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Paramaribo Strategic Flood Risk Assessment

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Abbreviations

AAB	Annual Average Benefit
ACP-EU NDRR	Africa-Caribbean-Pacific EU Natural Disaster Risk Reduction Program
AAD	Annual Average Damages
AdKUS	Antom de Kom University of Suriname
AFD	Agence Francaise de Development
ARI	Annual Recurrence Interval
CBA	Cost-benefit analysis
CBR	Cost-benefit ratio (ratio of costs and benefits, each weighted according to discount rate)
CRA	Coastal Resilience Assessment
CCRIF	Caribbean Catastrophic Risk Insurance Facility
CELOS	Centre for Agricultural Research Suriname
CHARIM	Caribbean Handbook on Risk Information Management
CI	Conservation International
COP21	Conference of Parties 21
CPA	Coastal Protection Act
CPS	Country Partnership Strategy
DEM	Digital Elevation Model
DRM	Disaster Risk Management
DTM	Digital Terrain Model
EU	European Union
FRA	Flood Risk Assessment
GCM	Global Climate Model
GFDRR	Global Facility for Disaster Risk Reduction and Recovery
GLIS	Ground and Land Information System Management Institute
GoS	Government of Suriname
GPS	Global Positioning System
HEC-RAS	US Corp of Engineers Flood Modelling Software
HWM	High Water Mark
ICZM	Integrated Coastal Zone Management Plan (2010)
IDB	Inter-American Development Bank
IDF	Intensity-Duration-Frequency
IPCC	Intergovernmental Panel on Climate Change
ITCZ	Inter Tropical Convergence Zone
JICA	Japan International Cooperation Agency
LAC	Latin America and the Caribbean
LD	Local Datum
MAS	Maritime Authority of Suriname
MJO	Madden-Julian Oscillation
MoPW	Ministry of Public Works, Government of Suriname
MSL	Mean Sea Level
NAPAs	National Adaptation Programme of Actions

NCCR	National Coordination Centre for Disaster Preparedness
NIMOS	National Institute for Environment and Development in Suriname
NOAA	US-National Oceanic and Atmospheric Administration
NPV	Net Present Value
NSP	'Normaal Surinaams Plein' (national reference plane for Suriname)
PLP	Property Level Protection
RR	Required Return
SBB	Foundation for Forest Management and Housing, Government of Suriname
SHOM	French National Hydrographic Service
SOBEK	Deltares Flood Modelling Software
SRTM	Shuttle Radar Topography Mission
STU	Sediment Trapping Unit
TA	Technical Assistance
UFCOP	World Bank Urban Flood Community and Practice
UN	United Nations
UNDP	United Nations Development Programme
WB	World Bank
WWF	World Wildlife Fund
yr	year

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Executive Summary for Flood Risk Assessment

Overview

This report presents an outline of the methodology and findings of a strategic flood risk assessment carried out for Suriname's capital city of Paramaribo under the World Bank-funded Technical Assistance Project P159234, during 2016-2017. The flood risk assessment aims to enhance the Government of Suriname's capacity to manage disaster risk by assessing flood risk in the Greater Paramaribo area in order to develop a prioritized and targeted flood risk reduction investment plan.

Objectives of the FRA:

- Undertake a Strategic Flood Risk Assessment for the city and surrounding area to develop a better understanding of the complex flood dynamics and flood risk.
- Carry out a high-level options analysis for a range of outline flood mitigation proposals.
- Prepare a prioritised investment plan for flood risk reduction.

Suriname is one of the most vulnerable countries in the world to the impact of flooding. Around 30% of the country is within a few meters above mean sea level and it is therefore particularly susceptible to coastal flooding. Almost 90% of Suriname's population live along the 384 km long coastal plain, and two thirds of that in Paramaribo. Recognizing the country's vulnerability to both coastal and pluvial (surface water) flooding is paramount to improving its economic sustainability and macro stability. Suriname's 2012-2016 National Development Plan identifies climate change and disaster risk reduction as priorities for the country. This plan places a focus on mitigation and adaptation, and a task-force has been established within the Office of the President to inform relevant strategies. The Financial Year 2015-2019 Country Partnership Strategy with the World Bank identifies the reduction of vulnerability to climate change-related floods as one of its two pillars and the improvement of flood risk management in Paramaribo as the main associated result.

This Technical Assistance is therefore a broad scale investigation into the causes and impact of flooding, quantifying the risk and impact of potential flood events, and assessing at a planning level, the likely effectiveness and costs of a range of mitigation options. The outputs of this study will set the scope and direction of a risk reduction investment programme, and provide a basis for decision making at an operational, technical and institutional level.

Paramaribo is located on a flat coastal area with poor natural drainage, adjacent to the River Suriname. Figure FRA-1 shows the study area which covers the entire city of Paramaribo and the surrounding less urbanised areas. These have been included to provide coverage of areas potentially under pressure from future urban growth.

Flooding is a frequent occurrence, associated with heavy rainfall and inadequate drainage. Although less frequent, coastal flooding linked with high tides and strong winds is increasing, and also poses a potentially devastating threat. Not only is there a significant risk from rising sea levels, but the complex and finely balanced dynamics of the muddy coastline along the Guiana Shield compounds the issues, with the need for coastal protection against excessive and irreversible erosional damage.

Figure FRA-1. Paramaribo Strategic Flood Risk Assessment Study Area

Against this backdrop of continuing flooding within the Greater Paramaribo area, and increasing risk due to a number of complex and inter related factors, it was recognized that a strategic approach would be required to develop an effective and sustainable approach to flood management. It was also acknowledged that no single solution alone would provide the answer, and a holistic approach was needed.

The causes of flooding in greater Paramaribo are well documented, and to some extent are a natural feature of the landscape and climate. The impact is, however, made significantly worse by a number of anthropogenic factors:

- Expansion of the city into low lying formerly agricultural land throughout the last century
- Continued and still poorly controlled development in areas likely to be prone to flooding, and with the potential to make flooding worse elsewhere
- Inadequate and poorly maintained drainage system in parts of the city (canals, pumps, sluice gates etc)
- Rapid and often uncontrolled runoff from the built environment exacerbated by the combined rainwater and domestic foul water sewers, common throughout the city, making the management of surface water flooding more difficult
- Limited community awareness of the risks associated with flooding and response mechanisms

- Lack of formal emergency response capability
- Lack of flood forecasting and warning capability
- Mangrove deforestation and loss of natural erosion protection along the coastal strip.

A set of eight strategic objectives were identified to address the flood problem within Greater Paramaribo, which could be implemented in a variety of ways and scales in order to reduce flood risk. These are:

Pluvial flooding

1. Slow the rate of storm water run-off at source (i.e. at individual property, street, or development level) to reduce the impact on the drainage network;
2. Increase the available storage within the drainage system (i.e. on canals, or pipework) to minimise flooding whilst the system drains down;
3. Increase the rate of discharge through and from the drainage system into the sea;

Tidal flooding

4. Improve the coastal resilience to on-going and long-term erosion;
5. Reduce the probability and extent of damaging inundation resulting from high tides or wave action along the coast or river wall;

All sources of flooding

6. Increase resilience of both people and assets to the impact of flooding;
7. Prevent further increase in flood risk due to unplanned and unregulated development;
8. Provide flood forecasting and early warning, with an effective response capability.

To determine how these strategic objectives could be met, and the relative priority for the effort and cost of implementation as a solution, they have been conceptualised to form practical mitigation options. These options do not represent a specific project, but they reflect the type of schemes, projects or developments that could be implemented, and importantly, they capture the likely costs of implementation, and reflect the likely benefits.

A hydraulic flood model was developed for the area to help analyse the problem and assess these solutions more systematically. The model was designed to capture the rainfall run-off response, and included the coastal strip to the north, the river frontage to the east, and the area to the south and west that drains towards the Saramacca Canal.

The model was used to simulate a range of scenarios and mitigation options, including (i) the current baseline, (ii) the 'do nothing' future scenario looking at the year 2050 and (ii) a number of mitigation options. This has allowed the quantification (in terms of Annual Average Damages) of the impact on residential and commercial property, their contents and services, and on agricultural land under both pluvial (fresh water) and coastal (saline water) flood events. This modelling has shown that the city and surrounding area faces an average annual flood damage of approximately US$91m from heavy rainfall (pluvial) flood events, and US$350m annually from coastal flood events. These values are estimated to increase by the year 2050 to US$112m for pluvial and nearly US$700m for coastal flooding events.

Figure FRA-2 is derived from an analysis of the data produced by the model for a range of mitigation options and shows the relative benefits over a 15 year period against the 'do nothing' option, and the associated costs for each of the mitigation options selected over the same 15 year period (all future costs and benefits discounted at 3.5% per year to reflect present day values).

