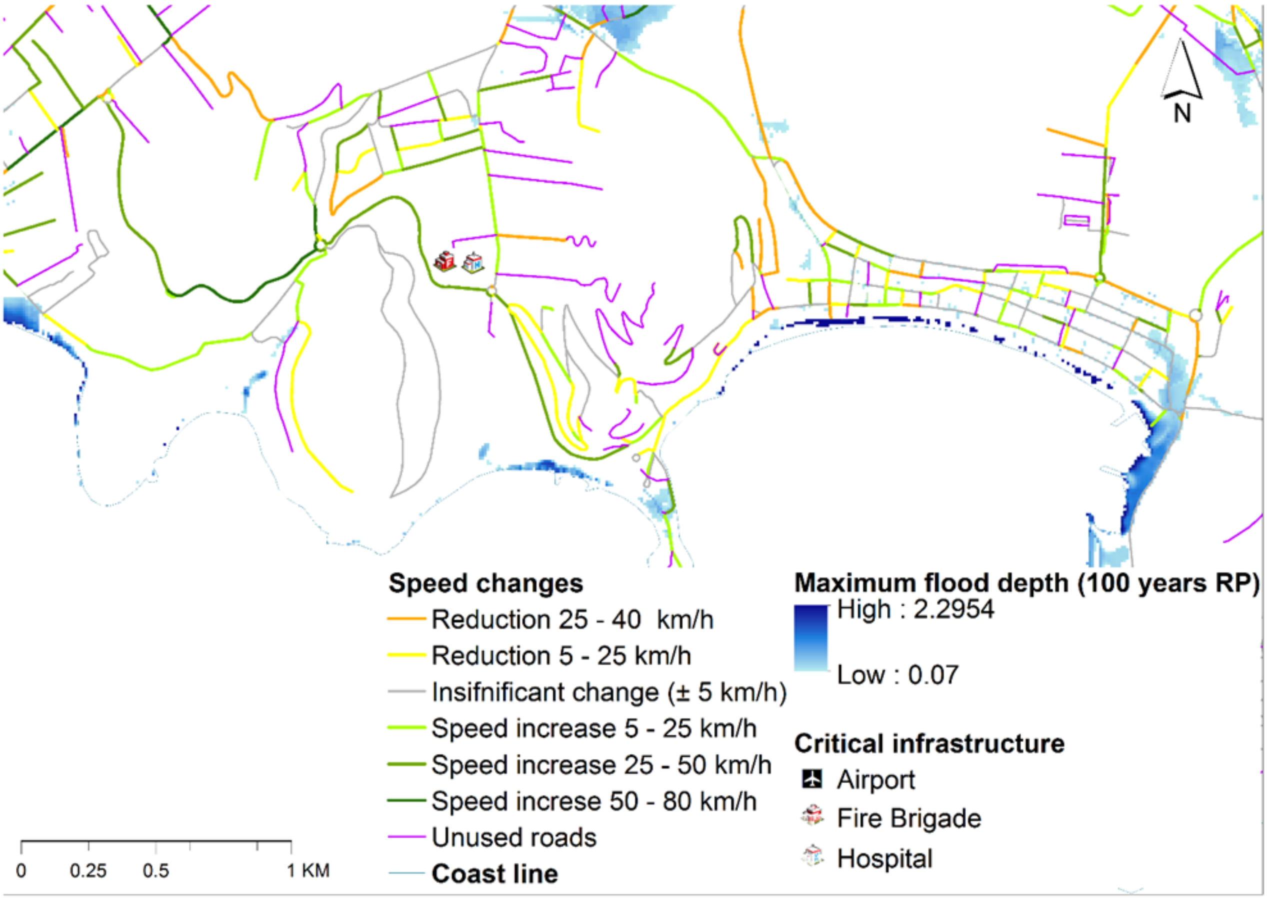


Figure 5.26. Speed changes with the implementation of a mitigation measure

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Appendix A. Household survey – Oral interview

Questionnaire Post- Hurricane IRMA.	pearl IHE DELFT

To citizens of Sint Maarten,

Thank you for supporting this household survey.

This questionnaire is part of an international research project. IHE Delft – Institute for water education is performing a study aiming to gather valuable information on the perception, preparedness, and risk for hurricane evacuation, as well other specific insights on hurricane and flood related hazards potentially affecting the population of Sint Maarten.

Your participation in this survey will be treated **anonymously** and all the information will be kept confidential and individual records won't be shared with any officials of the Island or any other administrative entity.

Your answers will help the research to gain a deeper understanding of flood risks and hurricane evacuation in the island which will enhance future decision making processes for land use and spatial planning, risk reduction and infrastructure improvement as well as evacuation plans if they are found necessary.

The questionnaire consists of three parts: General information, preparedness and reaction and risk perception/awareness. It is estimated to take you around 10 to 15 minutes to fill it in completely. Please read every question carefully and in case of doubts do not hesitate to contact the responsible team that handed the survey to you.

Thank you again for your support. With your help we can build a safer Sint Maarten for all!!!

Questionnaire Post- Hurricane IRMA.			pearl IHE DELFT
Survey ID:______	Map #:_______	Field Paper:__________	

Part 1. General / Household Information

#	Question	Answer
1.1	Were you born in Sint Maarten?	❑ Yes ❑ NO where: ____________________
1.2	Year of birth (interviewee)	______________
1.3	Gender	❑ Female ❑ Male ❑ Other
1.4	Which year did you move to the part of the island you are currently living?	______________
1.5	Total number of inhabitants in the household (**Including yourself**)	______________
1.6	Are you tenant or owner of the house / apartment?	❑ Tenant ❑ Owner
1.7	Do you know the year of construction of the house?	❑ Yes Specify: ____________ ❑ No
1.8	If working. What describe best your job location:	❑ Permanent or Fixed location ❑ Changing location
1.9	How many cars are within your household?	______________
1.10	How many smartphones/tablets are within your household?	______________
1.11	Do you have any pets or animals?	❑ Yes ❑ No
1.12	Is your home insured for natural disasters?	❑ Yes ❑ No
1.13	Is your home insured against lootings or riots?	❑ Yes ❑ No

Questionnaire Post- Hurricane IRMA.		
Survey ID:______	Map #:_______	Field Paper:_________

Part 2. Events, Preparedness and reaction

#	Question	Answer
2.1	How many hurricanes and tropical storms, if any, do you remember to have hit Sint Maarten during the time you have lived here?	_____________
2.2	Do you know where to get up-to-date information on early warnings and actual evacuation news/instructions?	☐ To a great extent ☐ To a moderate extent ☐ To some extent ☐ To a small extent ☐ Not at all ☐ Prefer not to answer / Not Applicable
2.3	From where do you get the latest updates on warnings or evacuation information? Mark all that apply.	☐ TV ☐ Radio ☐ Sint Maarten government channel ☐ Sirens / Speakers / Megaphone ☐ Sign posted in my neighbourhood ☐ Mobile App. Name:_____________ ☐ Friend or relative ☐ Internet ☐ Other services. Please specify __________________
2.4	Regarding Hurricane IRMA. Did you receive any warning information before the hurricane hit the Island?	☐ Yes → Please Specify # days: _________ ☐ No
2.4.a	If warning information was received. From whom did you receive it? Mark all that apply	☐ Sint Maarten government official ☐ Army or Police department ☐ Fire department ☐ Weather Broadcast (TV or internet) ☐ Family member or Friend ☐ Red Cross / Civil defence ☐ Other. _______________ ☐ Prefer not to answer / Not Applicable
2.5	Did you and your family evacuate for Hurricane IRMA?	☐ Yes → Please answer from **2.6.a to 2.6.e** ☐ No → Please answer from **2.7.a to 2.7.m**
If you answered **YES** to question 2.5 please answer questions 2.6.a to 2.6.e		
2.6.a	When did you evacuate (leave your home or work) to go someplace safe during hurricane IRMA?	☐ Before the hurricane arrived ☐ Just as the hurricane arrived ☐ During the hurricane ☐ After the hurricane has passed ☐ Prefer not to answer / Not Applicable

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Questionnaire Post- Hurricane IRMA.		
Survey ID:______	Map #:_______	Field Paper:_________

#	Question	Answer
2.6.b	Was the warning/evacuation information given with sufficient time to take actions?	☐ Yes ☐ No → Specify # of days you would need to complete a safe evacuation: __________
2.6.b.1	If no sufficient time, and in order to complete a safe evacuation. Could you estimate how many days in advance would need to receive the evacuation information?	☐ 1 -2 days ☐ 3 - 4 days ☐ 4 - 6 days ☐ More than 6 days
2.6.c	What type of information did you receive? Mark all that apply	☐ General evacuation order ☐ Shelter location ☐ Expected date/time of hurricane ☐ Driving/walking direction ☐ What to bring to shelter ☐ Other. Please specify ________________________
2.6.d	Did you follow the given instructions?	☐ Yes ☐ No ☐ Prefer not to answer / Not Applicable
2.6.e	If you evacuated from hurricane IRMA before the hurricane hit the island, where did you choose to go?	☐ Public shelter ☐ Special needs Shelter ☐ Pet-Friendly shelter ☐ Home of a relative or friend ☐ Hotel ☐ I left the island ☐ Other. Please specify ________________________

IF QUESTION 2.5 was Negatively answer. This is you did **NOT** evacuate please answer questions **2.7.a** to **2.7.m**

2.7 How strongly did each of the following factors influence your decision to remain at home and **NOT** evacuate during hurricane IRMA?
For each factor, please use the scale, ranging from "Not at all influential" to "Extremely Influential".

		Not at all influential	Slightly Influential	Somewhat Influential	Very Influential	Extremely Influential	Prefer not to Answer
2.7.b	I felt Hurricane IRMA would not be a threat						
2.7.c	My home is strong enough to resist a hurricane						
2.7.d	Someone I know said there was no need for me to evacuate						
2.7.e	I did not know where to evacuate						

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Questionnaire Post- Hurricane IRMA.		
Survey ID:______	Map #:_______	Field Paper:_________

#	Question	Not at all influential	Slightly Influential	Somewhat Influential	Very Influential	Extremely Influential	Prefer not to Answer
2.7.f	I did not trust the official warning						
2.7.g	I needed assistance to evacuate myself or a relative						
2.7.i	I did not receive an official warning						
2.7.j	In my experience, it is better to stay at home						
2.7.k	I was waiting to reunite with family and/or friends						
2.7.l	I did not want to leave my property alone for fear of looters						
2.7.m	I consider the facilities of the shelters are not adequate to evacuate						

Continue questions to all respondents

#	Question	Answer
2.8	Based on your experiences during previous evacuations. Do you trust official sources of warning or evacuation in the island?	❑ To a great extent ❑ To a moderate extent ❑ To a some extent ❑ To a small extent ❑ Not at all ❑ Prefer not to answer / Not Applicable

2.9 To what extent do you agree with the following statements: In Sint Maarten...

#	Statement	Strongly Disagree	Disagree	Slightly Disagree	Slightly Agree	Agree	Strongly Agree	Prefer not to answer
2.9.a	*"... the number of available shelters is adequate."*							
2.9.b	*"...the location of the shelters are adequate"*							
2.9.c	*"...the road infrastructure to evacuate is adequate""*							

#	Question	Answer
2.10	Did your household experience a shortage of critical infrastructure services due to Hurricane Irma? Please choose all that apply	❑ Medical services / Access to hospitals ❑ Electricity ❑ Water supply ❑ Sanitation ❑ Transport ❑ No affected ❑ Other ______________________ ❑ Prefer not to answer / Not Applicable

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Questionnaire Post- Hurricane IRMA.		
Survey ID:______	Map #:_______	Field Paper:_________

Part 3. Risk Perception / Awareness

#	Question	Answer
3.1	With regard to Hurricanes, floods and natural disasters who do you think is responsible for taking action in Sint Maarten? Please choose and rank the three most relevant to you. Where **1** is the most important and **3** the least important	____ Sint Maarten Government ____ Dutch Government ____ Police / Fire department ____ Citizens ____ Red Cross / Civil Defence ____ Others. Please Specify ______________________________

3.2 How likely is it that you would evacuate if the following events are forecasted to hit your local area? ...

#	Event	Definitely would not	Probably would not	About 50/50	Probably would	Definitely would	Prefer not to answer
3.2.a	Tropical depression (winds less than 68 km/h)						
3.2.b	Tropical depression (winds 63–118 km/h)						
3.2.c	Hurricane Category 1 (winds 19–153 km/h)						
3.2.d	Hurricane Category 2 (winds 154–177 km/h)						
3.2.e	Hurricane Category 3 (winds 178–208 km/h)						
3.2.f	Hurricane Category 4 (winds 209–251 km/h)						
3.2.g	Hurricane Category 5 (winds more than 252 km/h)						

3.3. To what extent do you agree with the following statements:

#	Statement	Strongly Disagree	Disagree	Slightly Disagree	Slightly Agree	Agree	Strongly Agree	Prefer not to answer
3.3.a	*"If the early warnings that I receive would be more precise and would reach me more directly. I would follow them more than I do now"*							
3.3.b	*"In Sint Maarten, the losses due to the recent hurricane could have been prevented by more appropriate planning and management from the City authorities"*							

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Questionnaire Post- Hurricane IRMA.		
Survey ID:_____	Map #:_______	Field Paper:_________

#	Question	Answer
3.4	When a hurricane or tropical storm approaches your local area, how frequently, do you check the forecasts on TV, mobile, radio, and/or on the Internet?	❑ Less than once a day ❑ About once a day ❑ Several times a day ❑ Every couple of hours ❑ Throughout the whole day ❑ No Answer / Not Applicable
3.5	Have you previously received any official training/ or had community meetings, regarding procedures for hurricane or disaster evacuation?	❑ Yes ❑ No ❑ No Answer / Not Applicable
3.6	To the best of your knowledge, which one of the following is the most likely cause of injury or death during a hurricane? Please choose all that apply	___ Flying or falling objects from high winds ___ Rising water levels and high waves (storm surge) ___ Flooding from heavy rains ___ Accidents during evacuation ___ Not really sure ___ Others Specify ______________________

3.7. To what extent do you agree with the following statements:

		Strongly Disagree	Disagree	Slightly Disagree	Slightly Agree	Agree	Strongly Agree	Prefer not to answer
3.7.a	*"After hurricane Irma I would definitely acquire a home insurance for natural disasters"*							
3.7.b	*"After hurricane Irma I would definitely acquire a home insurance for Riots and Looting"*							
3.7.c	*"After hurricane Irma I would definitely acquire a life insurance for myself or my relatives"*							

Final Remarks.

Please share any additional comments, suggestions or information related with Hurricane evacuation, floods, natural disasters and institutions in Sint Maarten.

____

____

____

____

Questionnaire Post- Hurricane IRMA.		
Survey ID:_____	Map #:_______	Field Paper:_________

Thank you for your time completing this questionnaire. If you want to be contacted once we have the results from this survey, please provide us with your personal information.