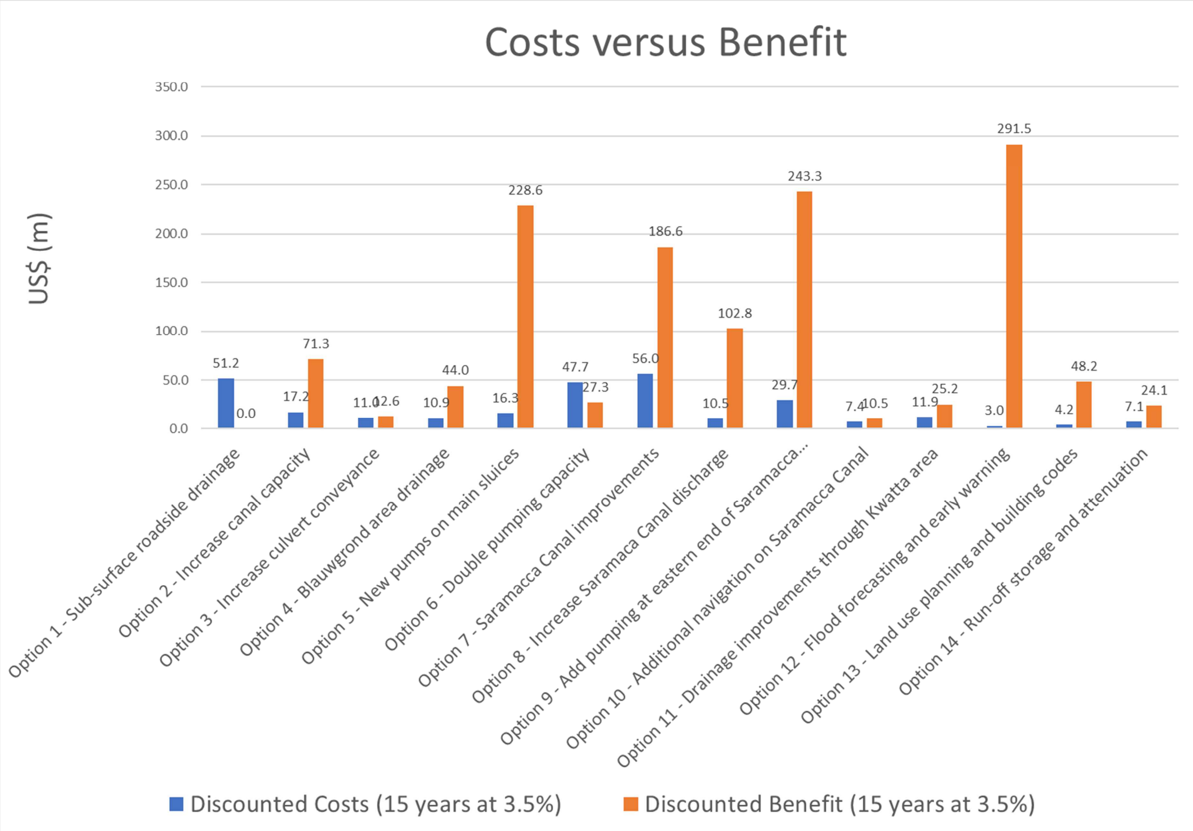

Figure FRA-2. Cost versus Benefit over 15 years

This clearly demonstrates the effectiveness of each approach, showing the economic benefit relative to the costs of implementing them.

It has not been possible within the scope of this study to quantify indirect costs or damages caused by flooding, such as the social or environmental impacts, and the longer-term disruption to local commerce and industry that flooding can cause. These are however, strongly linked to the damage values that have been quantified, so although the direct damage costs are likely to be an underestimation of the real costs (studies suggest a typical value of indirect and non-tangible damages at 30% of direct costs), the distribution and scale of damages can still be used for the key strategic purpose of identifying and prioritising mitigation options.

In considering the relative merits of the different mitigation options, the study has included any obvious drawbacks or additional benefits in a qualitative way. This has resulted in some refinement of the options proposed for implementation, and a more balanced and objective set of recommendations.

A summary of the mitigation options and their costs are provided in Table FRA-1 (see Table 5-3 for further details).

Mitigation option	Investment cost estimate	Based on:	Annual operational and maintenance costs	Based on:
Structural mitigation options				
Option 1 – Install sub-surface roadside drainage in heavily urbanised areas	**US$ 50m**	US$ 0.5m/km for 100km of road	**US$ 100,000/yr**	
Option 2 - Increase the capacity (volume and conveyance) of the canal network	**US$ 11m**	US$ 23,000 for canal clearance and US$ 250,000 for machinery for 450km of canal	**US$ 500,000/yr**	based on US$ 1000/km for 450km of canal
Option 3 - Increase conveyance through culverts and improve connectivity	**US$ 9.6m**	US$ 50,000 per road crossing for 480 crossings along 225km of road	**US$ 80,000 / yr**	
Option 4 - Extensive drainage network from Blauwgrond area to the north coast	**US$ 8.5m**	US$ 140,000/km of canal for 9km = US$1.26m. 1 x 10 cumec pumping station = US$7m 1 x single tidal gate = US$0.2m	**US$ 230,000 / yr**	US$1,000/km/yr for channel = US$9,000; US$25,600/yr for tidal gate; US$194,000/yr for pump and power
Option 5 - New pumps on the 5 main river wall sluices	**US$ 15m**	US$ 3m/site for 5 sites	**US$ 100,000 /yr**	
Option 6 - Double pumping capacity at the 22 existing sites.	**US$ 34m**	US$ 0.35m for 0.2 to 0.5 cumec pumps x 4; US$ 0.71m for 0.5 to 1.9 cumec pumps x 6; US$1.4m for 1.0 to 2.5 cumec pumps x 5; US$ 2.3m for 2.5 to 5 cumec pumps x 5; US$ 5.0m for >5 cumec pumps x 2	**US$ 1.1m /yr**	

Option 7 - Saramacca Canal improvements – re-profiling and clearing	**US$ 25m**	US$1m / km for dredging and excavating for 25km	**US$ 2.5m/yr**	US$ 2.5m / yr (with 10% for initial dredging)
Option 8 - Increase discharge capacity through the tidal gates at eastern end of Saramacca Canal	**US$ 10m**	US$ 2m to refurbish and improve each existing gate	**US$ 40,000/yr**	
Option 9 - Increase discharge capacity through addition of pumping at eastern end of Saramacca Canal	**US$ 25m**	US$ 25m for 20 cumec pumping station	**US$ 380,000/yr**	
Option 10 - Navigation lock in the middle of the canal to improve water level management	**US$ 7.4m**	US$1.2m for pair of lock gates x 2 (US$ 2.4m); US$5m for lock structure and civil work	**US$ 30,000/yr**	
Option 11 - Major drainage improvements to the north west of Paramaribo through Kwatta area	**US$ 9.2m**	US$140k for 9km of canal (US$1.26m); US$170k for single sluice gate x 3 (US$0.58m); US$7m for single 10cumecs pumping station	**US$ 230,000/yr**	US$1,000/km for 9km (US$9,000); US$25,000 for tidal gates; US$194,000 for annual pump maintenance & power
Total structural mitigation options				
	US$ 204.7m		**US$ 5.29m/yr**	

Non-structural mitigation options				
Option 12 - Flood forecasting and early warning	**US$ 0.5m**	US$50k for system hardware; US$50k for data interface US$5k for software development and implementation; US$200k for rainfall runoff and tidal model development/integration; US$75k for procedures development and institutional process integration	**US$ 200,000/yr**	
Option 13 - Land use planning and building codes	**US$ 0.5m**	One-off cost to establish legal framework, planning laws, policies, procedures and processes	**US$ 300,000/yr**	Running costs for land use planning and regulation team
Option 14 - Run-off attenuation to greenfield rates for all new development	**US$ 0.3m**	One-off cost to establish legal framework, principles and technical requirements	**US$ 550,000/yr**	US$3,500 per scheme (US$350,000); US$200k/yr annual costs for administration
Total non-structural mitigation options				
	US$ 1.3m		**US$ 1.05m/yr**	
Total structural and non-structural mitigation options				
	US$ 206m		**US$ 6.34m/yr**	

Table FRA-1. Summary of mitigation options and cost estimates.

The need for a strategic and integrated programme of improvements to the provision of flood risk management services and infrastructure within and surrounding the city of Paramaribo is clear from the study. The overall approach of 'keeping the water away from people' through drainage network improvements etc., need to be coupled with a 'keeping people away from the water' approach, that helps people avoid flooding, or become more resilient when flooding does occur. The following is a summary of the recommendations (in no specific order) resulting from the analysis:

1. The greatest single benefit identified by the study in terms of flood risk reduction comes from implementing a flood forecasting and early warning system. As well as the obvious benefit from

early warning of impending floods, secondary benefits such as improved public awareness, improved emergency response planning and enhanced readiness, will significantly help reduce flood risk and improve sustainability. This has been identified as a high priority initiative and should to be taken forward as part of a strategic flood risk management plan.

2. The Saramacca Canal is a key element of the drainage network and is an important part of any flood risk reduction solution. The largest benefit associated with the canal comes from increased discharge to the Suriname River through installation of pumps, and to a slightly lesser (but still significant) extent, through improved efficiency of drainage through the sluice gates. It is likely that a combination of both would deliver even greater benefits, and could be implemented in combination more efficiently, therefore reducing overall costs of implementation. This has been identified as a high priority initiative and should to be taken forward as part of a strategic flood risk management plan.

3. Additional pumping at a relatively small number of key locations has been shown to be very effective at reducing flood risk in parts of the city and surrounding areas. Four locations with existing sluice gates have been identified where pumping could be added with significant flood risk reduction benefit, and should to be taken forward as part of a strategic flood risk management plan.

4. Improving the volume and conveyance capacity of the Saramacca Canal has been shown to significantly reduce flood risk within the extensive area that directly drains towards the canal. The benefits of this provide the 4th largest reduction in damages that were calculated, and would be justified on its own merits with a benefit-cost ratio of more than 3:1. This option would however provide significant other benefits, which would include enhancing the effectiveness of other discharge improvement proposal for the eastern end of the canal, and would provide additional social, economic and environmental benefit through improved water level and flow management. This has been identified as a high priority initiative and should to be taken forward as part of a strategic flood risk management plan.

5. The final part of the overall drainage system improvements is the proposed increase in capacity and conveyance within the main canal network throughout the city and surrounding area. This approach in isolation has not demonstrated significant reduction in flood risk, however it is known that some parts of the network are less effective than others, and whilst there is clearly some benefit from these improvements, the real benefit stem from the combined effect of increased conveyance from within the city to the Saramacca Canal, the improved storage and conveyance within the Saramacca Canal, and the increased rate and duration of discharge into the Suriname River. This has therefore been identified as a high priority initiative and should to be taken forward as an integral part of a strategic flood risk management plan.

6. Although less compelling in terms of simple benefit-cost ratio, improved spatial and land use planning that takes full account of flood risk, with associated building and drainage regulations, will have an important part to play in sustainable and effective flood risk management. By careful zoning and regulation of land use to avoid inappropriate development in flood risk areas, and more stringent requirements on developers to reduce run-off from new developments, and introduce greater resilience (i.e. individual property level flood protection), long term

sustainable flood risk reductions can be achieved. This has therefore been identified as a high priority initiative and should to be taken forward as an integral part of a strategic flood risk management plan.

7. The increasing risk of flooding from the ocean to the north of the city, due to rising sea level and increased frequency of storms, surge tides and waves, is a significant threat. This study has identified the areas at risk from coastal flooding and the high level of current and potential future damages. A separate study has also been carried out to specifically address the issues of coastal management, and has identified mitigation options for coastal flood risk and erosion (see Coastal Resilience Assessment (CRA) Report). A key finding of that analysis is the need for careful management of the coastal strip and the inevitability of continued natural dynamic processes along this coast. The analysis also finds that to manage surface water flooding due to rainfall events, construction of hard engineering infrastructure near or at the coast needs to be avoided, particularly where they affect the natural and delicate balance of sediment movement and land drainage within the coastal fringe. A priority recommendation of this analysis is that no further infrastructure projects are initiated where the drainage using canals, sluice gates or pumping stations is towards the north coast. All drainage towards the north should be directly discharged to wetland areas strategically positioned in a broad strip of land designated for coastal protection to the north of any coastal defences that are implemented to protect the city. Critical to this will be the implementation of the Coastal Protection Act, and future land use planning regulations.

The overall flood risk study has been carried out in two parts, with this study focussing on carrying out the analytical assessment and quantification of flood risk associated with all types of flooding, and focusing on mitigation options associated with pluvial flooding of the city. The second study focusses on coastal vulnerability and coastal management options.

Before any design or construction work is carried out – more detailed analysis is likely to be required. This will include the collection of more accurate topographic data (LiDAR and ground survey), re-running of the existing or more detailed models, and the relevant social and environmental assessments.

1 Introduction.

1.1 Introduction and context.

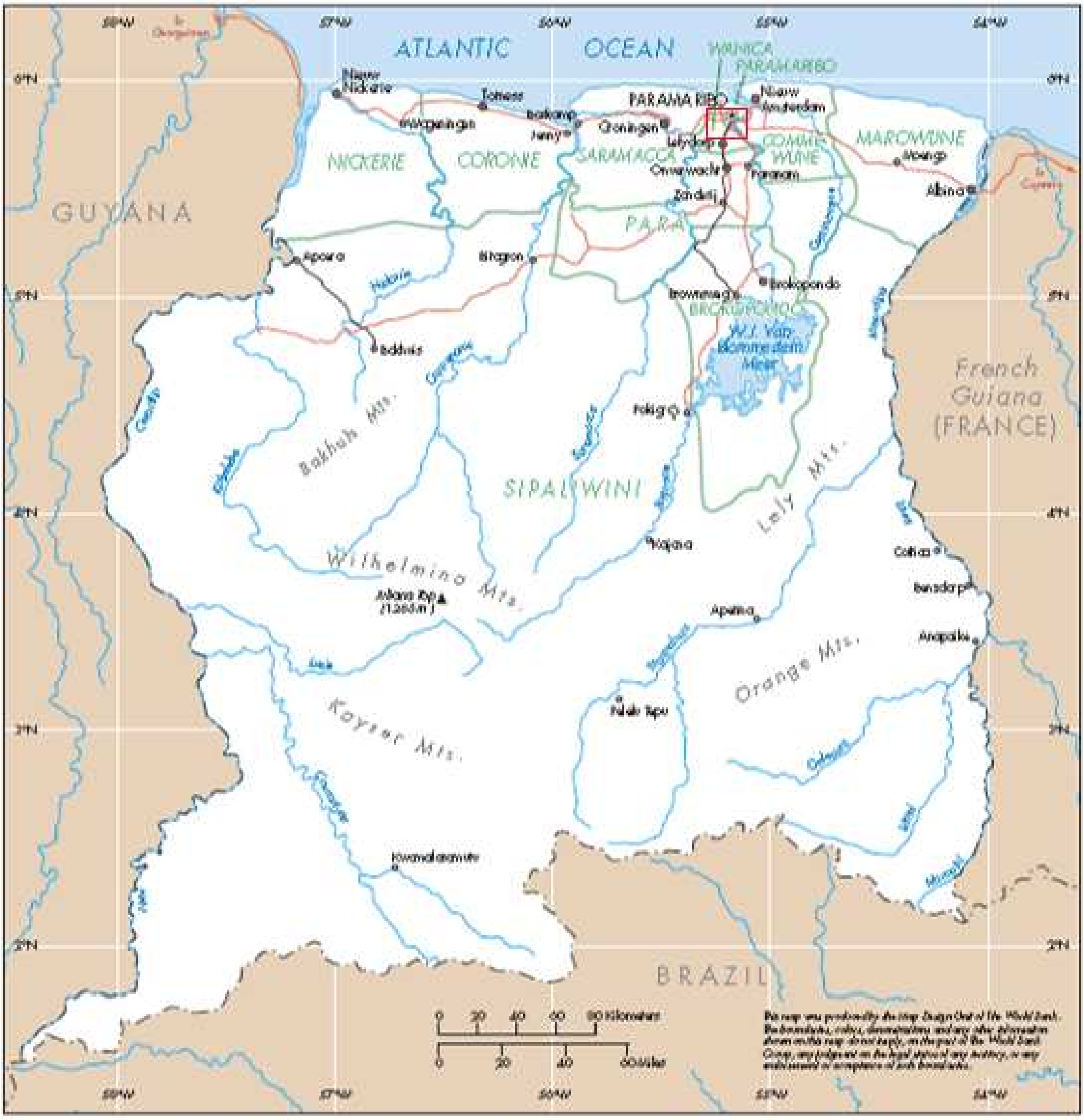

Figure 1-1. Suriname location map.

1.1.1.1 Disaster Risk.

Suriname is one of the most vulnerable countries in the world to the impact of coastal, fluvial and pluvial floods[1]. Around 30 percent of Suriname is within a few meters above mean sea level and it is therefore particularly susceptible to coastal flooding. Relatively frequent flooding is a result of poor drainage in the relatively highly populated urban areas on the coast and in the capital city of Paramaribo, exacerbated further by high tides reducing the effectiveness of the largely gravity-based drainage systems within the area. Urban flooding is frequent, with parts of the city and surrounding area suffering inundation frequently every year. Severe flooding also occurs in the less densely

[1] Dasgupta S., Laplante B., Meisner C., Wheeler D., Yan J. 2009 The impact of sea level rise on developing countries: a comparative analysis. Climate Change 93, 379-388 doi: 10.1007/s10584-008-9499-5

populated interior such as experienced in 2006[2] and 2008[3], however this study focuses only on the coastal area around Paramaribo. Figure 1-1 shows the location of Suriname relative to its neighbours, French Guiana to the east, Guyana to the west, and Brazil to the south, with the capital city of Paramaribo located close to the north coast.

Approximately 87 percent of Suriname's population of 541,638[4] live along the 386 km long coastal plain (around 67 percent in the capital city, Paramaribo, and 20 percent in other coastal districts). The district of Paramaribo, which makes up much of the study area, is divided into twelve resorts as shown in Figure 1-2.

Parts of the coastal areas and river estuaries are particularly susceptible to erosion following mangrove deforestation and degradation leading to loss of fertile agricultural and/or urban land and further flood risk, as well as destruction of fragile ecosystems[5].