Name: ______________________________

Telephone: ______________________________

e-mail: ______________________________

Questionnaire Post- Hurricane IRMA.			
Survey ID:______	Map #:_______	Field Paper:_________	

Annex 1. Survey General Information. (INTERVIEWER)

#	Question	Answer
a	Survey Number (Code)	______________________________
b	Pollster Name	______________________________
c	Date and Time of Survey	______-..______...2017 (dd) (mm) Time: ______-..______hours
d	Area of house In addition, please mark the house in the attached map.	☐ Cay Bay ☐ Hill Side ☐ Cay Hill/Little Bay ☐ Middle Region ☐ Cole Bay ☐ Point Blanche ☐ Cul de Sac ☐ Simpsons Bay ☐ Dawn Beach ☐ Suckergarden/ Over the Pont ☐ Dutch Quarter ☐ Greater Philipsburg ☐ Low Lands ☐ Guana Hill/Saint Peters Battery ☐ Other: _______________
e	Style of survey	☐ Interviewed Administered ☐ Self-Administered ☐ Web based
f	Stories of house	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ More than 4
g	House Material Please specify the most prominent construction material	☐ Bricks ☐ Concrete ☐ Wood ☐ Other ______________________
h	Roof Material Please specify the most prominent construction material	☐ Concrete ☐ Metallic sheets ☐ Asbestos ☐ Clay tiles ☐ Thatched ☐ Other ______________________
i	Floor Material Please specify the most prominent construction material	☐ Tiles ☐ Cement ☐ Earth ☐ Wood ☐ Other ______________________
j	Was the house flooded	☐ Yes Water depth: ____________cm ☐ No
K	Damage estimate	☐ 0 – 25% ☐ 26- 50% ☐ 51 – 75% ☐ > 75 %

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Appendix B. Household survey – Web administered

Section 1

Post - Irma - Vulnerability and Risk Assessment

IHE Delft – Institute for water education is performing a study aiming to gather valuable information on the perception, preparedness, and risk regarding floods and hurricanes potentially affecting the population of Sint Maarten. With your help we can provide a valuable input to enhance future decision making processes for land use and spatial planning, hurricane risk reduction and infrastructure improvement among others.

In this survey we are not asking any personal information and your participation in this survey will be treated anonymously, all the information will be kept confidential and individual responses won't be shared with anyone.

It is estimated to take you around 10 to 15 minutes to fill it in completely. Please read every question carefully and in case of doubts do not hesitate to contact the responsible team using the following email: n.medina@un-ihe.org

Thank you again for your support. With your help we can build a safer Sint Maarten for all!!!

NEXT

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Section 2

Post - Irma - Vulnerability and Risk Assessment

* Required

Event, Preparedness and Reaction

How many hurricanes and tropical storms, if any, do you remember to have hit Sint Maarten during the time you have lived here? *

- ○ 1-2
- ○ 2-4
- ○ 4-6
- ○ more than 6
- ○ None

When a hurricane or flood event is about to hit Sint Maarten. Do you know where to get up-to-date information on early warnings and actual evacuation news/instructions?

- ○ To a great extent
- ○ To a moderate extent
- ○ To some extent
- ○ To a small extent
- ○ Not at all
- ○ Prefer not to answer / Not Applicable

From where do you get the latest updates on warnings or evacuation information? – Mark all that apply

- ☐ Television
- ☐ Radio
- ☐ Sint Maarten government channel
- ☐ Sirens / Speakers / Megaphone
- ☐ Sign posted in my neighbourhood
- ☐ Cellphone / Mobile App
- ☐ Friend or relative
- ☐ Internet
- ☐ Other: ____________

Based on your experiences during hurricanes and storms. Do you trust official sources of warning or evacuation in the island?

- ○ To a great extent
- ○ To a moderate extent
- ○ To a some extent
- ○ To a small extent
- ○ Not at all
- ○ Prefer not to answer / Not Applicable

To what extent do you agree with the following statements: In Sint Maarten ...

	Strongly Disagree	Disagree	Slightly Disagree	Slightly Agree	Agree	Strongly Agree	Prefer not to answer	Does not Know
"... the number of available shelters is adequate."	○	○	○	○	○	○	○	○
"...the location of the shelters are adequate"	○	○	○	○	○	○	○	○
"...the road infrastructure to evacuate is adequate"	○	○	○	○	○	○	○	○

Regarding Hurricane IRMA. Did you receive any warning information before the hurricane hit the Island?

- ○ Yes
- ○ No

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Section 3

Post - Irma - Vulnerability and Risk Assessment

Received Information regarding Irma

Information about the time and type of information received about Irma

How many days in advance were you aware that Irma may hit Sint Maarten before it actually hit the island?

- ○ 0 - 3 days
- ○ 4 -7 days
- ○ 8 - 14 days
- ○ more than 14 days

How many days in advance were you aware that Irma will pose a real threat to you and the Island of Sint Maarten? (i.e cat 5+)

- ○ 0 - 3 days
- ○ 4 -7 days
- ○ 7 - 14 days
- ○ more than 14 days

What type of information did you receive? --Mark all that apply

- ☐ General evacuation order
- ☐ Shelter location
- ☐ Expected date/time of hurricane
- ☐ Driving/walking direction
- ☐ What to bring to shelter
- ☐ Other: ____________

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Section 4

Post - Irma - Vulnerability and Risk Assessment

* Required

Evacuation

Section to know if you evacuate because of Irma

Did you evacuate your home because of hurricane Irma? *

- ○ Yes
- ○ No

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Section 5

Post - Irma - Vulnerability and Risk Assessment

Questions if you evacuate because of Irma

When did you evacuate (leave your home or work) to go someplace safe because of hurricane Irma?

- ○ Before the hurricane arrived
- ○ Just as the hurricane arrived
- ○ During the hurricane
- ○ After the hurricane has passed
- ○ Prefer not to answer / Not Applicable

If you evacuated from hurricane IRMA, where did you choose to go

- ○ Public shelter
- ○ Special needs Shelter
- ○ Pet-Friendly shelter
- ○ Home of a relative or friend
- ○ Hotel
- ○ I left the island
- ○ Other: ____________

Section 6

Post - Irma - Vulnerability and Risk Assessment

Not enough time Warning

If no sufficient time, and in order to complete a safe evacuation. Could you estimate how many days in advance would need to receive the evacuation information?

- ○ 1 -2 days
- ○ 3 - 4 days
- ○ 4 - 6 days
- ○ More than 6 days

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Never submit passwords through Google Forms.

Section 7 (part 1)

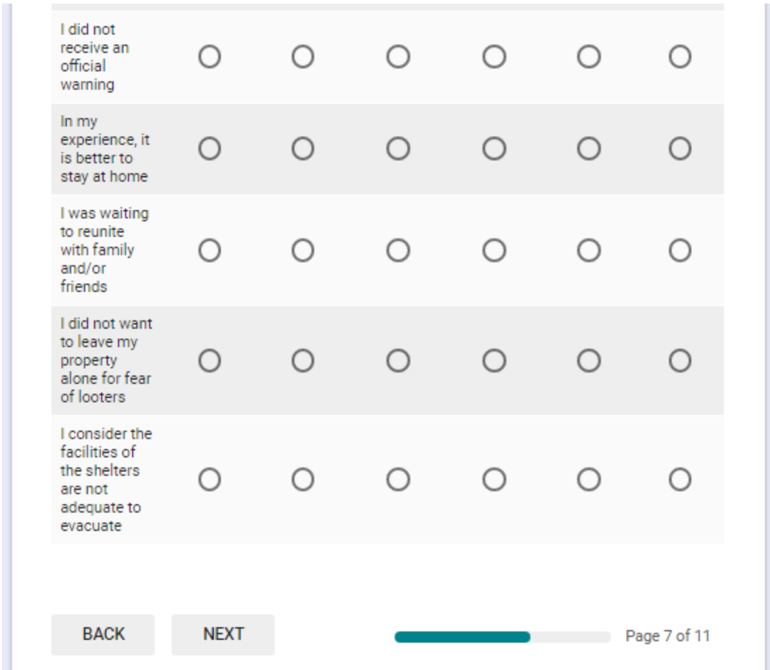
Post - Irma - Vulnerability and Risk Assessment

Questions if you did Not Evacuate because of Irma

How strongly did each of the following factors influence your decision to remain at home and NOT evacuate during hurricane IRMA? -- For each factor, please use the scale, ranging from “Not at all influential” to “Extremely Influential”.

	Not at all influential	Slightly Influential	Somewhat Influential	Very Influential	Extremely Influential	Prefer not to Answer
I felt Hurricane IRMA would not be a threat	○	○	○	○	○	○
My home is strong enough to resist a hurricane	○	○	○	○	○	○
Someone I know said there was no need for me to evacuate	○	○	○	○	○	○
I did not know where to evacuate	○	○	○	○	○	○
I did not trust the official warning	○	○	○	○	○	○
I needed assistance to evacuate myself or a relative	○	○	○	○	○	○

Section 7 (part 2)



I did not receive an official warning	○	○	○	○	○	○
In my experience, it is better to stay at home	○	○	○	○	○	○
I was waiting to reunite with family and/or friends	○	○	○	○	○	○
I did not want to leave my property alone for fear of looters	○	○	○	○	○	○
I consider the facilities of the shelters are not adequate to evacuate	○	○	○	○	○	○

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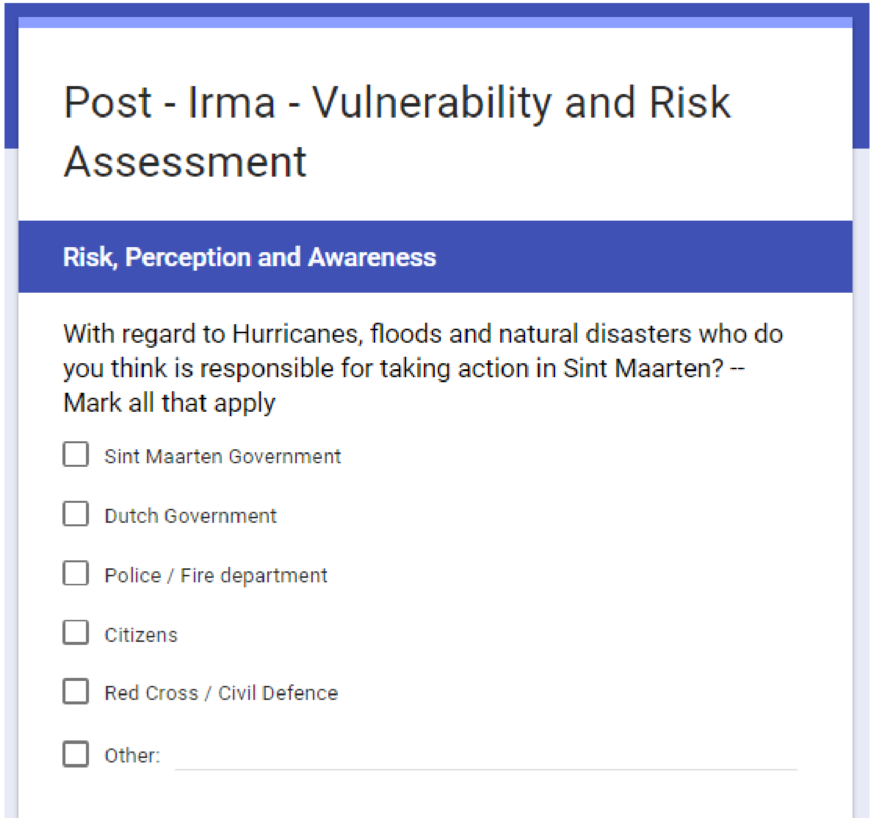
Section 8 (part 1)



Post - Irma - Vulnerability and Risk Assessment

Risk, Perception and Awareness

With regard to Hurricanes, floods and natural disasters who do you think is responsible for taking action in Sint Maarten? -- Mark all that apply

- ☐ Sint Maarten Government
- ☐ Dutch Government
- ☐ Police / Fire department
- ☐ Citizens
- ☐ Red Cross / Civil Defence
- ☐ Other: ______

Section 8 (part 2))

For another hurricane season, how likely is it that you would evacuate if the following events are forecasted to hit your local area? ...

	Definitely would not	Probably would not	About 50/50	Probably would	Definitely would	Prefer not to answer
Tropical depression (winds less than 68 km/h)	○	○	○	○	○	○
Tropical depression (winds 63–118 km/h)	○	○	○	○	○	○
Hurricane Category 1 (winds 119–153 km/h)	○	○	○	○	○	○
Hurricane Category 2 (winds 154–177 km/h)	○	○	○	○	○	○
Hurricane Category 3 (winds 178–208 km/h)	○	○	○	○	○	○
Hurricane Category 4 (winds 209–251 km/h)	○	○	○	○	○	○
Hurricane Category 5 (winds more than 252 km/h)	○	○	○	○	○	○

To what extent do you agree with the following statements:

	Strongly Disagree	Disagree	Slightly Disagree	Slightly Agree	Agree	Strongly Agree	Prefer not to answer
"If the early warnings that I receive would be more precise and would reach me more directly. I would follow them more than I do now"	○	○	○	○	○	○	○
"In Sint Maarten, the losses due to the recent hurricane could have been prevented by more appropriate planning and management from the City authorities"	○	○	○	○	○	○	○

When a hurricane or tropical storm approaches your local area, how frequently, do you check the forecasts on TV, mobile, radio, and/or on the Internet?

- ○ Less than once a day
- ○ About once a day
- ○ Several times a day
- ○ Every couple of hours
- ○ Throughout the whole day
- ○ No Answer / Not Applicable

Section 8 (part 3)

To the best of your knowledge, which one of the following is the most likely cause of injury or death during a hurricane? -- Please choose all that apply

- [ ] Flying or falling objects from high winds
- [ ] Rising water levels and high waves (storm surge)
- [ ] Flooding from heavy rains
- [ ] Accidents during evacuation
- [ ] Not really sure
- [ ] Other: ____

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Section 9 (part 1)

Post - Irma - Vulnerability and Risk Assessment

* Required

General / Household information

In which country were you born?

Your answer

How old are you?

Your answer

Gender

- ( ) Female
- ( ) Male
- ( ) Prefer not to say
- ( ) Other: ____

In which neighbourhood do you live? *

Your answer

Section 9 (part 2)

Which year did you move to the part of the island you are currently living?

Your answer

Total number of inhabitants in the household (Including yourself)

Your answer

Are you tenant or owner of the house / apartment

- ○ Tenant
- ○ Owner

Do you know the year of construction of the house? If Yes. Could you please write the year.

Your answer

What describe best your job status:

- ○ I work in a permanent or fixed location
- ○ I work in a Changing location - moving across the island
- ○ I am retired
- ○ I am not currently working
- ○ I am looking for a job
- ○ Other: ______

How many cars are within your household?

Your answer

How many smartphones/tablets are within your household?

Your answer

Do you have any pets or animals?

- ○ Yes
- ○ No

Is your home insured for natural disasters?

- ○ Yes
- ○ No
- ○ Do not Know
- ○ Prefer not to answer

Is your home insured against looting or riots?

- ○ Yes
- ○ No
- ○ Do not know
- ○ Prefer not to answer

How many stories is your house?