The coastal plain relief is flat and generally only a meter or so above mean sea level. The greatest risk in the Greater Paramaribo area has been identified as coastal flooding, with potentially rapid inundation of extensive areas, with damaging floodwater inundating northern parts of the city. Less damaging but far more frequent flooding occurs within the city as a result of heavy rainfall and the inability of the urban drainage system to cope. Pluvial flooding tends to form locally with rainwater ponding in low lying areas across the city in response to the heaviest rainfall and areas with poor drainage. This means that flooding is unlikely to be deep or fast flowing, but could be widespread and damaging, and in low lying areas, could be very slow to clear.

Suriname's main disaster risks are likely to be intensified further by climate change and although also inconclusive, there does appear to be a trend towards higher rainfall totals during extreme events due to an intensification of the hydrological cycle[6]. However, trends for changing rainfall patterns within observed rainfall records are not clear, and there is insufficient sub-daily data to allow any firm conclusions. Similarly, maximum values for 1 and 5 day rainfall events show little consistent change. Projections from Global Climate Models (GCM) are also inconclusive and show that average daily rainfall totals could vary between +40% and –65% by the 2090s[7]. Maximum 1 day rainfall totals tend to suggest an increase during the November to January and February to April periods, particularly in the southern parts of the country. Therefore, although uncertainties exist due to the lack of data, climate change is likely to have a significant impact on Suriname, especially if as suggested, the hydrological cycle intensifies leading to more intense rainfall events.

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[2] ECLAC Studies and Perspectives Series – The Caribbean – No 3: Suriname: The impacts of the May 2006 floods on sustainable livelihoods by R Buitelaar, A Kambon, M Hendrickson, E Blommestein. March 2007

[3] Suriname Floods Emergency Appeal No MDRSR002 Red Cross 27 June 2008

[4] IBRD, IFC and Multilateral Investment Guarantee Agency Country Partnership Strategy for Suriname, for the period FY15-19. April, 2015.

[5] ICZM Plan Suriname Component I – Development of an Integrated Coastal Zone Management Plan Final Report (financed by IDB), Lievense Deltares. Feb 2010

[6] Gloor M, Briensen R.J.W, Galbraith D., Feldpausch T.R., Schongart J., Guyot J.L., Espinoza J.C., Lloyd J., Phillips O.L. Intensification of the Amazon hydrological cycle over the last two decades. Geophysical Research Letters, 40, 1729-1733 doi:10.1002/grl.50377

[7] McSweeney, C., New, M. & Lizcano, G. 2010. UNDP Climate Change Country Profiles: Suriname. Available: http://country-profiles.geog.ox.ac.uk/

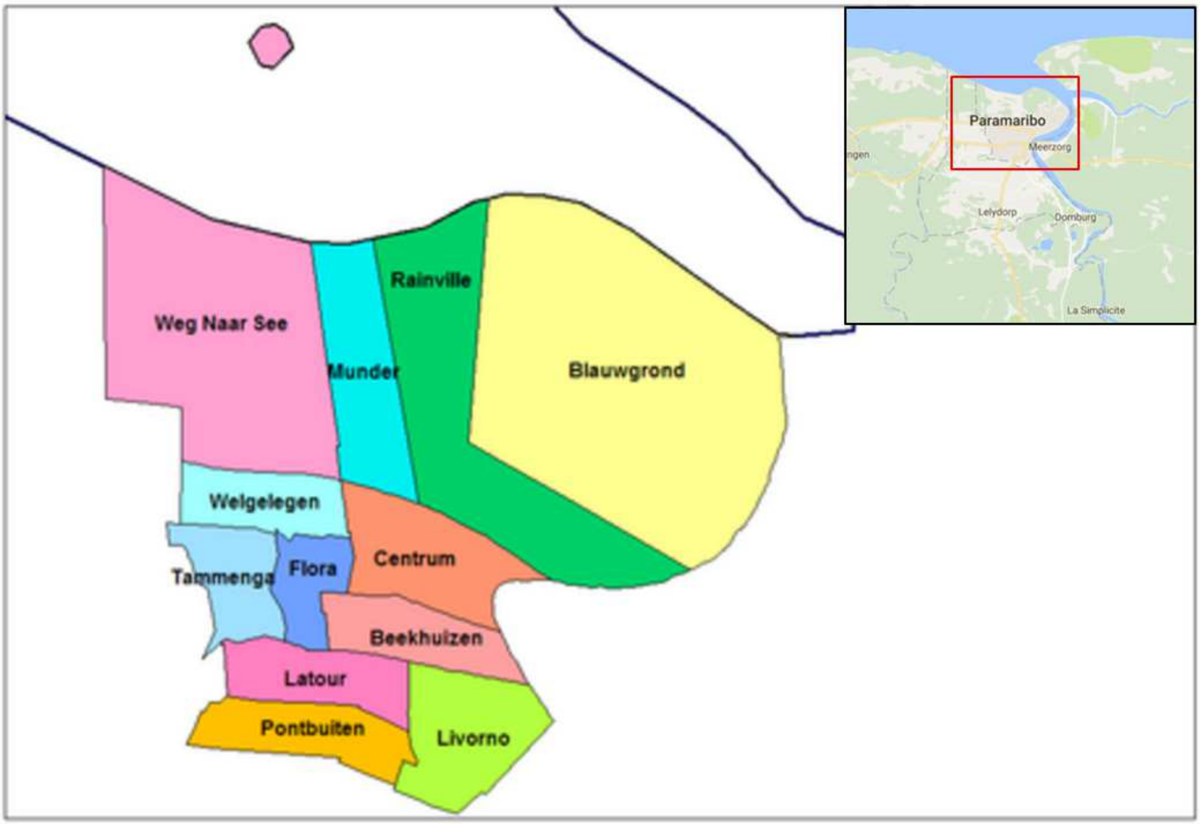

Figure 1-2. District of Paramaribo, showing division of twelve resorts.

Sea level rise is also expected to increase the risk from coastal flooding in the future, and erosion of the offshore mud flats and the relatively soft sedimentary coastline. This coastal erosion is a natural process with a typical cycle between erosion and deposition phases of around 30 years. The current erosional phase is thought to be coming to an end, however the loss of mangrove forests along parts of the coast have the potential to reduce the recovery capability of the coastline, leaving it more vulnerable to future erosion.

Suriname ranks amongst the top 10 most impacted countries in the world for a 1m sea level rise (3rd for percentage of agricultural land impacted (5.6%); 4th for percentage of population impacted (7%) and GDP impacted (6.35%) and 9th for percentage of urban area impacted (4.2%)[1]). Relatively densely populated areas on the coast and economically important coastal agricultural areas are especially at risk. Estimates indicate that the sea level has risen at least 20cm over the last two decades with climate model projections simulating sea level rises of up to 1m under the most extreme scenario by the 2090s[7]. This sea level rise has significant consequences for Suriname, and particularly Paramaribo. A 50cm sea-level rise, together with changes in wind patterns and intensity is likely to result in intensified wave attacks on the shore leading to increased erosion and flooding. A 1m or 3m sea-level rise is likely to severely impact 7% and 30% of Suriname's population, affecting 5% and over 20% of economic activity respectively[8].

[8] World Bank Policy Research Working Paper WPS4136, Feb 2007. The impacts of sea level rise on Developing Countries: A comparative analysis by S Dasgupta, B Laplante, C Meisner, D Wheeler, J Yan.

1.1.1.2 Disaster mitigation & policy.

The ongoing problem with flooding in Paramaribo and the surrounding areas is well known, and has been evident for many years. As early as the 1970's, studies have been carried out recognizing the drainage issues and the need for solutions to deal with the on-going problem of dewatering Paramaribo. Suriname's 2012-2016 National Development Plan identifies climate change and disaster risk reduction as priorities. Due to Suriname's vulnerability, the National Development Plan places a focus on mitigation and adaptation, and a task-force has been established within the Office of the President to inform relevant strategies.

Additionally, the 2010 Integrated Coastal Zone Management (ICZM) plan[5] commissioned by the Ministry of Planning and Development Cooperation identifies coastal erosion and protection; destruction of mangroves; unplanned or inappropriate spatial development; and inadequate drainage of residential areas as the most urgent problems to tackle along the coast.

Suriname also has a Drainage Master Plan, which was commissioned in 2001 by the Ministry of Public Works (MoPW) specifically to address structural disaster risk reduction interventions in the Paramaribo area, the country's most densely populated area. Amongst general improvements to the drainage system and carrying out essential (back-logged) maintenance, the Saramacca Canal was identified as a key drainage structure to be rehabilitated. It was proposed that the canal be allocated as primary drainage for 50 percent of the urban area of Paramaribo, especially the central and southern parts in order to:

- create sufficient water retention area for agriculture;
- improve the drainage capacity making possible to clean and flush the channel in its entirety;
- allow small vessel transport with optimum water levels.