- ○ 1
- ○ 2
- ○ 3
- ○ 4
- ○ More than 4

Main house material (walls)

- ○ Briks
- ○ Concrete
- ○ Wood
- ○ Other: ______

Main roof material

- ○ Concrete
- ○ Metallic sheets (zinc or other)
- ○ Asbestos
- ○ Clay tiles
- ○ Tatched
- ○ Other: ______

Main floor material

- ○ Tiles
- ○ Cement
- ○ Earth
- ○ Wood
- ○ Other:

Damage estimate in your house due to Irma

- ○ 0 - 25%
- ○ 26 - 50%
- ○ 51 - 75%
- ○ 75 - 100%

Does your house usually gets flooded during hurricanes or storms?

- ○ Yes
- ○ No

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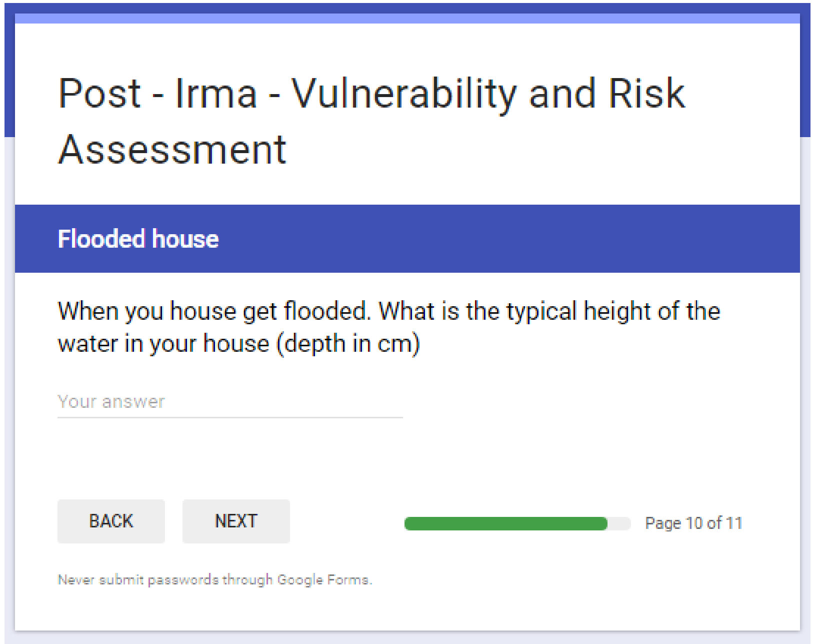
Section 10



Post - Irma - Vulnerability and Risk Assessment

Flooded house

When you house get flooded. What is the typical height of the water in your house (depth in cm)

Your answer

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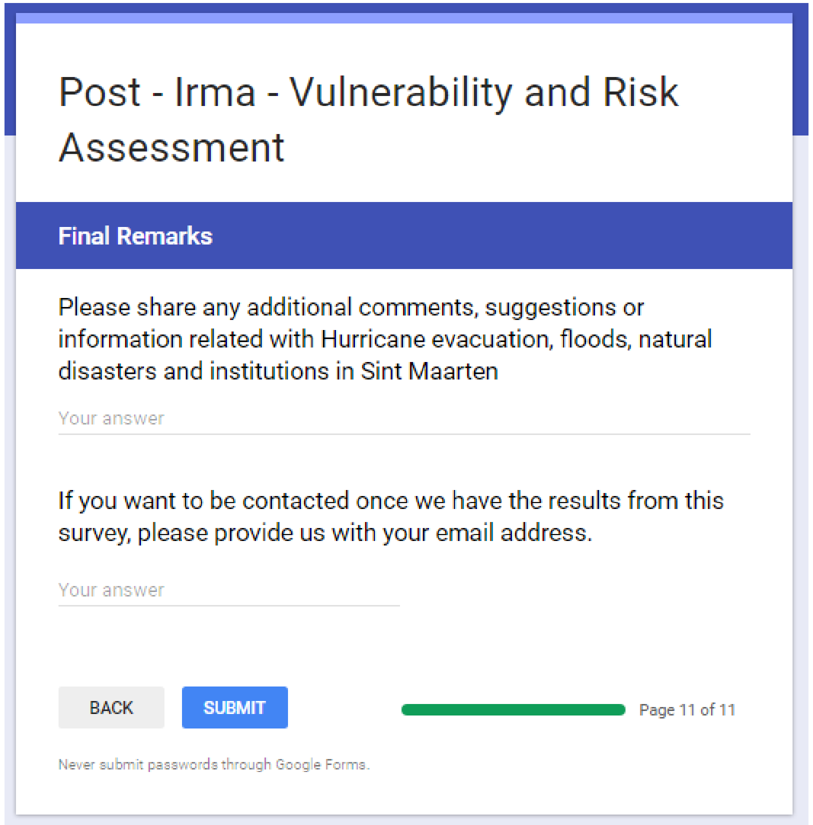
Section 11



Post - Irma - Vulnerability and Risk Assessment

Final Remarks

Please share any additional comments, suggestions or information related with Hurricane evacuation, floods, natural disasters and institutions in Sint Maarten

Your answer

If you want to be contacted once we have the results from this survey, please provide us with your email address.

Your answer

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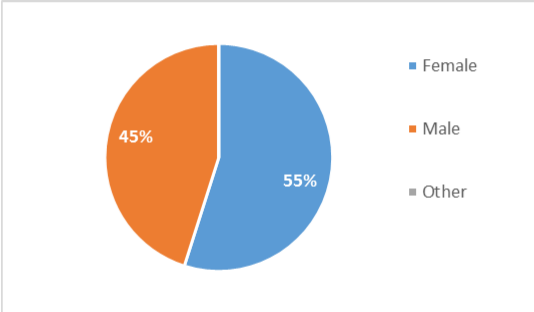
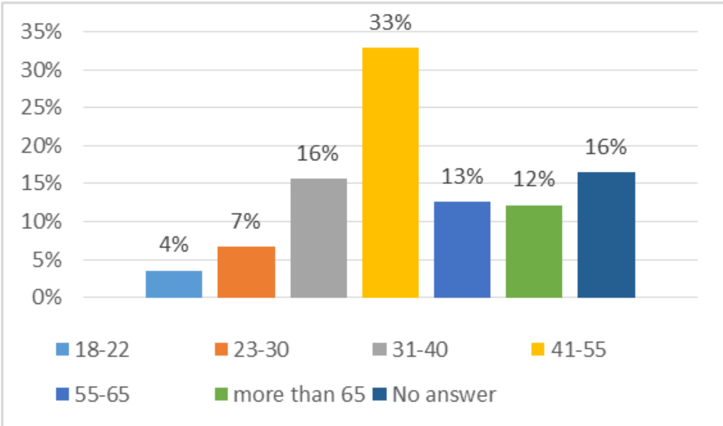
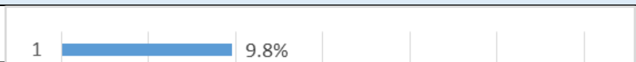
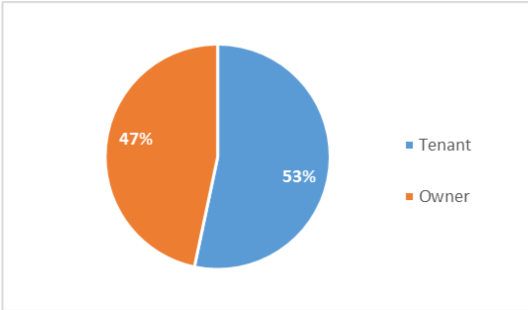
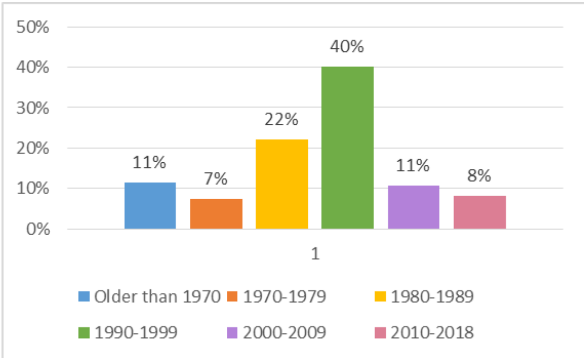
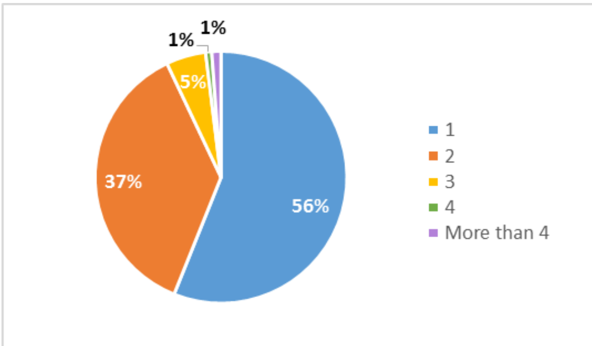
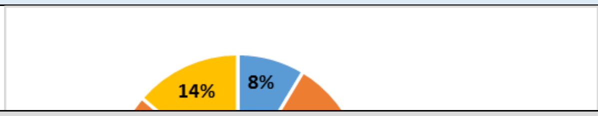
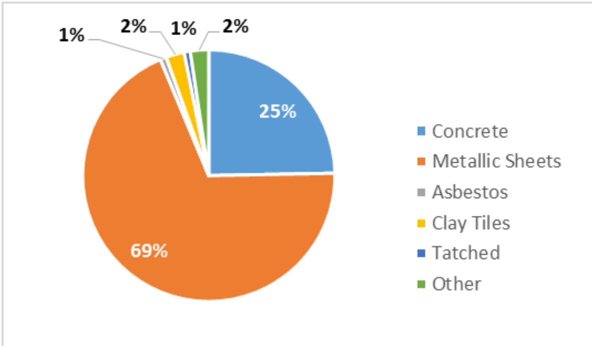
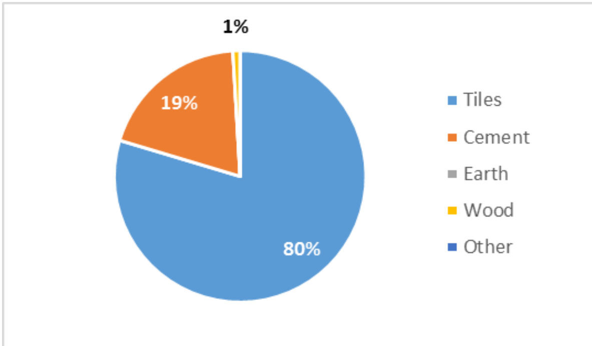
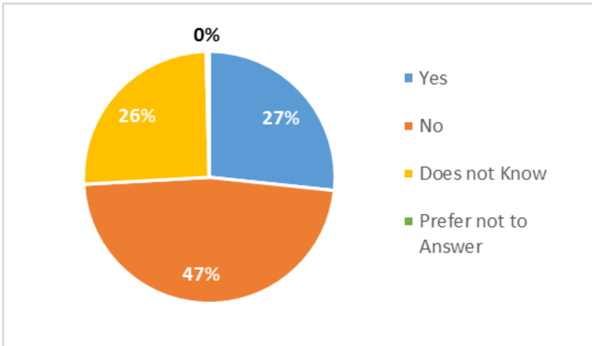
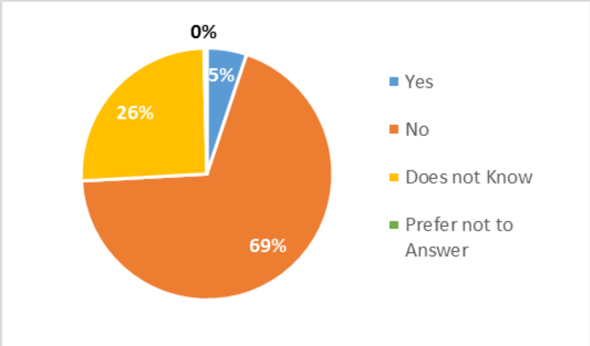
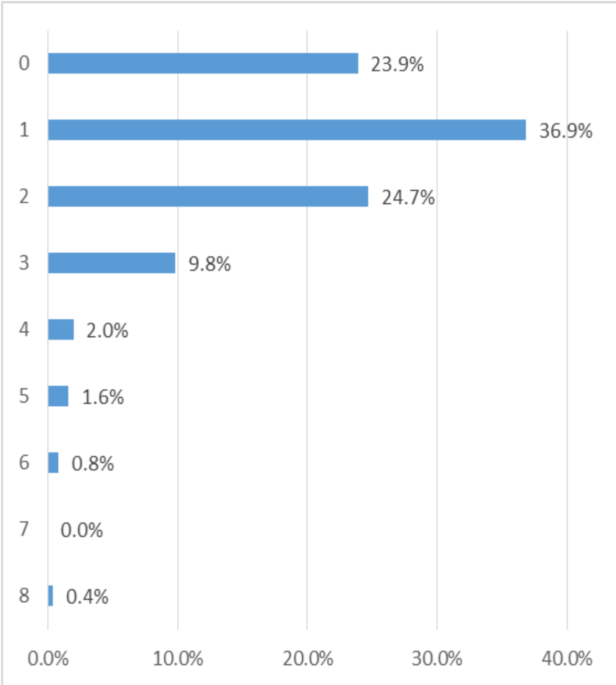
Appendix C. Household survey results

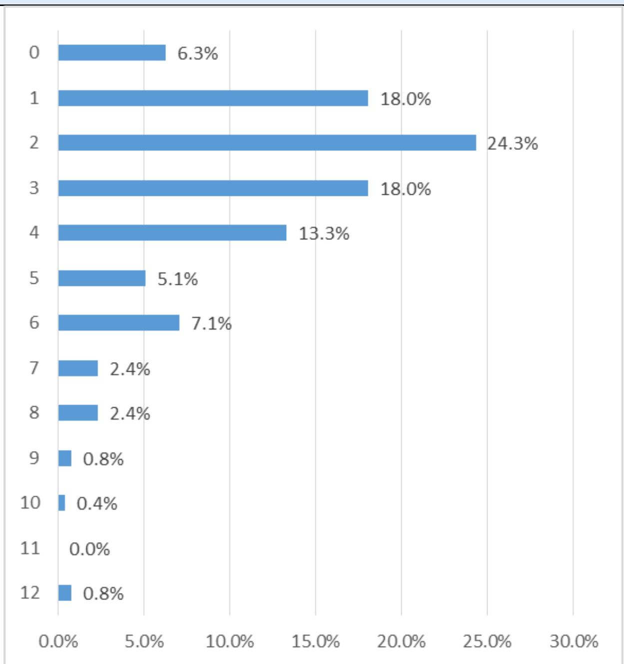
- **Household and demographic parameters**

Criteria	Total	
Gender		
Female	140	
Male	115	
Other	0	
Age Range		
18-22	9	
23-30	17	
31-40	40	
41-55	84	
55-65	32	
more than 65	31	
No answer	42	
Household Size		
1	25	
2	61	
3	57	
4	50	
5	31	
6	14	
7	9	
8	3	
9	1	
10	1	
12	2	