A Technical Assistance (TA) programme was conceived by the Suriname MoPW and the World Bank in order to help build the foundation for a more comprehensive disaster risk management program in the Greater Paramaribo area. The TA (2016-2017) is also fully consistent with the World Bank Group's Country Partnership Strategy (CPS) with Suriname for FY15-19, which identifies the reduction of vulnerability to climate change-related floods as one of its two pillars and the improvement of flood risk management in Paramaribo as the main associated result. The TA has a strong emphasis on flood risk management interventions so that potential works may be funded by the World Bank as foreseen in the CPS, and is largely aligned to the existing Ministry of Public Work's Drainage Master Plan recommendations.

The analytical work and consultation carried out for this report took place during 2016-2017 and derives from this TA.

1.2 Objectives.

The overall objective of the TA is to carry out a comprehensive strategic study to enhance the Government of Suriname's capacity to manage flood risk in the Greater Paramaribo area. It was agreed that this would be achieved through production of a strategic flood risk assessment report that would quantify flood risk from both coastal and pluvial events, completion of an associated options analysis, and assistance in developing a prioritized risk reduction investment plan. This options analysis and investment plan will not only consider cost effectiveness of a range of possible mitigation options, but would aim to set priorities that align with existing Policy objectives (public health; poverty; environmental; economic; growth etc.). This report documents the work carried out and the findings from the assessments of both sources of flooding. Appendices are provided for more in depth discussion of the methods and science behind the analysis, with more detailed presentation of the results.

1.3 Sectoral and institutional context.

Suriname's main Disaster Risk Management (DRM) priority relates to mitigation of flood risk from the sea, rivers and from heavy-rainfall. Associated DRM priorities include:

(i) Improvement of the national hydro-meteorological capability;

(ii) Environmental protection activities such as mangrove restoration that are urgently required to rescue the currently decimated coastal mangrove forests, and which are critical in developing comprehensive, integrated and sustainable flood risk management and coastal protection;

(iii) Enhancing the DRM institutional framework, for example, by legally formalizing the status of the National Coordination Centre for Disaster Preparedness (NCCR) which will enhance Suriname's disaster preparedness and risk response mechanisms; and

(iv) Developing a disaster risk financing and insurance framework, which may include instruments such as the Caribbean Catastrophic Risk Insurance Facility (CCRIF) already available to Suriname.

Both the 2001 Master Plan for the Drainage of Greater Paramaribo9 and the 2010 Integrated Coastal Zone Management (ICZM)[10] recommended various physical interventions, and institutional and regulatory actions to reduce flood-risk, but neither plan has yet been fully implemented due in part to lack of funding. The Drainage Master Plan, commissioned by the MoPW, specifically addressed structural disaster risk reduction interventions in the Paramaribo area, the country's most densely populated area, whilst the ICZM plan, commissioned by the Ministry of Planning and Development Cooperation identified coastal erosion and protection, destruction of mangroves, unplanned or inappropriate spatial development, and inadequate drainage of residential areas as the most urgent problems to tackle along the coast. As mentioned before, Suriname's 2012-2016 National Development Plan identifies climate change and disaster risk reduction as priorities for the country.

Suriname's Disaster Response is currently managed through the National Coordination Centre for Disaster Preparedness (NCCR), established in 2006 under the mandate of the Ministry of Defence then relocated under the Office of the President. The NCCR is the entity responsible for coordination of all DRM efforts and for developing policy and non-structural disaster risk reduction measures, however the 2006 floods prevented the Government from issuing the necessary legislation to fully adopt a National Emergency Plan and officially establish NCCR. Nevertheless, efforts have been made by the NCCR to define the country disaster risk profile, address climate change, develop early warning systems, carry out disaster risk reduction assessments, develop an emergency response policy and address the increasing mining and oil activities that may negatively affect the livelihood of

[9] Executive Summary, Masterplan Ontwatering Groot Paramaribo, Ministrie van Openbare Werken, Project UPO 08 – SR/002214 prepared by DHV-WLDelft-AMI-Sunecon, 15 June 2001

[10] ICZM (Integrated Coastal Zone Management) Plan Suriname: Coastal morphodynamics report prepared by Lievense Deltares, Oct 2009

the rural population. The legal adoption of a clear mandate for NCCR and the necessary resources to respond to them would greatly benefit the country and improve its resilience to disasters.

Suriname's 2012-2016 National Development Plan includes an investment plan for each of the country's 5 national priorities (good governance, economic diversification, social development, education, and natural resource management). One of the specific objectives of the plan is to strengthen disaster risk management and catastrophe risk insurance to lessen the impact of floods and other climatic shocks. A budget allocation of US$1 million, established in 2006 and managed by the Ministry of Finance, provides minimum funds to face a disaster event in the country but there are no other risk retention or transfer tools in place. The international community present within the country working on DRM includes AFD, EU, IDB, and the UN but none of them support risk reduction programs through budgetary support to the government. The country therefore needs a strategic vision to address and develop a disaster risk financing framework.

The Government of Suriname (GoS) has a number of legislative reform efforts underway to strengthen the framework for environmental and disaster risk management. The DRM law would, for example, make official the leading coordination role that the NCCR plays in the country. The same legislation would also establish the basis for an emergency fund. These institutional and legal policy reforms will set the tone for more systematic public and private risk reduction interventions as well as climate change adaptation actions as expressed by the country before the COP2111. In addition to the DRM law, Suriname has drafted the Protected Coastal Area Law which will respond to the international commitments on building resilience to climate events, and will aim at decreasing mangrove degradation and strengthening coastal protection in the economically active coastal area, in which building permits and other development plans will be prohibited. At the time of preparing this report this law had the endorsement of the Cabinet.

The institutional mandate for the operation and maintenance of the drainage system lies with the MoPW, along with the Ministry of Agriculture and the Ministry of Regional Development. Both the meteorological monitoring and forecasting service, provided by the National Meteorological Service, and the hydrological monitoring and analysis service, provided by the Hydraulic Research Division, also come under the auspices of the MoPW; however, they operate independently, and fail to maximize their synergies and opportunities to improve efficiencies and increase efficiency through sharing systems, resources and data. These institutional arrangements could be strengthened considerably by consolidating NCCR's leading role and by defining clearer roles and responsibilities of the institutions involved in DRM activities.

The GoS therefore requested this Technical Assistance (TA) to carry out a baseline assessment and provide analytical tools to support the country in developing a program of strategic interventions and policies to address recurrent flooding and the anticipated impacts resulting from climate change and sea level rise.

[11] see "Republic of Suriname, Intended Nationally Determined Contribution Under UNFCCC" September 30, 2015

1.4 Principal activities.

Following a period of project planning, the main activities under the TA flood risk assessment were:

(i) Initial data gathering and development of a broad conceptual understanding of the flooding hazard and risk related issues;

(ii) Hydrological and tidal analysis to help understand the frequency and severity of extreme rainfall and tidal events;

(iii) Development of a numerical flood model for Greater Paramaribo, including the drainage systems and flow paths within the city and surrounding area;

(iv) Preparation of digital flood maps for a range of extreme weather scenarios and flood mechanisms;

(v) Preparation of exposure and vulnerability data sets to use in combination with the flood maps to help quantify flood risk from all sources (coastal, fluvial and pluvial) – both now and in the future;

(vi) Use of the baseline model developed for the flood risk assessment to carry out an options analysis on a range of possible mitigation solutions for pluvial flooding;

(vii) Development of a prioritized flood risk management and investment plan.

In parallel, a coastal resilience assessment and management options analysis was carried out under Part 2 of the study.

1.5 Key outputs.

The studies, analysis and tasks carried out under this TA and associated outputs are as follows.

- A strategic flood risk assessment for Greater Paramaribo associated with the urban drainage including the function of the Saramacca Canal, coastal inundation including the influence of existing mangroves forests and mangrove rehabilitation, and impacts of climate change looking forward to the year 2050. This has provided an initial baseline assessment against which mitigation options are assessed.
- Based on the Strategic Flood Risk Assessment, a prioritized flood management investment plan including a high-level analysis of costs and benefits of available mitigation options/investments has been developed. This investment plan consists of a range of strategic, operational and technical recommendations, allowing direct procurement of services and products where clear benefit-cost has been shown, and the level of technical analysis has been sufficient to define the requirements. Where more detailed design work is required, the strategic plan directs further studies or analysis, but provides sufficient information and data to help scope the work, and support the production of suitable terms of reference.
- Analytical tools have been developed, which are necessary for flood risk management, including an urban flood map to improve land zoning and urban development and land use planning, and a modelling system has been set-up and handed-over to the MoPW so that further developments and improvements can be made by the Ministry.
- Improved institutional capacity has resulted from various training workshops (for example use and development of the hydrological model) and enhanced communication has occurred between relevant stakeholders and departments through various workshops and meetings.

- The TA has also helped to build the foundation for a more comprehensive disaster risk management program in the Greater Paramaribo area, with a strong emphasis on flood risk management interventions that may be funded by the Bank as foreseen in the CPS and in line with the Ministry of Public Work's Drainage Master Plan recommendations.