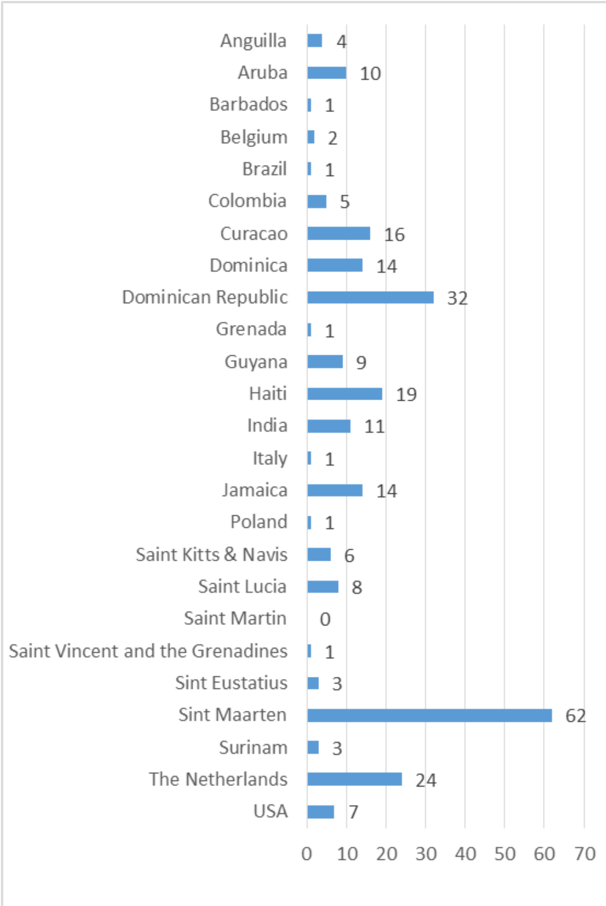
Criteria	Total	
16	1	
Household Ownership		
Tenant	136	
Owner	119	
Decade Construction of the house		
1970-1979	9	
1980-1989	27	
1990-1999	49	
2000-2009	13	
2010-2018	10	
Unknown	133	
Older than 1970	14	
Number of Stories		
1	143	
2	94	
3	13	
4	2	
More than 4	3	
Main House Material		
Bricks	22	
Concrete	198	
Wood	35	

Criteria	Total	
Other	0	
Main Roof Material		
Concrete	63	
Metallic sheets	176	
Asbestos	2	
Clay Tiles	6	
Thatched	2	
Other	6	
Main Floor Material		
Tiles	172	
Cement	42	
Earth	0	
Wood	2	
Other	0	
Insurance for Natural Disasters		
Yes	68	
No	121	
Does not know	65	
Prefer not to say	1	
Insurance for Looting		
Yes	13	
No	176	
Does not know	65	

Criteria	Total	
Prefer not to say	1	
Number of Cars		
0	61	
1	94	
2	63	
3	25	
4	5	
5	4	
6	2	
8	1	
Number of Cell phones / Tablets		
0	16	
1	49	
2	62	
3	46	
4	34	
5	13	
6	18	
7	6	
8	6	

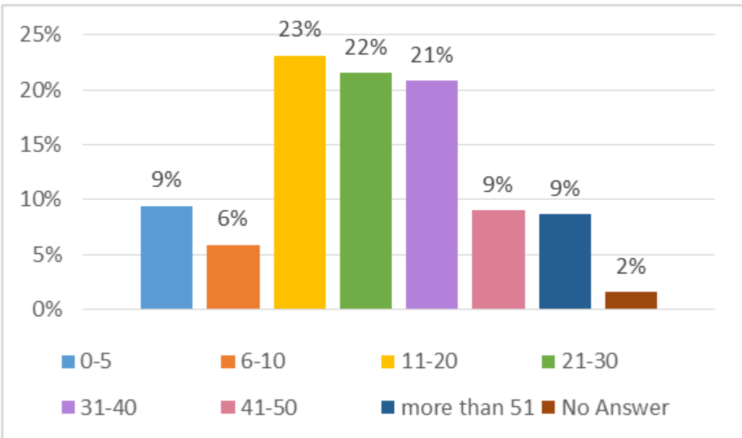
Criteria	Total	
9	2	
10	1	
12	2	

Criteria	Total
Country of Origin	
Anguilla	4
Aruba	10
Barbados	1
Belgium	2
Brazil	1
Colombia	5
Curacao	16
Dominica	14
Dominican Republic	32
Grenada	1
Guyana	9
Haiti	19
India	11
Italy	1
Jamaica	14
Poland	1
Saint Kitts & Navis	6
Saint Lucia	8
Saint Vincent and the	1
Sint Eustatius	3
Sint Maarten	62
Surinam	3
The Netherlands	24

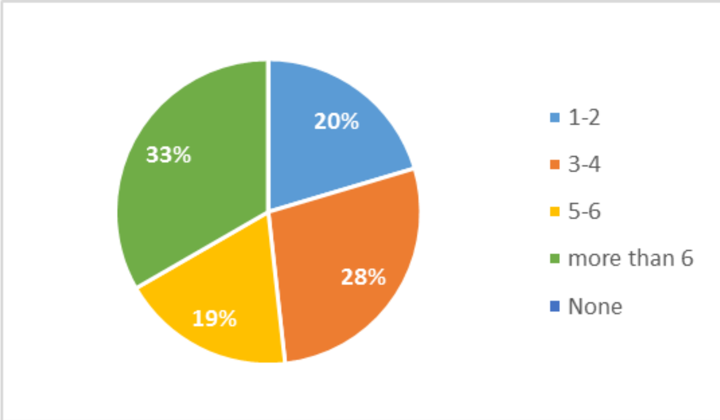


- **Information, Awareness and Experience with Hurricanes and Storms**

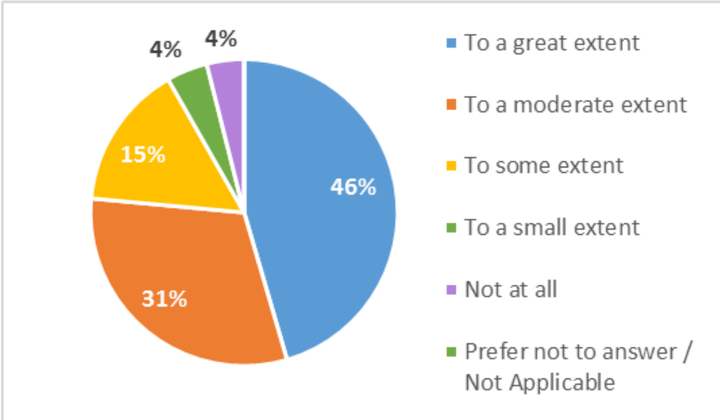
Criteria	Total
Number of Years in Sint Maarten	
0-5	24
11-20	59
21-30	55
31-40	53
41-50	23
6-10	15
More than 51	22
No Answer	4



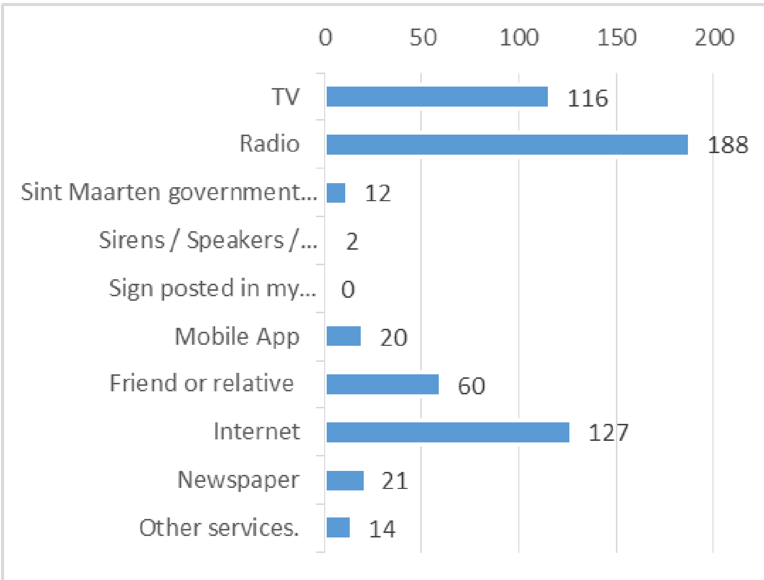
Criteria	Total
Number of hurricanes remembered	
1-2	52
3-4	71
5-6	47
More than 6	85

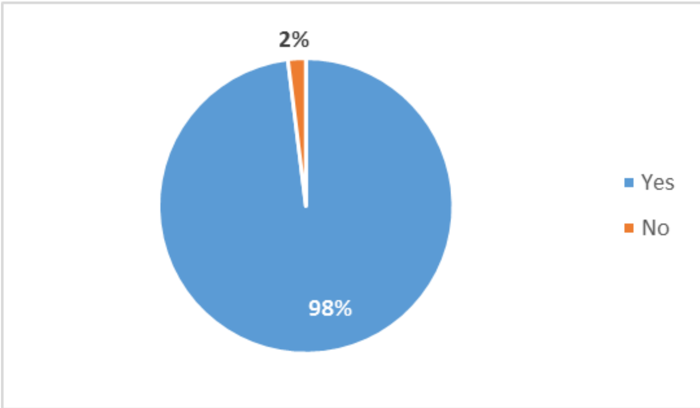
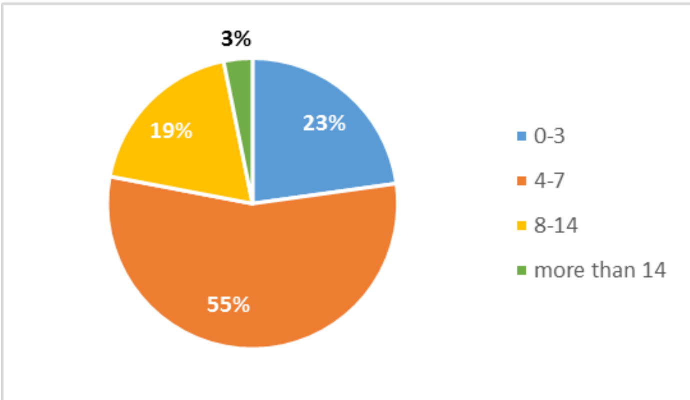
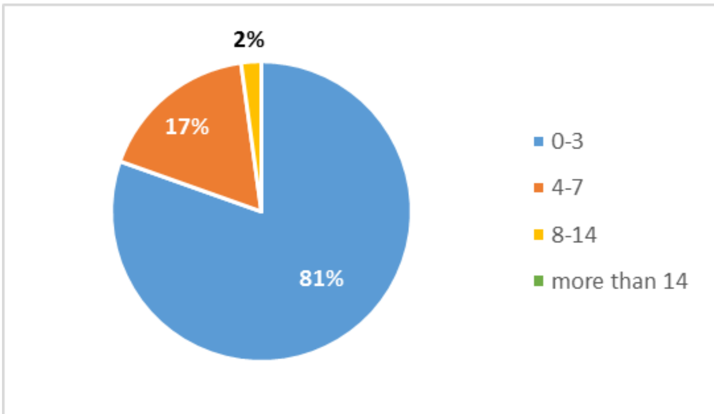


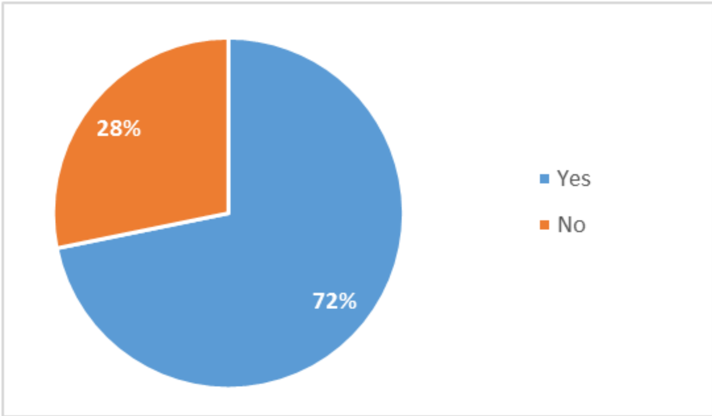
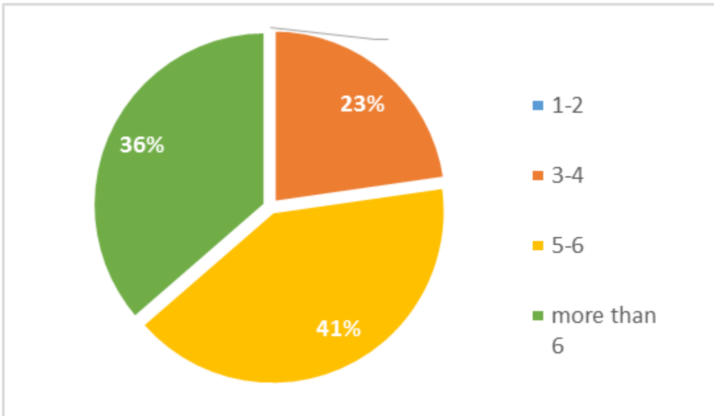
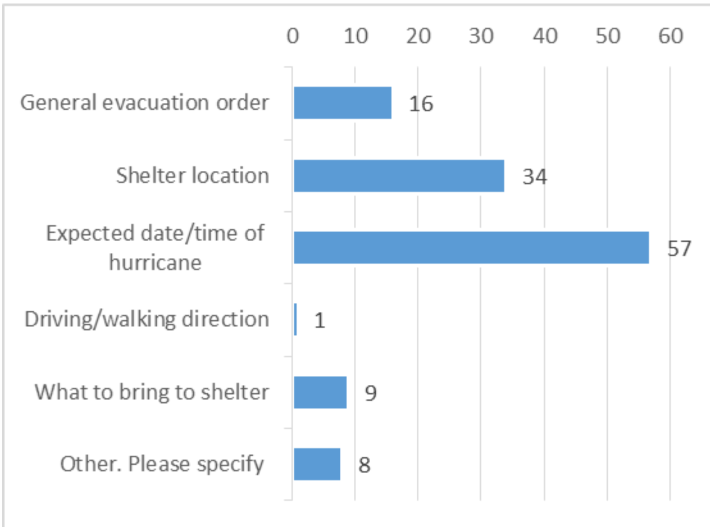
Criteria	Total
Know where to get warning/evacuation information	
To a great extent	116
To a moderate extent	79
To some extent	39
To a small extent	11
Not at all	10
Prefer not to answer / Not Applicable	0



Criteria	Total
Sources of information used	
TV	116
Radio	188
Sint Maarten government channel	12
Sirens / Speakers / Megaphone	2
Signposted in my neighbourhood	0
Mobile App	20
Friend or relative	60
Internet	127
Newspaper	21
Other services.	14

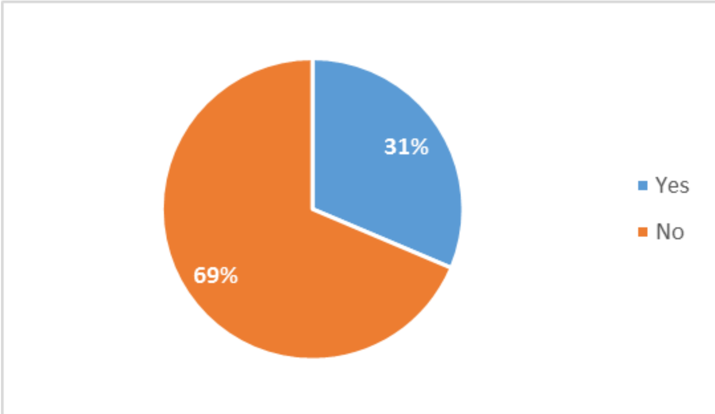


Criteria	Total	
Received information before Irma hit Sint Maarten		
Yes	250	
No	5	
Number of days aware before Irma hit Sint Maarten		
0-3	57	
4-7	138	
8-14	47	
More than 14	8	
Number of days aware of the severity of Irma before hit Sint Maarten - Only Web survey		
0-3	37	
4-7	8	
8-14	1	
More than 14	0	

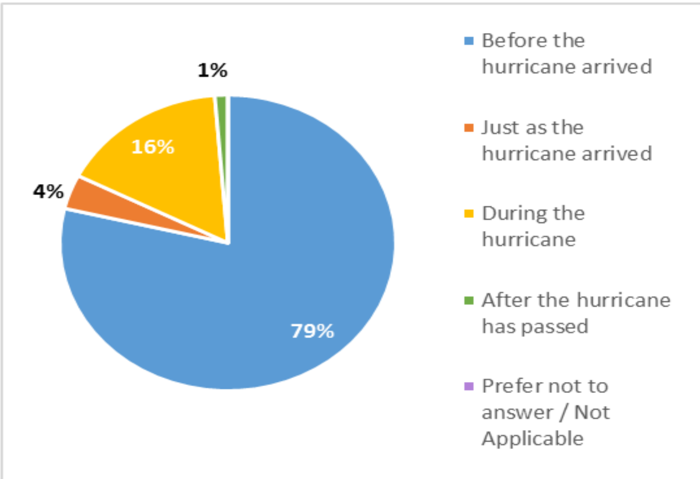
Criteria	Total	
Was the warning received with sufficient time		
Yes	56	
No	22	
Not sufficient time - How many days needed?		
1-2	0	
3-4	5	
5-6	9	
More than 6	8	
Type of Information received If Evacuate		
General evacuation order	16	
Shelter location	34	
Expected date/time of the hurricane	57	
Driving/walking direction	1	
What to bring to the shelter	9	
Other. Please specify	8	

- Evacuation behaviour

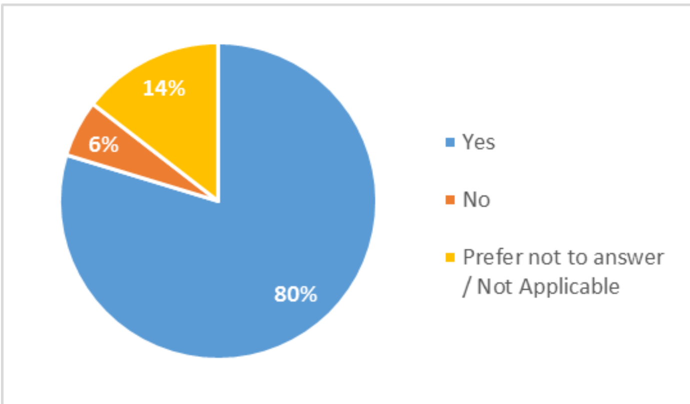
Criteria	Total	
Evacuation because of Irma		
Yes	80	
No	175	



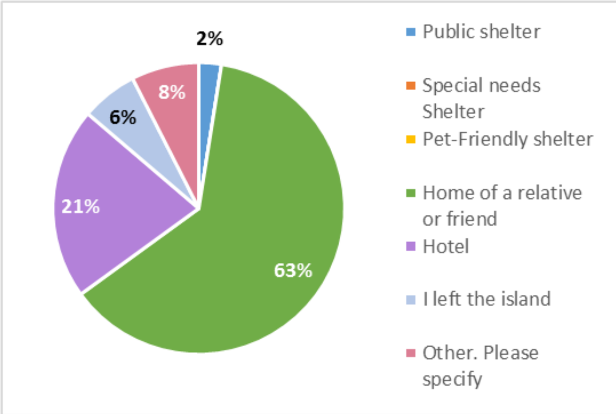
Criteria	Total	
Moment of Evacuation		
Before the hurricane arrived	63	
Just as the hurricane arrived	3	
During the hurricane	13	
After the hurricane has passed	1	
Prefer not to answer / Not Applicable	0	



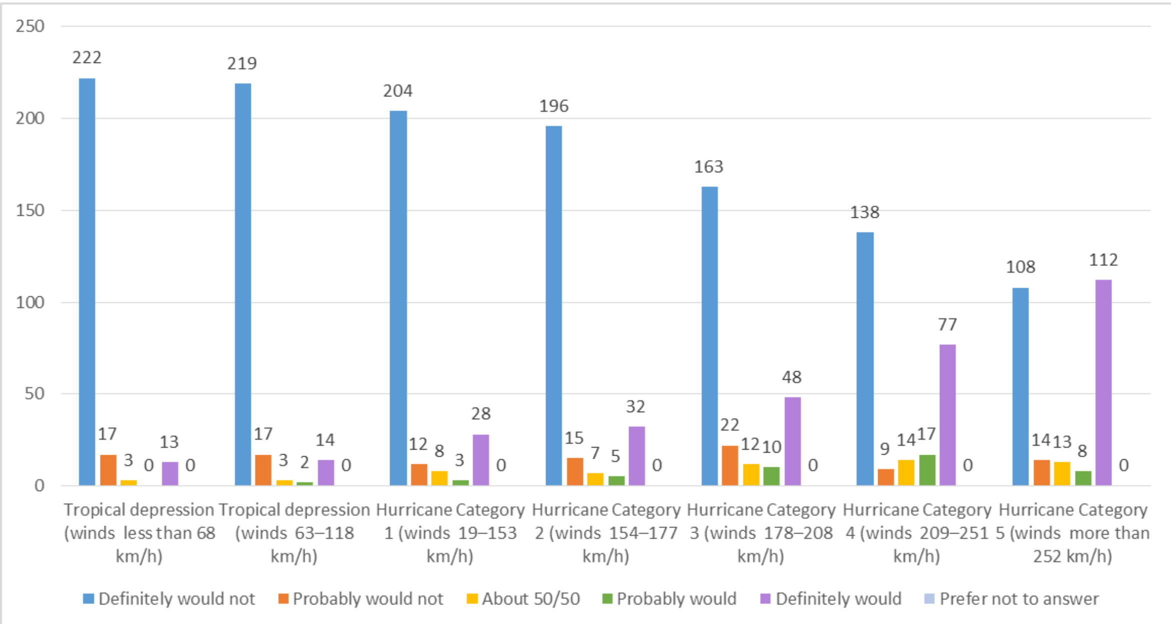
Criteria	Total	
Evacuation Following Instructions – Only Field		
Yes	55	
No	4	
Prefer not to answer / Not Applicable	10	



Chosen Evacuation place during Irma	
Public shelter	2
Special needs Shelter	0
Pet-Friendly shelter	0
Home of a relative or friend	50
Hotel	17
I left the island	5
Other. Please specify	6

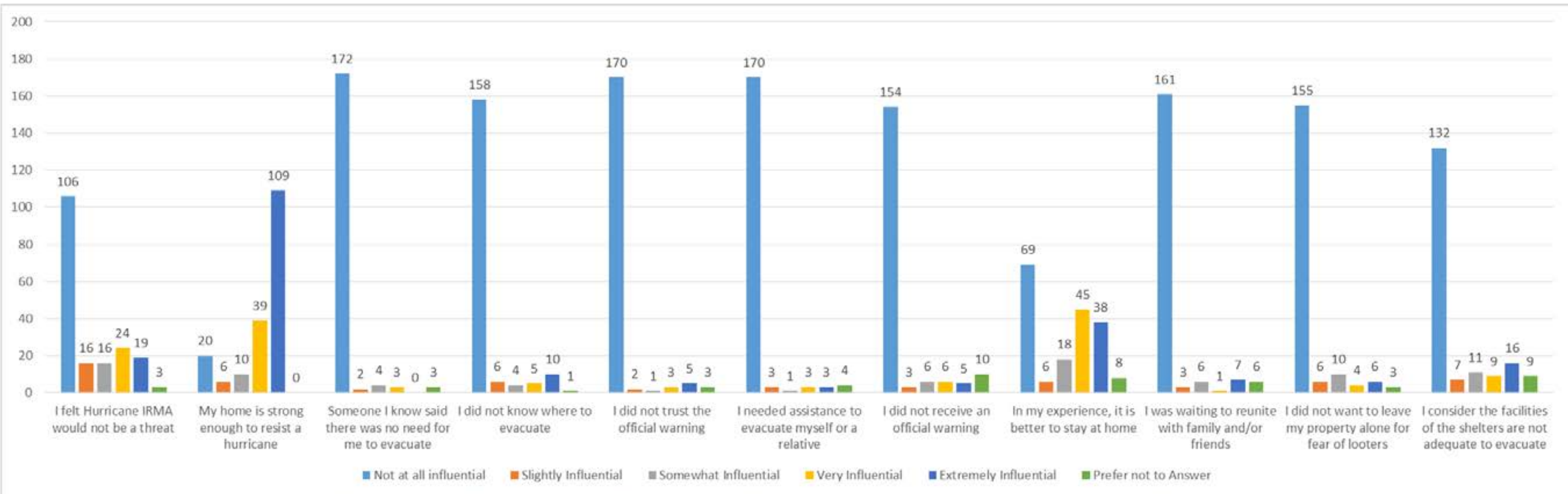


Future Evacuation Behaviour	Tropical depression (winds less than 68 km/h)	Tropical depression (winds 63–118 km/h)	Hurricane Category 1 (winds 19–153 km/h)	Hurricane Category 2 (winds 154–177 km/h)	Hurricane Category 3 (winds 178–208 km/h)	Hurricane Category 4 (winds 209–251 km/h)	Hurricane Category 5 (winds more than 252 km/h)
Definitely would not	222	219	204	196	163	138	108
Probably would not	17	17	12	15	22	9	14
About 50/50	3	3	8	7	12	14	13
Probably would	0	2	3	5	10	17	8
Definitely would	13	14	28	32	48	77	112
Prefer not to answer	0	0	0	0	0	0	0

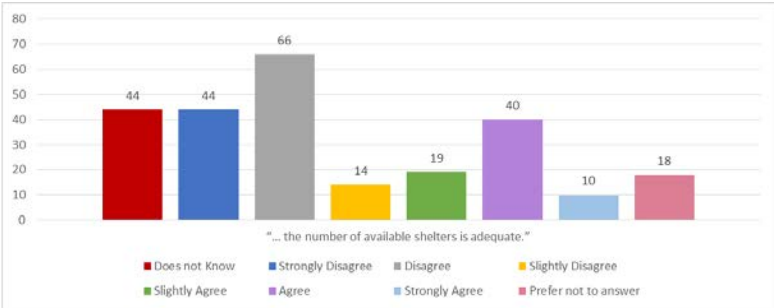


- Risk perception

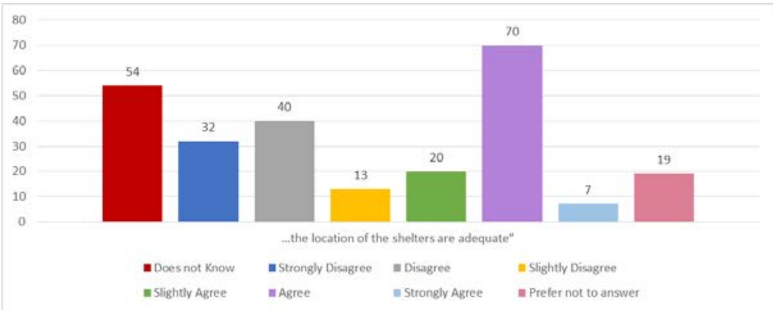
Influence of Factors to NOT evacuate	I felt Hurricane IRMA would not be a threat	My home is strong enough to resist a hurricane	Someone I know said there was no need for me to evacuate	I did not know where to evacuate	I did not trust the official warning	I needed assistance to evacuate myself or a relative	I did not receive an official warning	In my experience, it is better to stay at home	I was waiting to reunite with family and/or friends	I did not want to leave my property alone for fear of looters	I consider the facilities of the shelters are not adequate to evacuate
Not at all influential	106	20	172	158	170	170	154	69	161	155	132
Slightly Influential	16	6	2	6	2	3	3	6	3	6	7
Somewhat Influential	16	10	4	4	1	1	6	18	6	10	11
Very Influential	24	39	3	5	3	3	6	45	1	4	9
Extremely Influential	19	109	0	10	5	3	5	38	7	6	16
Prefer not to Answer	3	0	3	1	3	4	10	8	6	3	9



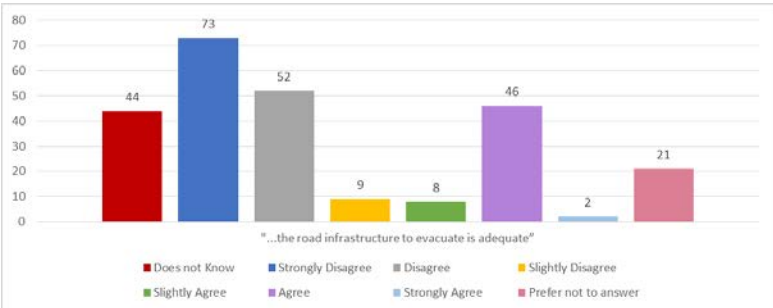
Criteria	Total
Number of shelters in Sint Maarten is adequate	
Does not Know	44
Strongly Disagree	44
Disagree	66
Slightly Disagree	14
Slightly Agree	19
Agree	40
Strongly Agree	10
Prefer not to answer	18



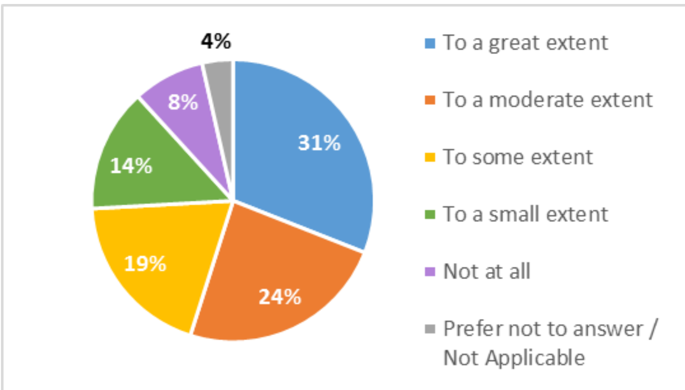
Criteria	Total
Location of shelters in Sint Maarten is adequate	
Does not Know	54
Strongly Disagree	32
Disagree	40
Slightly Disagree	13
Slightly Agree	20
Agree	70
Strongly Agree	7
Prefer not to answer	19