1.6 Relationship to country partnership strategy.

After a hiatus of nearly 30 years, the World Bank (WB) has established a renewed relationship with Suriname. Following an Interim Strategy Note in FY15 (July 2014-June 2015), the WB FY15-19 Country Partnership Strategy (CPS) aims to promote a more sustainable, inclusive, and diversified growth model through creating a conducive environment for private sector development, and supporting better flood risk management to minimize related human, economic and financial losses and reduce the vulnerability to climate change. This TA is fully consistent with both the Interim Strategy Note and the current CPS which identifies the reduction of vulnerability to climate change-related floods as one of its two pillars and the improvement of flood risk management in Paramaribo as the main associated result.

Flood risk is currently absorbed by the GoS at great cost. Hence, increasing the country's resilience to natural hazards is consistent with the World Bank's twin goals of eradicating extreme poverty and boosting shared prosperity.

This work carried out under the TA will help build the foundation for a more comprehensive DRM program in the Greater Paramaribo area with a strong emphasis on flood risk management interventions that may be funded by the WB as foreseen in the CPS.

1.7 Relationship with other in-country activities.

The activities under the TA are consistent with and complementary to the objectives of various DRM projects and initiatives in Suriname and funded by other development partners. The project team have and will continue working with partners leading these efforts and make sure to consult and coordinate with key stakeholders during the grant implementation. Continued coordination with the EU Delegation to Guyana and Suriname will ensure productive involvement in any future project activities, including participation and contribution to workshops, trainings, regular coordination meetings and any public outreach or press releases.

World Bank (WB): The project is complementary to a LAC-region project "Vision 2030" which aims at quantifying disaster risk on public infrastructure by establishing a multi-hazard risk management capability to enable the governments to quantify and reduce current asset risks. The objective is to enable Governments to quantify disaster risk specific to public infrastructure while taking into consideration the impacts of climate change. The project focuses on multiple hazards such as flooding, landslides and hurricane impact and will serve as basis for the governments towards the development of a comprehensive DRM strategy.

The findings and developments from the flood risk assessment will be of interest to and will be shared with the World Bank Urban Flood Community of Practice (UFCOP) that aims to gather and share best practices on urban flood operations throughout the Bank, and will also contribute to the implementation of the World Bank Forest Action Plan 2016-2020, particularly on the cross-cutting theme of "climate change and resilience".

European Union (EU): The TA is in line with the Joint EU-Caribbean Partnership Strategy (2012), which commits to foster cooperation in a number of areas including climate change and natural disasters.

The grant is also consistent with and complements the objectives of the forthcoming US$3 million Suriname Global Climate Change Alliance+ Project. This EU-funded project to be implemented by UNDP, aims to mainstream climate change into poverty reduction development strategies, and support adaptation building and the design of National Adaptation Programmes of Action (NAPAs). It is expected that the outcomes of the grant will allow the Government to leverage further financial support from donors such as JICA, IDB, EU and the WB to address flood risk reduction investments.

Agence Francaise de Development (ADF): The AFD-funded €12.5 million Water Supply Facilities Improvement Project for Paramaribo, Wanica, Para and Moengo signed in May 2015 aims to contribute to the welfare of Suriname's growing urban population through the supply of quality drinking water based on sustainable water resources management. One of the project's components will be managed directly by the MoPW and will assess the status of the Drainage Master Plan for Paramaribo, with regards to the impacts of wastewater on health and the environment.

Inter-American Development Bank (IDB): The US$ 12 million IDB-funded Water Supply Infrastructure Rehabilitation Project that started in 2011 aims to support the Government of Suriname to improve quality, efficiency and sustainability in the potable water services by (i) improving management and operating practices, and (ii) improving the water supply system in Paramaribo through rehabilitation works and efficiency enhancement measures.

The Global Facility for Disaster Risk Reduction and Recovery (GFDRR): The TA activity is fully aligned with GFDRR's mandate and focuses on addressing GFDRR's first two pillars, which are risk identification (strengthening disaster risk management knowledge) and risk reduction (identifying, prioritizing and implementing structural and non-structural disaster risk reduction investments). Additionally, the findings of this project fully supports the implementation of the ACP-EU Natural Disaster Risk Reduction Program, in particular, the Program Result Target R2 which aims to mainstream DRR in ACP countries to ensure the sustainable integration of disaster risk reduction and climate change adaptation into development policies and strategies. In particular, the Program supports ACP countries in implementing DRR actions such as hazard mapping and disaster risk assessments like the one foreseen in this TA.

Other: The TA activity also complements previous coastal habitats restoration efforts such as an ongoing study "Mangrove rehabilitation project at Weg naar Zee using sediment trapping technique", which aims to promote coastal resilience through the application of a sediment trapping technique. GEF funded activities implemented by UNDP and Conservation International projects may complement these efforts, as well as the WWF-Suriname's Project "Assessment of Peri-urban Coastal Protection Options in Paramaribo".

2 Methodology.

In order to support the Government of Suriname in developing coping strategies and mitigation actions, a strategic flood risk assessment for the Greater Paramaribo area has been developed. The study area was defined through an iterative process of discussions, site visits and a review of available data and mapping, in an effort to ensure that the main areas of concern were captured. The final study area is shown in Figure 2-1.

Through numerical modelling of the flood hazard that threatens the city and surrounding area, and a comprehensive impact assessment, taking into account exposure and vulnerability of people and property, a much clearer picture of the risks posed by flooding has been built. Not only does this analysis provide a baseline understanding of the flood risk associated with pluvial and coastal flood hazard within the city and surrounding areas, but it also supports strategic and policy decision making for the future.

Figure 2-1. Study area.

The approach adopted follows the general guidance provided by the Caribbean Handbook on Risk Information Management (CHARIM)[12] which was initiated by the World Bank GFDRR in 2014 and developed with a grant from the ACP-EU Natural Disaster Risk Reduction Program. A consortium led by the Faculty ITC of the University of Twente from the Netherlands was responsible for generating training materials, and creating guidance documentation for all aspects of risk assessment for flood

[12] Caribbean Handbook on Risk Management - developed by a consortium of five international institutions: University Twente, Faculty ITC (UT-ITC), the Netherlands; The University of the West Indies, Faculty of Engineering (UWI) Trinidad and Tobago; Asian Institute of Technology (AIT), Thailand; SSBN – Flood Risk Solutions, United Kingdom; Envirosense, The Netherlands. (http://www.charim.net/)

and landslide, and developing risk information for decision-making. This useful and helpful set of guidance is publicly available on the CHARIM website, and has been followed extensively for this study.

The method description that follows provides an overview of the technical aspects of the study, however more detailed technical reports are included as Appendices A and B.

2.1 Component 1: Analysis of flood hazard affecting Greater Paramaribo.

2.1.1.1 Site Selection.

The study area has been defined in order to capture the full extent of the drainage watersheds which impact the City and surrounding hinterland, as well as the coastal strip where inundation due to extreme tides would reach the northern parts of the city. The Suriname River to the east is a major feature and is included within the study area. However, the close proximity to the coast means the river has become a wide tidal estuary and water levels are dominated by the tide. The risk to Paramaribo associated with flooding from the Suriname River are therefore linked to extreme tides, rather than river flows from upstream.

2.1.1.2 Data collection.

An essential part of developing a thorough understanding of the flood mechanisms and scale of flood risk within the city included the need to have an on-the-ground appreciation of the drainage system, which involved visiting many parts of the City and photographing and documenting the main features relating to flooding such as canals, pumping stations sluices, culverts and bridges, etc.

Site visits by the World Bank team were accompanied, when possible, by MoPW engineers and specialists, who provided valuable background information and local knowledge regarding the hydraulic, engineering and drainage background of the areas, as well as social, practical and situational context for the flood risk.

As much relevant data and information as possible was obtained during visits to Paramaribo and discussions with local knowledge holders, and online searches. However, the relatively broad-scale and strategic nature of the study inevitably placed some limitations on the efforts that could be make in collecting certain aspects of the data, and in some instances assumptions were made based on the data that was readily available from global or regional data sets. None the less, much valuable information was obtained from workshops and discussions with local MoPW staff, who operate and work with the drainage network on a daily basis.

The document review included gathering and consolidating available information from previous studies on water management and flooding within the Greater Paramaribo area, and in particular – in relation to canal and drainage networks. The De-Watering Master Plan study reports and model data files completed in 2001 by Deltares of the Netherlands provided a significant data resource, in terms of information held within the report, and raw data embedded in the SOBEC hydraulic model developed for the drainage system. Data used for the study include:

1. Digital Terrain Model (DTM) for the study area,
2. Additional ground survey to assist in calibration and checking of the DTM.
3. Locations, dimensions and capacity of hydraulically significant features, such as canals, culverts, bridges, pumps and sluices.

4. Observed river levels, tides and rainfall inputs used within the model to represent extreme flood events of varying severity.
5. Property data set for the study area to include location and types of all buildings, their use (i.e. residential, commercial, industrial), number of floors (single or multiple), and an indication of their structure (e.g. wooden, masonry, concrete etc.), and location (with boundary where practical) of any economically, strategically or socially important areas, assets or features. Where property level information is not available, the smallest unit of discretization available has been used in order to help categorize the property data set.
6. Location of critical infrastructure such as hospitals, schools and colleges, police stations or other emergency responders, religious centres, electricity sub-stations or distribution points, sewage treatment works, water treatment and distribution works.

2.1.1.3 Hydraulic model selection and approach.

A substantive part of the analysis was the development of a hydraulic model for the study area. This model needed to represent the behaviour of the flooding from all potential sources, and could include the dynamic interaction of the drainage system, the city landscape, and the movement and attenuation of flood water through the system. The decision regarding the software to use and approach to take was driven by consideration of a number of factors, including:

- Physical attributes of the situation to be modelled – i.e. canals and drains, wide flat flooded areas, water control features, direct rainfall events, and tidal events etc.
- The purpose of the study and the required outcomes of the modelling exercise – i.e. flood mapping showing depth and extent across the city, and a GIS-based risk analysis.
- Time and funding available for the modelling, and the scale and resolution of the outputs.
- Data available for input to the model, in terms of type, resolution, and accuracy.
- The requirement for the model and data once developed, to be handed over to local specialists, who with appropriate training, would continue to use and develop the model and data tools for future studies.
- Cost of the software – both initial purchase, and on-going support, maintenance and licensing.

As a result of this deliberation and discussions with MoPW staff, HEC-RAS was selected for the study. The latest release from the US Corp of Engineers (V5.0.3, May 2016) has a 2D capability, and some useful functions to help in the development of a city scale hydraulic model. The software is free, widely used and well supported, and relatively easy to learn as an inexperienced modeller. The 2D functionality allows direct flood mapping, and is particularly appropriate for modelling flat areas with poorly defined flow routes and floodplains. There are more sophisticated modelling packages available, however these tend to be expensive, with long-term costs for licencing and support, and are not always very easy to learn.

2.1.1.4 Model development inputs and data requirements.

One of the most important data requirements for any hydraulic model is a digital terrain model (DTM). This is a digital representation of the ground surface of the study area and determines where and how the model moves the water around. For hydraulic modelling purposes of this type, it is usual to start with a representation of the land surface with all artificial features such as buildings, vegetation etc. removed. These can be added back into the model at a later stage for detailed modelling if necessary, however for a strategic level assessment such as this, the bare earth DTM is best suited.

The usual means of capturing the DTM data is from an airborne radar scanning device (rather that ground survey which would be far too labour intensive). This can be done at various heights using different technology, but essentially reduces in accuracy with increase in height, with a corresponding reduction in time and cost of data capture. Initial investigations using widely available 30m SRTM (Shuttle Radar Topography Mission) data suggested that this data would not provide meaningful results, particularly in heavily vegetated coastal areas and the built-up areas within the city.

The data selected for the exercise was the AIRBUS World Digital Elevation Model (DEM), processed to produce the required DTM at a horizontal resolution of 12m. The advantages of this data set are:

- It is an 'off-the-shelf' product, and therefore available reasonably quickly and at a reasonable cost;
- The data is captured at 12m resolution (as opposed to measured at lower resolution but resampled to provide a smaller grid);
- It is the most recently flown/collected data of the readily available global data sets, uses the most up-to-date technology and captures the most up-to-date land form.

Although not perfect, this data was the best that could be obtained within the project constraints. However, recognising the potential uncertainty in the DTM, a ground survey was commissioned to collect check points at as many points across the city as reasonably possible. This was carried out using a GPS survey equipment mounted on a vehicle and driven along the main roads throughout the city, capturing many thousands of spot heights. These were used to adjust the DTM accordingly, resulting in an improved overall confidence in the DTM levels and resulting flood outputs.

The size and locations of the many kilometres of canals were extracted from the original 1D SOBEK model developed in the late 1990s by Deltares, and updated with satellite imagery which were used to identify any major new canals, and to expand the model area to the surrounding less urban areas. These canals (see Figure 2-2) were imprinted within the 2D model domain to better represent the storage and conveyance provided by the canals, whilst still capturing the dominant overland flow routes of the flooding. Figure 2-3 shows the 22 pumping stations and 7 sluice gates that were included within the hydraulic model. Friction values relating to the different types of surface which would affect the way water would travel across the surface were applied as Mannings 'n' values, and were determined from land use data and from the existing SOBEK model files.

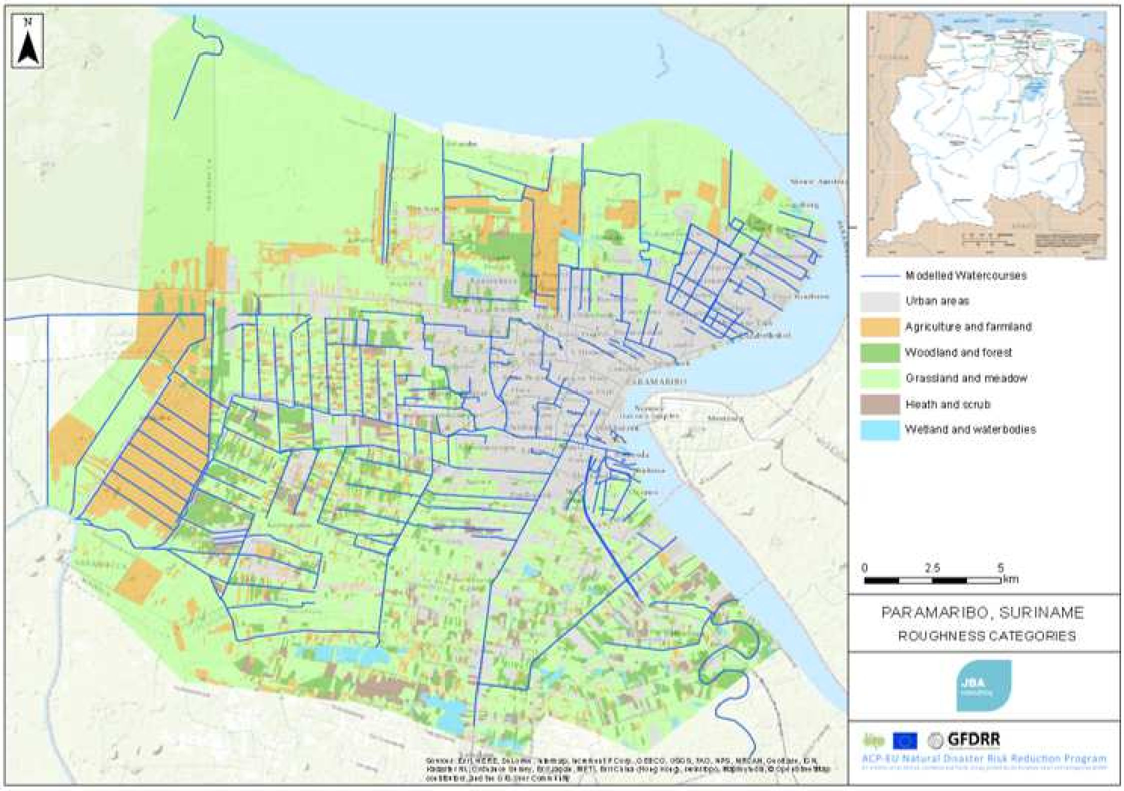

Figure 2-2. Canal network built into the model and land use areas used for Mannings 'n' values.

Figure 2-3. Sluice gates and pumping stations included within the hydraulic model.

Input data required for the modelling were direct rainfall design storms of different return periods, and tide levels to be applied at the coast and along the Suriname River for different extreme events (including storm surge and wave overtopping).

The rainfall inputs were created following an analysis of locally recorded rainfall, supplied by the Suriname Meteorological Office. The analysis looked at both daily and sub-daily rainfall records from a number of local stations (10 daily and 4 sub-daily) to derive intensity-duration-frequency (IDF) curves. A summary of these values used in the flood modelling study is provided in Table 2-1, and details of the analysis is presented in Appendix B.

Return Period (Yrs)	1 hour (mm)	2 hour (mm)	3 hour (mm)	5 hour (mm)	24 hour (mm)
2	41	54	59	64	81
5	55	68	73	82	109
10	63	77	83	94	128
25	75	89	95	108	152
50	83	97	104	119	169
100	91	106	113	130	187
200	99	115	122	141	204
500	110	126	133	156	227
1000	118	135	142	166	245
10000	145	163	171	203	302

Table 2-1. Rainfall IDF values calculated for the study (averaged from local gauges – see Appendix B for full details).

It is not realistic to just add all the daily rainfall to the model at once, or even to spread it evenly across the 24 hours. In order to represent a 'typical' rain storm within the model, a rainfall profile is needed that represents the likely distribution of rainfall during an extreme event. There is insufficient sub-daily rainfall available for Paramaribo to carry out a thorough analysis to develop a location specific distribution, however the short periods of record available have been reviewed and the hourly values for days with the largest rainfall totals are shown in figure 2-4. Although there is insufficient data to derive a rainfall profile, these plots show a consistent type of rainfall pattern for the four highest daily totals within the records. They all contain a short high intensity period of rainfall and much lower intensity rainfall before and after.