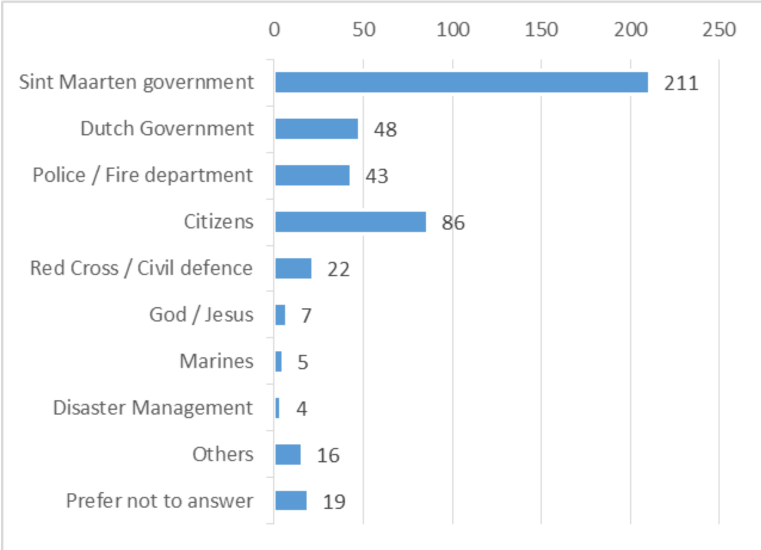
Criteria	Total
Roads in Sint Maarten for an evacuation are adequate	
Does not Know	44
Strongly Disagree	73
Disagree	52
Slightly Disagree	9
Slightly Agree	8
Agree	46
Strongly Agree	2
Prefer not to answer	21



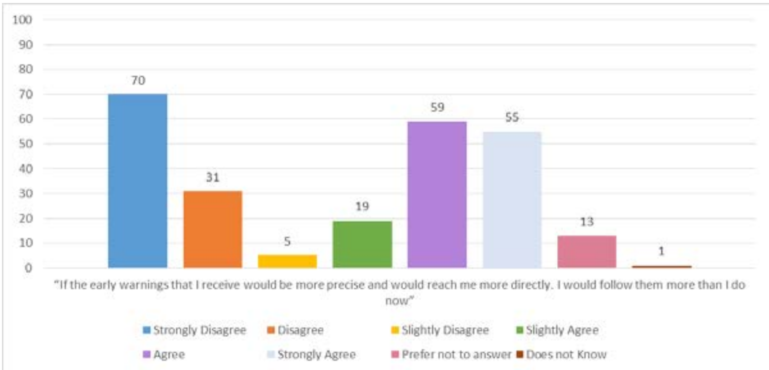
Criteria	Total
Trust in official sources of Information	
To a great extent	79
To a moderate extent	61
To some extent	49
To a small extent	36
Not at all	21
Prefer not to answer / Not Applicable	9



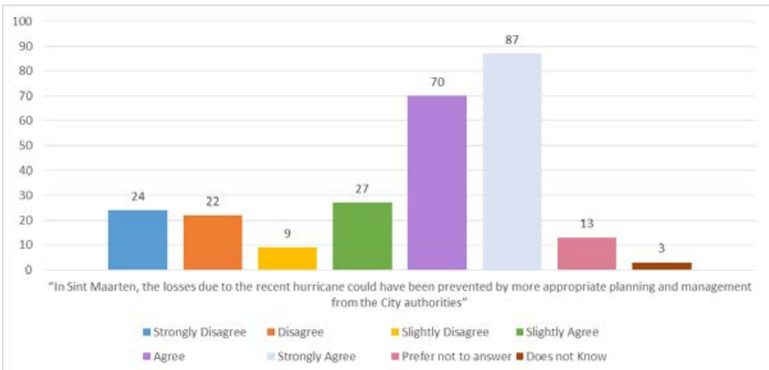
Criteria	Total
Responsible for actions with regards to Natural disasters	
Sint Maarten government	211
Dutch Government	48
Police / Fire department	43
Citizens	86
Red Cross / Civil defence	22
God / Jesus	7
Marines	5
Disaster Management	4
Others	16
Prefer not to answer	19

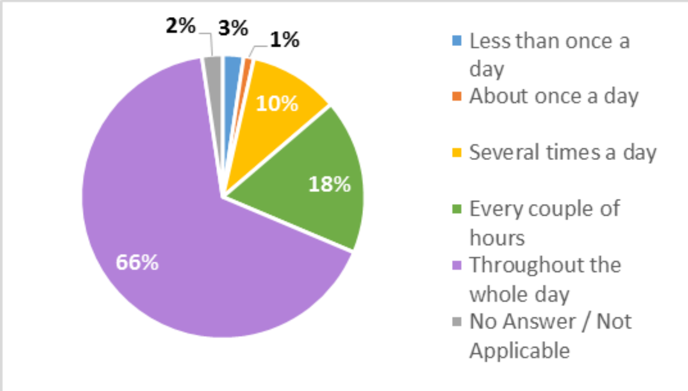
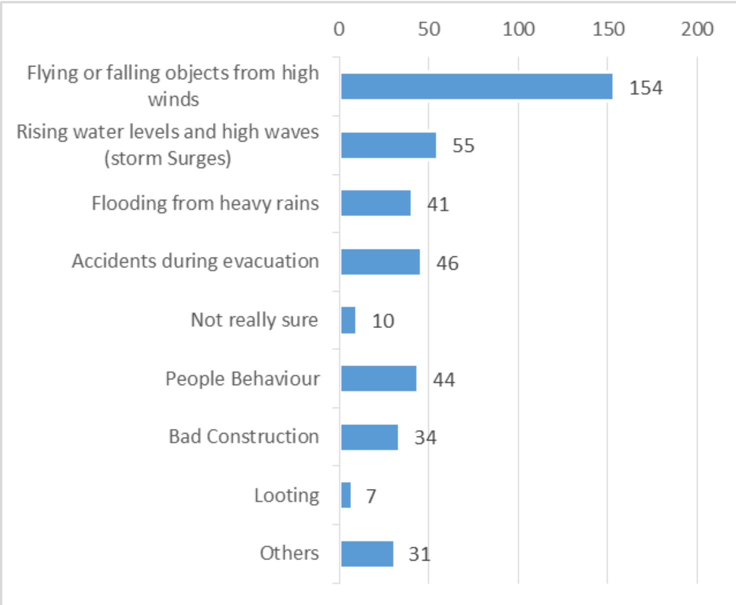


Criteria	Total
Willingness to follow orders if the message is more direct	
Strongly Disagree	70
Disagree	31
Slightly Disagree	5
Slightly Agree	19
Agree	59
Strongly Agree	55
Prefer not to answer	13
Does not Know	1

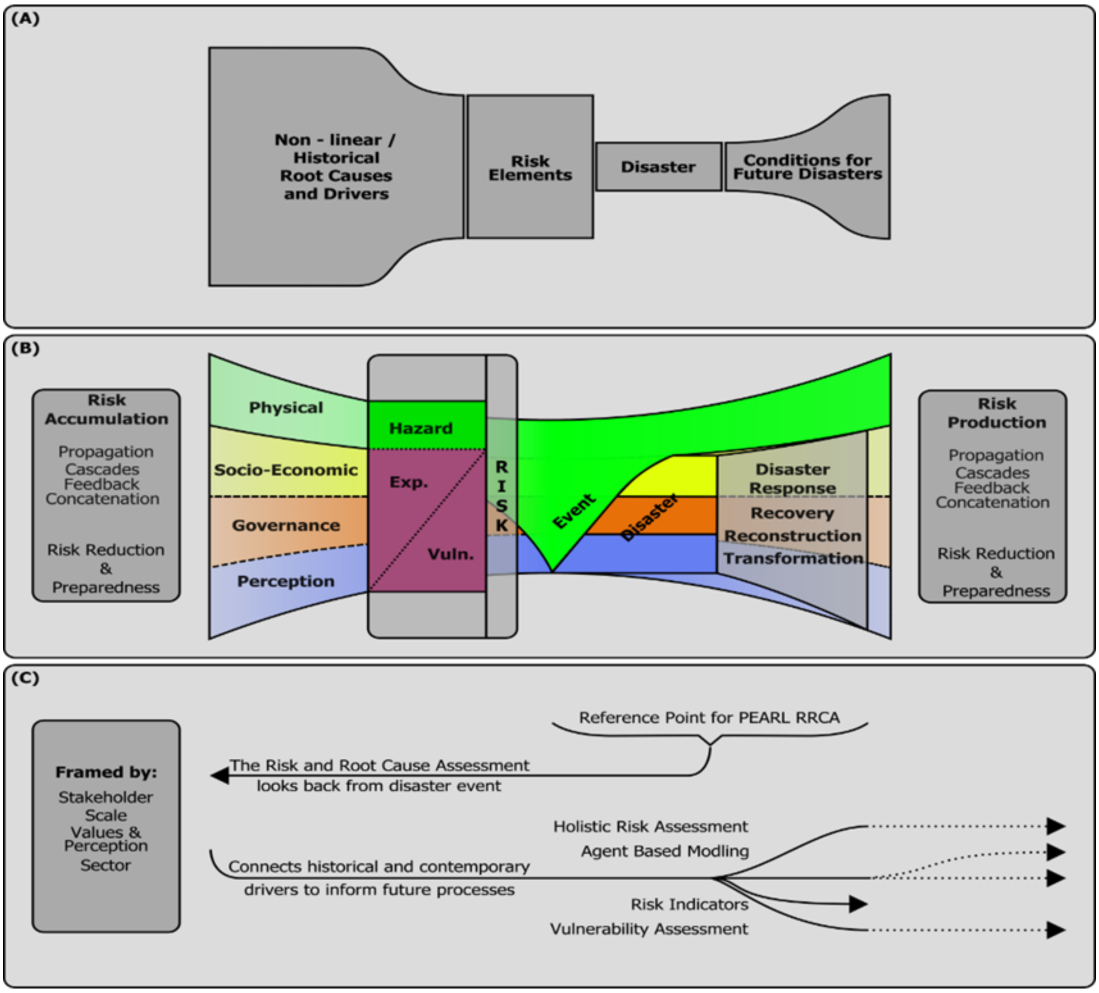


Criteria	Total
Losses could have been prevented if better planning	
Strongly Disagree	24
Disagree	22
Slightly Disagree	9
Slightly Agree	27
Agree	70
Strongly Agree	87
Prefer not to answer	13
Does not Know	3



<table>
<tr><th>Criteria</th><th>Total</th><th></th></tr>
<tr><td colspan="3">How often hurricane information is checked</td></tr>
<tr><td>Less than once a day</td><td>6</td><td rowspan="6">
</td></tr>
<tr><td>About once a day</td><td>3</td></tr>
<tr><td>Several times a day</td><td>26</td></tr>
<tr><td>Every couple of hours</td><td>45</td></tr>
<tr><td>Throughout the whole day</td><td>169</td></tr>
<tr><td>No Answer / Not Applicable</td><td>6</td></tr>
<tr><td colspan="3">The main cause of injuries or deaths during a hurricane</td></tr>
<tr><td>Flying or falling objects from high winds</td><td>154</td><td rowspan="9">
</td></tr>
<tr><td>Rising water levels and high waves (storm Surges)</td><td>55</td></tr>
<tr><td>Flooding from heavy rains</td><td>41</td></tr>
<tr><td>Accidents during evacuation</td><td>46</td></tr>
<tr><td>Not really sure</td><td>10</td></tr>
<tr><td>People Behaviour</td><td>44</td></tr>
<tr><td>Bad Construction</td><td>34</td></tr>
<tr><td>Looting</td><td>7</td></tr>
<tr><td>Others</td><td>31</td></tr>
</table>

Appendix D. PEARL Risk Root Cause Analysis Framework based on the FORIN approach



Appendix E. List of interviewees

- Jesper Jansweijer, Dutch Red Cross (9.02.2018)
- Kurt Ruan, VROMI (14.02.2018)
- Emilie Buffet and Joachim Sylvain, AFD (7.03.2018)
- Nicolas Maslach, RNN Saint Martin (19.03.2018)
- Anne-Marie Bouille, Conservatoire du Littoral (19.03.2018)
- Joachim Bel Mokhtar & Jean Marie Thevenet, Trait d'Union France Victimes (20.03.2018)
- Isaac Joseph, Sint Maarten Ministry of Tourism (20.03.2018)
- Jean Pierre Tey, SXM Verde (22.03.2018)
- Jan Vanden Eyden, ICE (20.03.2018)
- Cedric Peterson, Sint Maarten, Department of Communications (21.03.2018)
- Mark Schloss, Sint Marteen Department of social policy and Labour (20.03.2018)
- Charlotte Terrac, DRM COM (21.03.2018)
- Paul Marten & Silvanico, DRM Sint Maarten (21.03.2018)
- John Overington, Salvation Army (22.03.2018)
- Kamena Ntenda and Freddy Austli, UNDP (22.03.2018)
- Henk Van Hatten, Salvation Army (23.03.2018)
- Jean Noel Degrace, Meteo France (23.03.2018)
- Robert de Wilde & Chris Johnson , VNP (23.03.2018)
- Geerts Vanderleest , VROMI, (26.03.2018)
- Anna Kroon and Ingvill Morlandstoe , UNICEF (26.03.2018)
- Sabrina Placidoux, COM Urbanisme (28.03.2018)
- Annie Arbitter, Samaritan Purse, (28.03.2018)
- Frédéric Mortier, Delegue interministeriel a la reconstruction, (29.03.2018)
- Philippe Gustin & Dominique Devin-Mauzard, Delegation inter-ministerielle pour la reconstruction des iles de Saint Barthelemy et de Saint Martin, (12.04.2018)

Appendix F. Interview guidelines

A) Interviewee Background

- Can you describe your role / institution?
- How long have you been in your current position?
- How long have you lived on the island?
- How does your work relate to on-going reconstruction efforts?

B) Irma impacts and responses

- What were the main effects of Irma on a) housing and land use and b) the health sector, both in the first few days after the disaster, and now (6 months later)?
- What was different about the impacts of Irma in contrast to previous hurricanes (including 1995, for those who have memory of these events) for a) housing and land use and b) the health sector?
- What actions did your institution take in terms of a) preparing people for the storm in advance (preparedness) b) immediate response c) reconstruction? Did your response vary in comparison to responses to previous hurricanes and, if so, why?
- How well equipped were you to respond in terms of a) your knowledge and information (including meteorological information and warnings) b) your capacities - human resources (manpower, relationships), finance, technology and infrastructure?
- Who are the i) individuals and ii) organisations you work most closely with for disaster management? Do the individuals / organisations provide knowledge and information, human resource / finance / infrastructure and technology? What are the challenges in engaging these individuals / organisations?

C) The reconstruction process

- What is your vision for how SXM might be built back better withstand future hurricane, flooding and possibly tsunami events?
- Does the current reconstruction process support that vision and if not, why not?
- What do you see as the main opportunities and challenges to realising that vision (including how influenced by the operalisation of a Trust Fund for St Maarten)? Do you have the knowledge and information, human and resource capacities, relationships with other actors and institutions to realise that vision?

Appendix G. Workshop with local community organisations and first responders (Sint Maarten, 18 April 2018).

It was evident that this was a rare opportunity for local organisations to engage, share information and collaborate – nascent collaborations began to emerge. Civil society in SXM would therefore greatly benefit from regular meetings and engagement – particularly as such an important constituent of the post-Hurricane response. It was clear that the workshop was a very valuable opportunity for participants:

- "This was a very good opportunity. We know what we have to work on now – we need to get together as organisations."
- "It was a good start for collaboration and getting organised."
- "Thank you for your time and knowledge shared with us, I had a great time and was able to do a lot of networking."

Participating Organisations:

- Council of Churches
- Samenwerkende Fondsen (Dutch funding organisation for SXM CBOs)
- Senior Citizen Recreational Foundation
- The Windward Islands Federation of Labour (WIFOL) – local union
- Haitian Catholic Community
- Permanent Electoral Committee (Haitian)
- Sunrise Rotary Club
- Sint Maarten Pensioner Social Advocacy

Also interviewed:

- Sint Maarten Youth Council Association

Appendix H. Numerical wave simulation results

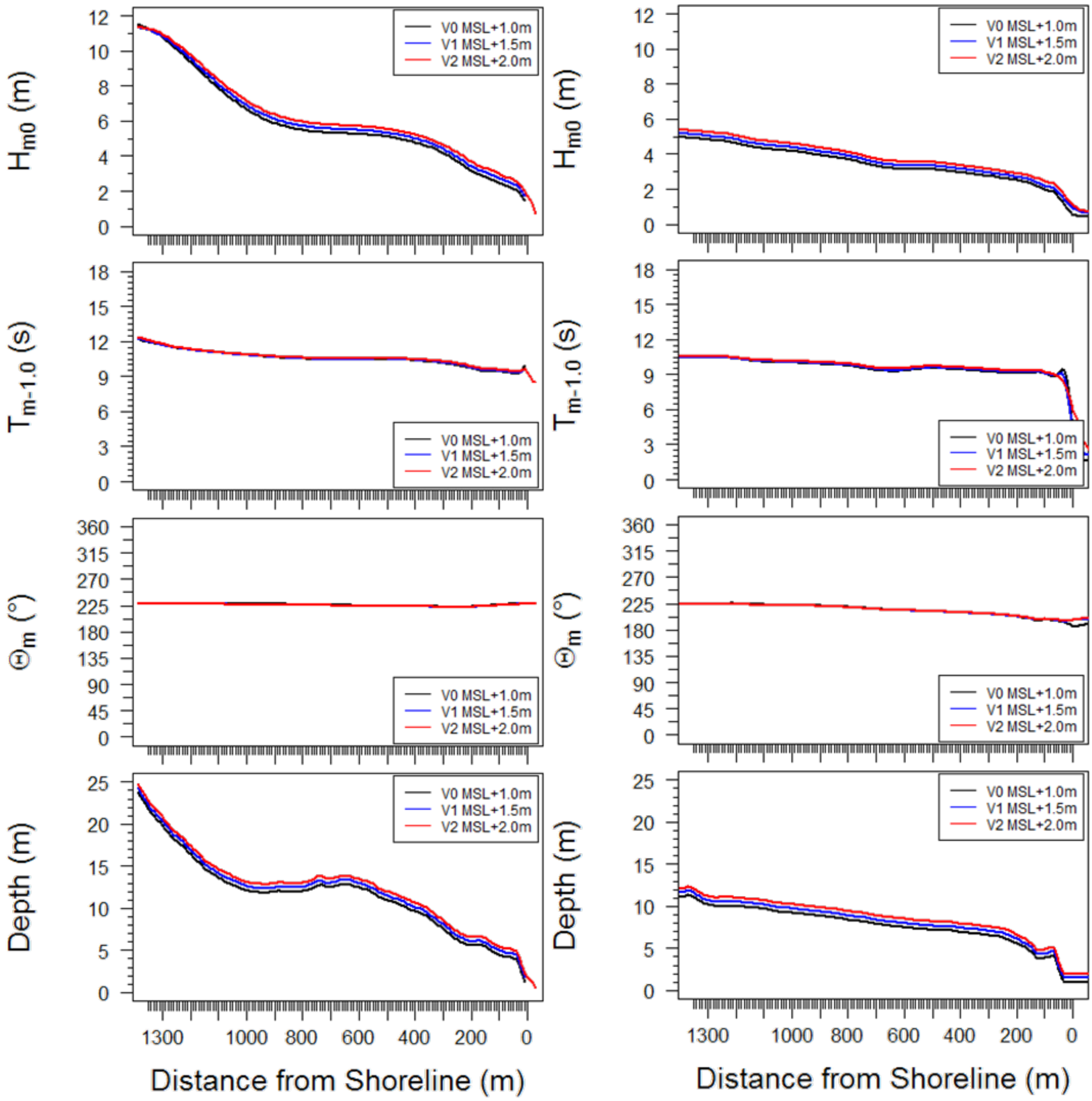


Figure H.1. Wave conditions along output curve C01 (left) and C02 (right), numerical simulations V0, V1 and V2

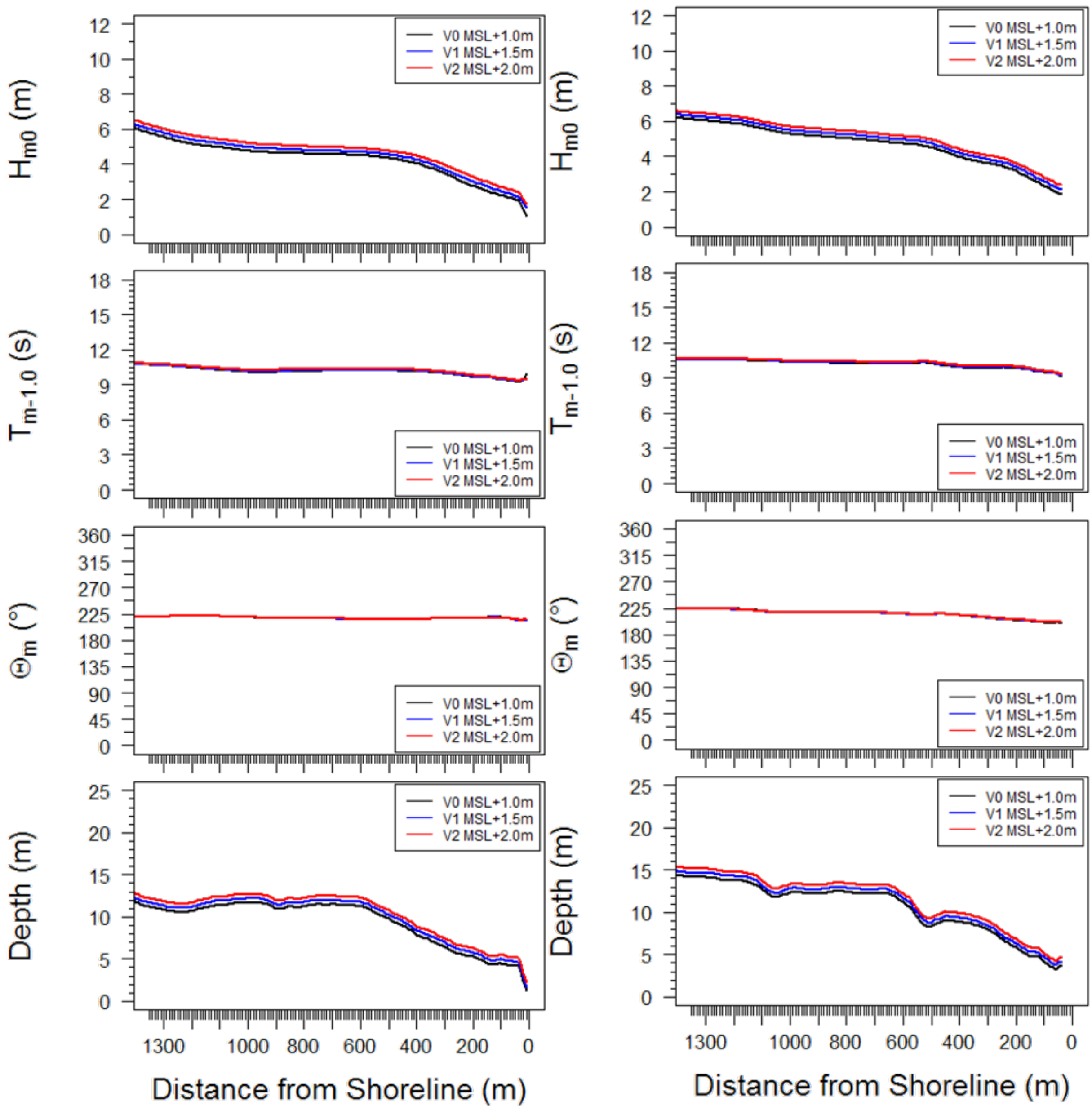


Figure H.2. Wave conditions along output curve C03 (left) and C04 (right), numerical simulations V0, V1 and V2

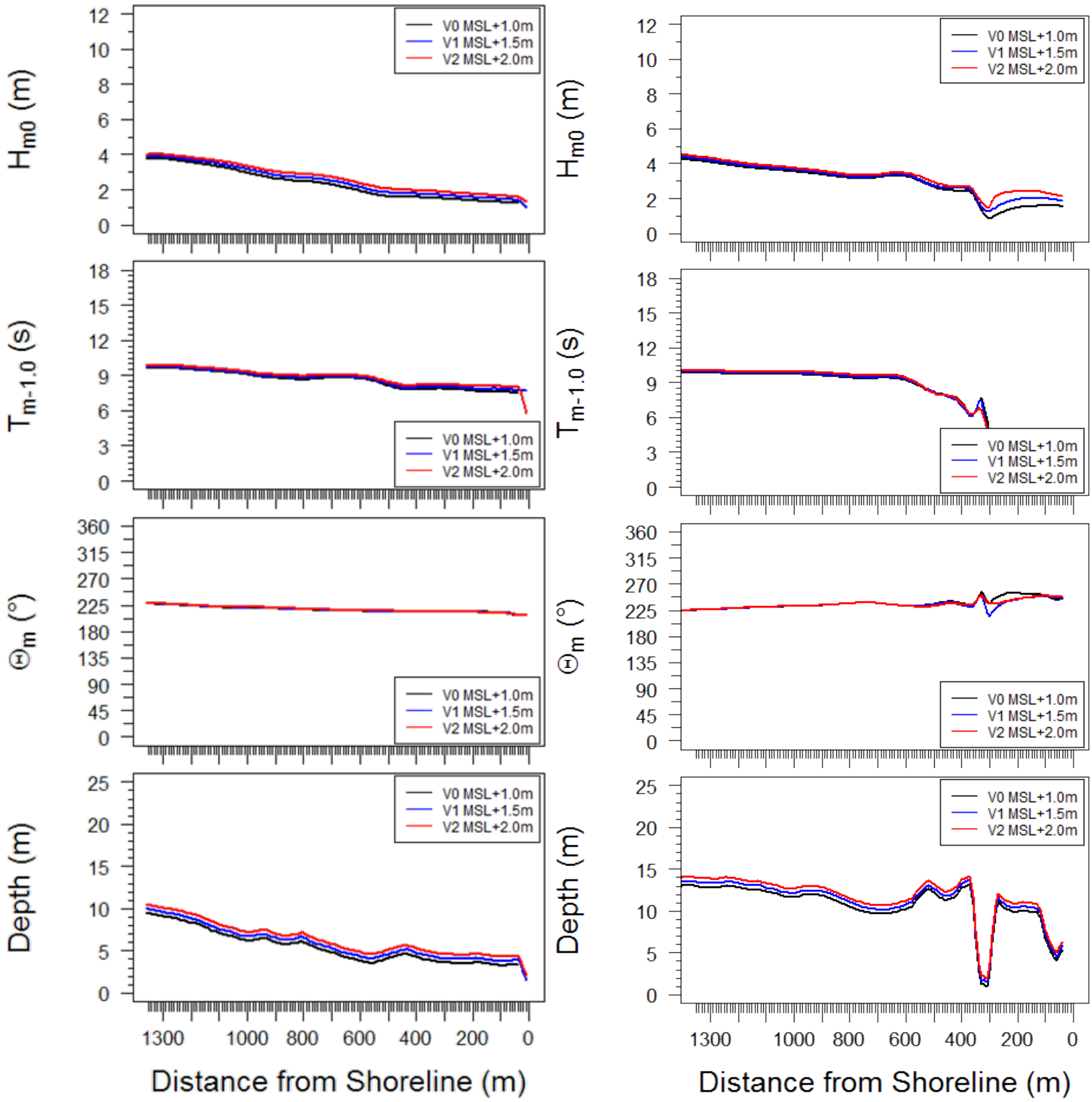
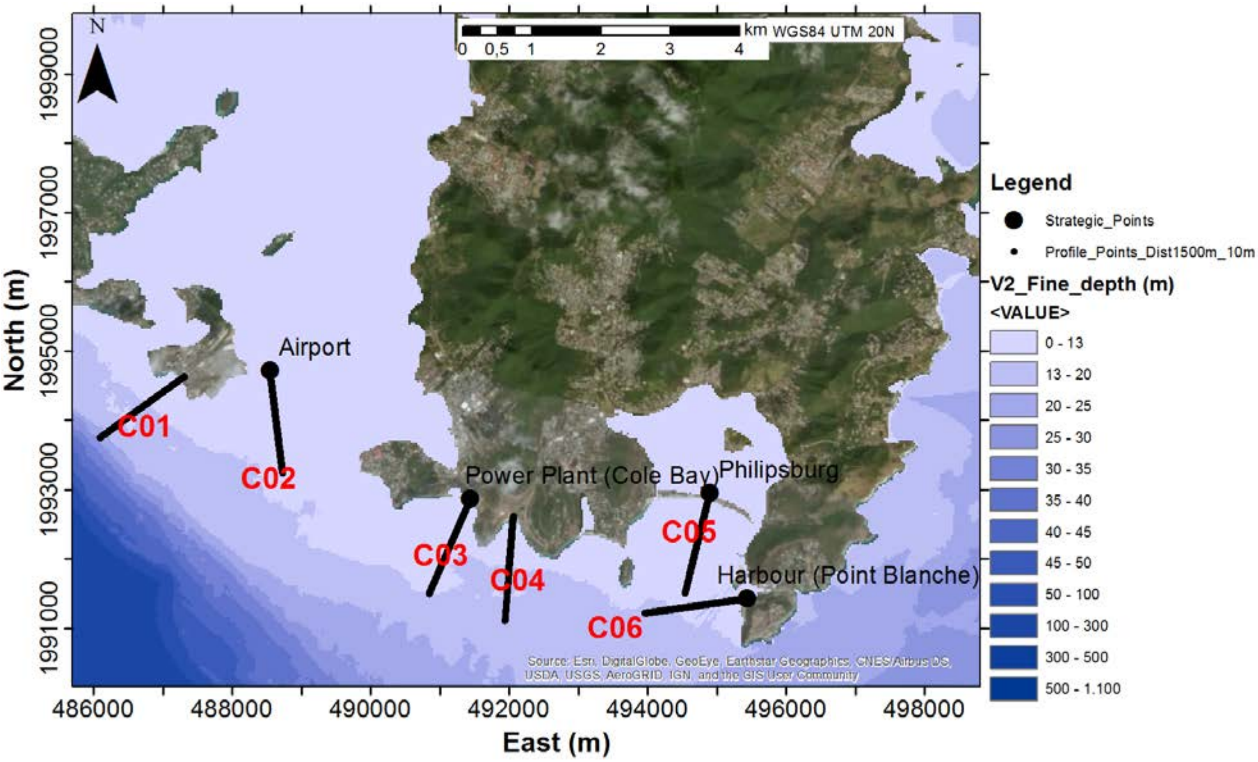


Figure H.3. Wave conditions along output curve C05 (left) and C06 (right), numerical simulations V0, V1 and V2



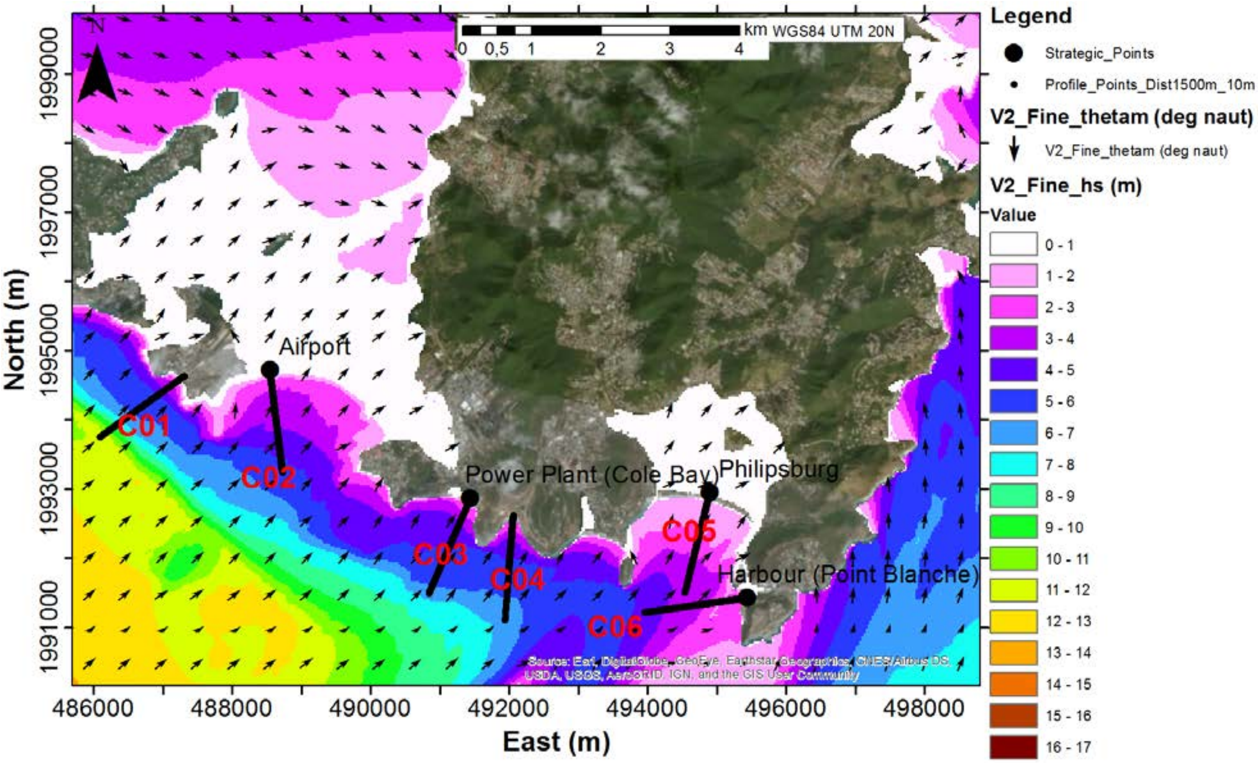


Figure H.4. Selected output for simulation V2 (MSL+2 m), water depths (top) and significant wave height H_s and mean wave direction θ_m (bottom)

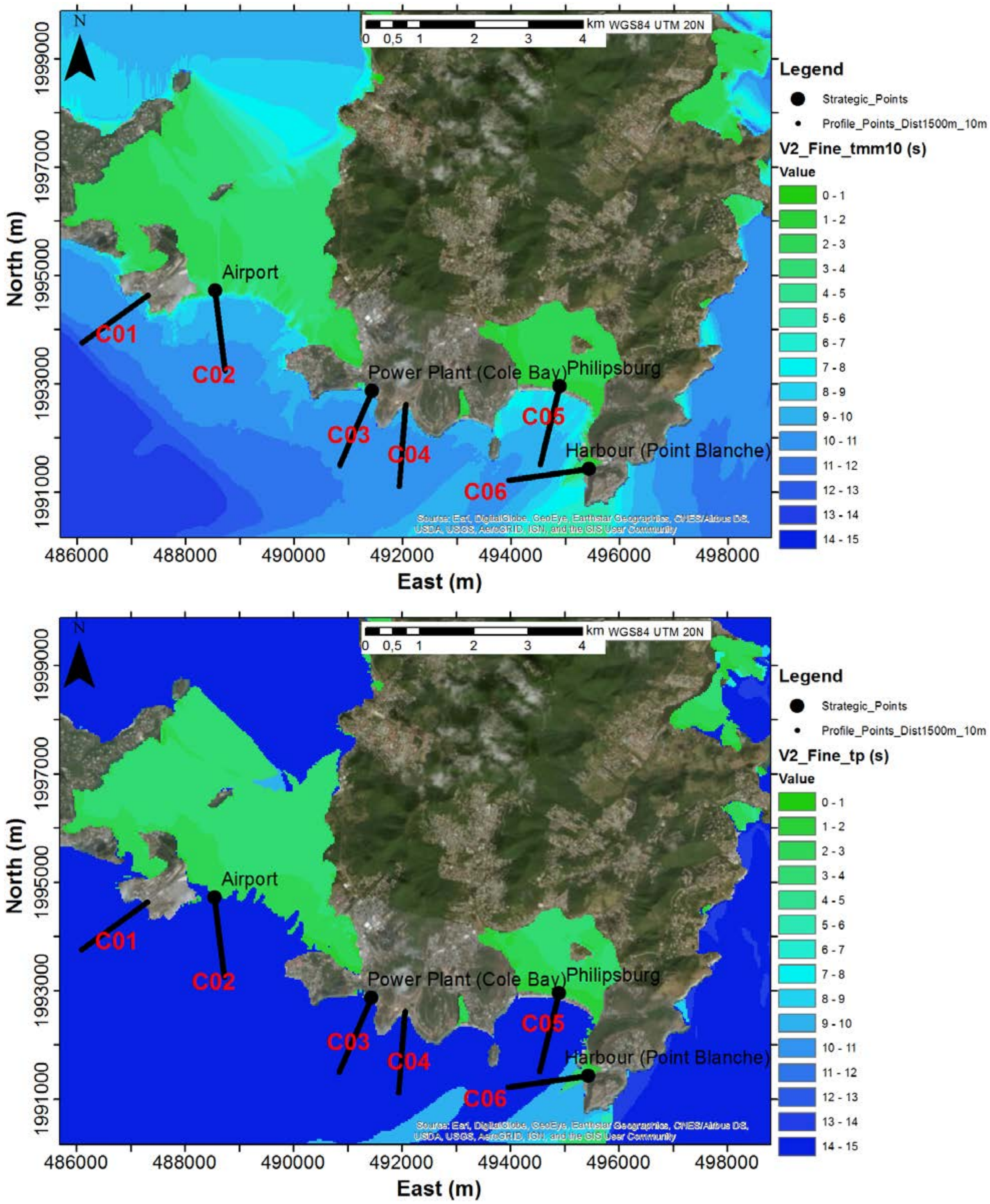


Figure H.5. Selected output for simulation V2 (MSL+2 m), spectral wave period $T_{m-1.0}$ (top) and peak wave period T_p (bottom)

Table H.1. Wave conditions at selected locations, numerical simulations V0, V1 and V2

V0: *W*=MSL+1.0 m								**Change of**
Curve	**Dist from Begin (m)**	**Dist from Shore (m)**	**Depth (m)**	H_{m0} **(m)**	$T_{m-1.0}$ **(s)**	T_p **(s)**	θ_m **(°)**	$H_{m0,V0}/H_{m0,V0}$ **(%)**
C01	120	10	1.3	1.4	9.9	17.5	229	0
C02	110	10	1.0	0.7	6.6	17.5	189	0
C03	90	10	1.2	1.1	10.0	17.5	215	0
C04	130	40	3.8	1.9	9.2	17.5	201	0
C05	180	40	3.4	1.2	7.5	15.9	207	0
C06	80	40	5.4	1.6	4.1	3.1	244	0
V1: *W*=MSL+1.5 m								**Change of**
Curve	**Dist from Begin (m)**	**Dist from Shore (m)**	**Depth (m)**	H_{m0} **(m)**	$T_{m-1.0}$ **(s)**	T_p **(s)**	θ_m **(°)**	$H_{m0,V1}/H_{m0,V0}$ **(%)**
C01	120	10	1.8	1.8	9.6	17.5	228	22
C02	110	10	1.5	1.1	5.6	17.5	196	53
C03	90	10	1.7	1.5	9.6	17.5	215	42
C04	130	40	4.3	2.1	9.2	17.5	201	13
C05	180	40	3.9	1.4	7.8	15.9	208	15
C06	80	40	5.9	1.9	4.0	3.5	247	21
V2: *W*=MSL+2.0 m								**Change of**
Curve	**Dist from Begin (m)**	**Dist from Shore (m)**	**Depth (m)**	H_{m0} **(m)**	$T_{m-1.0}$ **(s)**	T_p **(s)**	θ_m **(°)**	$H_{m0,V2}/H_{m0,V0}$ **(%)**
C01	120	10	2.3	2.0	9.7	17.5	228	40
C02	110	10	2.0	1.3	6.9	17.5	196	82
C03	90	10	2.2	1.7	9.5	17.5	215	64
C04	130	40	4.8	2.4	9.3	17.5	201	25
C05	180	40	4.4	1.6	8.0	14.5	208	30
C06	80	40	6.4	2.2	4.0	3.8	249	38

Table H.2. Wave conditions at selected locations, numerical simulations V0, V3 and V4

V0: U_{10}=67 m/s									
Curve	**Dist from Begin (m)**	**Dist from Shore (m)**	**Depth (m)**	H_{m0} **(m)**	$T_{m-1.0}$ **(s)**	T_p **(s)**	θ_m **(°)**	**Change of** $H_{m0,V0}/H_{m0,V4}$ **(%)**	H_{max}/d_b **> 0.78? 1=yes,0=no**
C01	120	10	1,3	1.4	9.9	17.5	229	0	1
C02	110	10	1,0	0.7	6.6	17.5	189	11	1
C03	90	10	1,2	1.1	10.0	17.5	215	1	1
C04	130	40	3,8	1.9	9.2	17.5	201	1	1
C05	180	40	3,4	1.2	7.5	15.9	207	-7	0
C06	80	40	5,4	1.6	4.1	3.1	244	-9	0
V3: U_{10}=60 m/s									
Curve	**Dist from Begin (m)**	**Dist from Shore (m)**	**Depth (m)**	H_{m0} **(m)**	$T_{m-1.0}$ **(s)**	T_p **(s)**	θ_m **(°)**	**Change of** $H_{m0,V3}/H_{m0,V4}$ **(%)**	H_{max}/d_b **> 0.78? 1=yes,0=no**
C01	120	10	1,3	1.4	9.5	17.5	229	0	1
C02	110	10	1,0	0.6	6.0	17.5	192	3	1
C03	90	10	1,2	1.1	9.7	17.5	215	1	1
C04	130	40	3,8	1.9	8.8	17.5	201	0	1
C05	180	40	3,4	1.3	6.1	14.5	210	-1	0
C06	80	40	5,4	1.7	4.4	3.8	234	-1	0
V4: U_{10}=55 m/s									
Curve	**Dist from Begin (m)**	**Dist from Shore (m)**	**Depth (m)**	H_{m0} **(m)**	$T_{m-1.0}$ **(s)**	T_p **(s)**	θ_m **(°)**	**Change of** $H_{m0,V4}/H_{m0,V4}$ **(%)**	H_{max}/d_b **> 0.78? 1=yes,0=no**
C01	120	10	1,3	1.4	9.2	17.5	229	0	1
C02	110	10	1,0	0.6	6.2	17.5	194	0	1
C03	90	10	1,2	1.1	9.4	17.5	215	0	1
C04	130	40	3,8	1.9	8.7	14.5	201	0	1
C05	180	40	3,4	1.3	5.7	14.5	211	0	0
C06	80	40	5,4	1.7	4.3	3.8	234	0	0

Table H.3. Wave conditions at selected locations, numerical simulations V0, V5 and V6

V0: ϑ_m=225° (SW)									
Curve	Dist from Begin (m)	Dist from Shore (m)	Depth (m)	H_{m0} (m)	$T_{m-1.0}$ (s)	T_p (s)	θ_m (°)	Change of $H_{m0,V0}/H_{m0,V4}$ (%)	H_{max}/d_b > 0.78? 1=yes,0=no
C01	120	10	1.3	1.4	9.9	17.5	229	0	1
C02	110	10	1.0	0.7	6.6	17.5	189	0	1
C03	90	10	1.2	1.1	10.0	17.5	215	0	1
C04	130	40	3.8	1.9	9.2	17.5	201	0	1
C05	180	40	3.4	1.2	7.5	15.9	207	0	0
C06	80	40	5.4	1.6	4.1	3.1	244	0	0
V5: θ_m=212.5° (SSW)									
Curve	Dist from Begin (m)	Dist from Shore (m)	Depth (m)	H_{m0} (m)	$T_{m-1.0}$ (s)	T_p (s)	θ_m (°)	Change of $H_{m0,V5}/H_{m0,V4}$ (%)	H_{max}/d_b > 0.78? 1=yes,0=no
C01	120	10	1.3	1.4	9.8	17.5	228	0	1
C02	110	10	1.0	0.7	6.2	17.5	188	2	1
C03	90	10	1.2	1.1	9.9	17.5	214	0	1
C04	130	40	3.8	1.9	9.1	17.5	200	0	1
C05	180	40	3.4	1.2	7.5	14.5	206	0	0
C06	80	40	5.4	1.5	4.2	3.5	240	-5	0
V6: θ_m=237.5° (WSW)									
Curve	Dist from Begin (m)	Dist from Shore (m)	Depth (m)	H_{m0} (m)	$T_{m-1.0}$ (s)	T_p (s)	θ_m (°)	Change of $H_{m0,V6}/H_{m0,V4}$ (%)	H_{max}/d_b > 0.78? 1=yes,0=no
C01	120	10	1.3	1.4	9.9	17.5	229	0	1
C02	110	10	1.0	0.7	7.0	17.5	192	-5	1
C03	90	10	1.2	1.1	10.0	17.5	215	0	1
C04	130	40	3.8	1.9	9.2	17.5	201	0	1
C05	180	40	3.4	1.2	7.6	17.5	208	0	0
C06	80	40	5.4	1.6	4.1	3.5	244	1	0