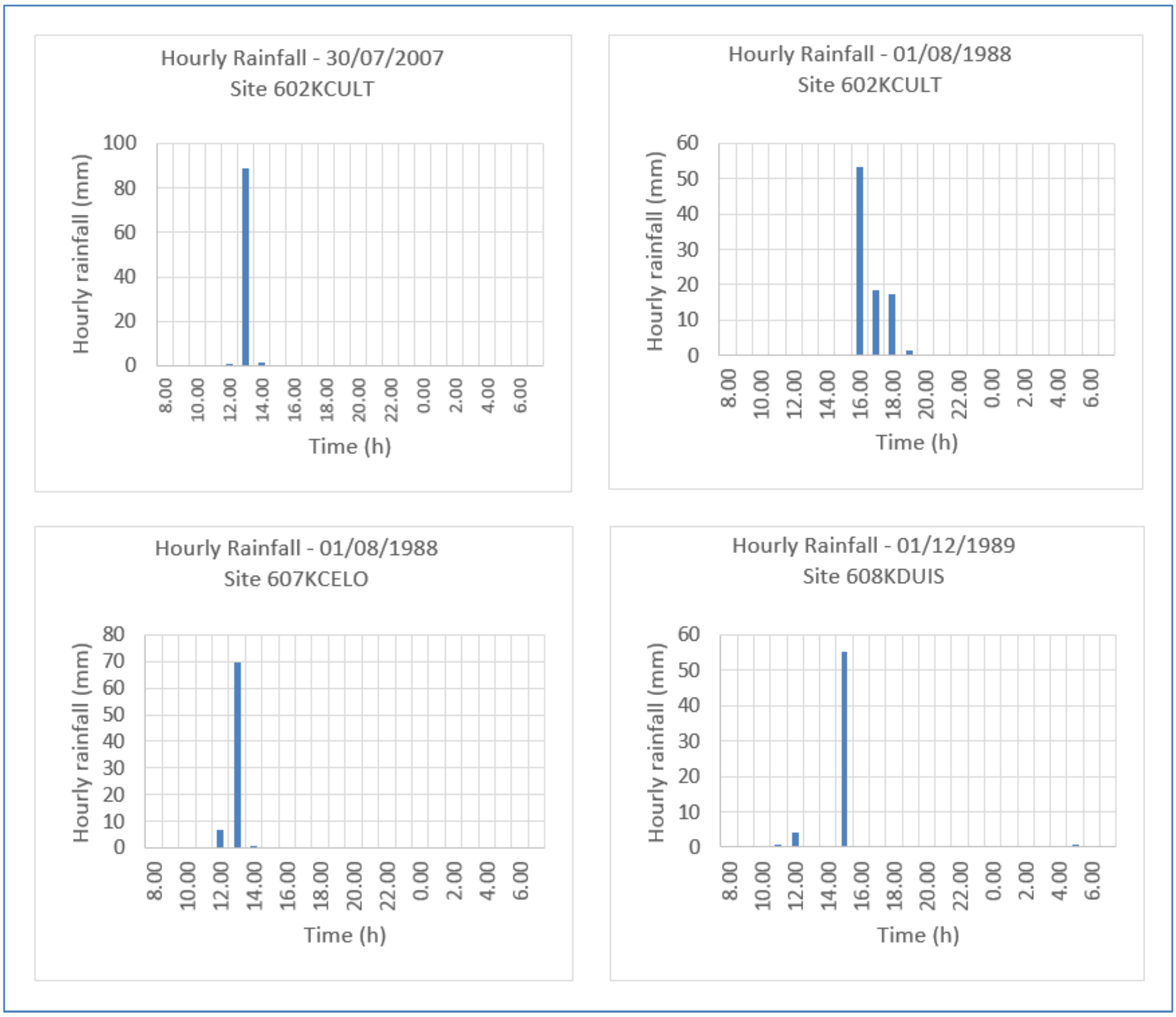

Figure 2-4. Hourly rainfall values for highest daily totals within period of record for local stations.

Due to the short length of the sub-daily rainfall records available for the rainfall profile analysis, a generalised profile has been used, derived by NOAA for Latin America and the Caribbean (see Figure 2-5), and is applicable across a wide area where convective and tropical storms are prevalent. Although it is recognised that this generalised profile contains hurricane events, local data has been used to confirm that this is still a reasonable approximation for Paramaribo and surrounding coastal areas. The comparison with the local events shown in Figure 2.4 clearly shows a similar pattern. Furthermore, the rainfall analysis (Appendix B), also supports this reasoning, as the resulting hourly values closely reflect the expected short duration rainfall totals in the above table; for example the 2 hour 100yr rainfall total is estimated as 106mm, whilst the two-hour peak total for the daily storm is approximately 95mm. The implication of this storm profile, however, is that more than 60% of the days' rainfall (i.e. over 100mm) falls within 3 hours. The remainder of the rainfall (i.e. 87mm) is distributed across the remaining 21 hours as lower intensity but persistent rainfall. This is considered to be representative of the worst-case scenario of an extreme rainfall event for this type of urban flooding, and will result in greater inundation than if the storm profile was lower and broader.

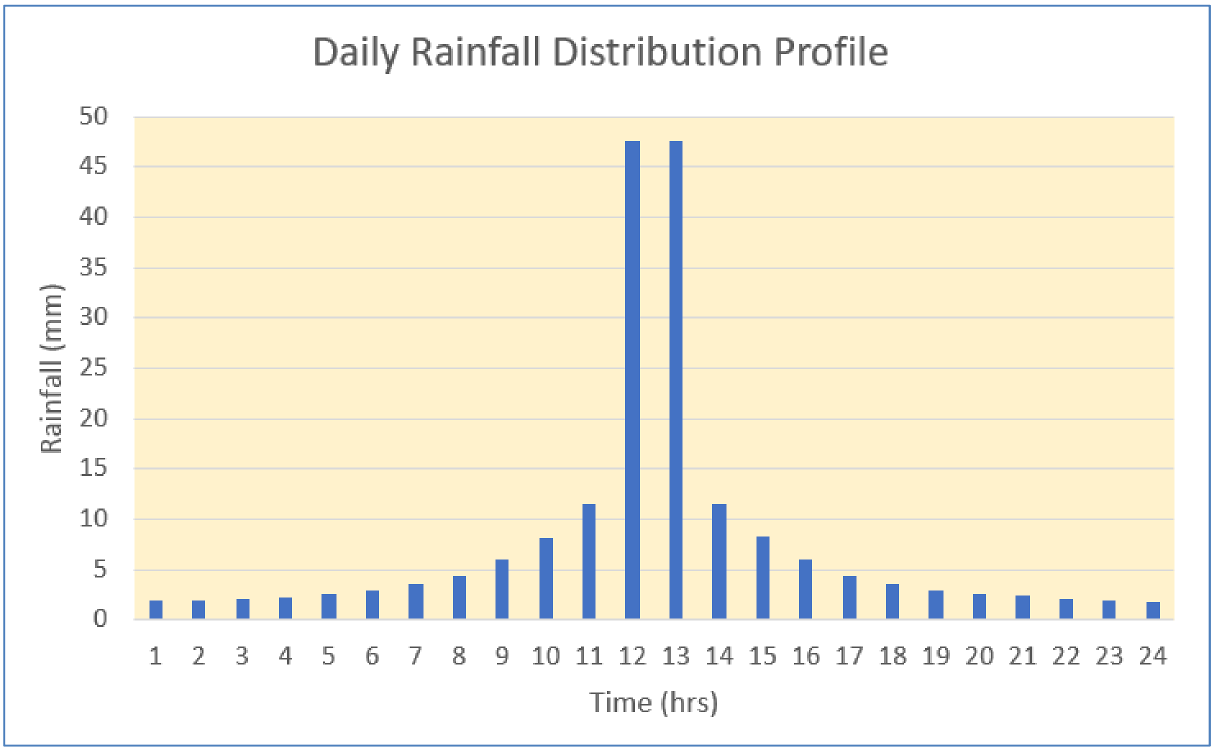

Figure 2-5. Standard Type III Rainfall distribution profile (NOAA) for the 100yr rainfall event.

Extreme tide levels have been derived from the 1960-1998 hydrometric record at Paramaribo (Station 6110), truncated to account for damming of the Suriname River and adjusted to account for the observational record from 2009-2013 reported by Sintec & Sunecon (2015)[13]. This observational data displayed log-linear behaviour, which was extrapolated to estimate the recurrence of extreme tide levels (Table 2-2).

ARI (years)	1 year	10 years	25 years	50 years	100 years	200 years
Water Level (MSL) *	1.82m	1.95m	2.02m	2.06m	2.11m	2.16m

* Water levels are presented to 2 decimal places for clarity, rather than as a reflection of accuracy.

Table 2-2. Extreme tide levels for Annual Recurrence Intervals (ARI) at Paramaribo.

Differences between the 1965-1998 and 2009-2013 distributions were consistent with the mean sea level change suggested by satellite altimetry and the tide gauge record in French Guiana, combined with the effect of inter-annual tidal variation. The extrapolated extreme water levels were in the order of 0.2-0.3m below those derived by Sintec & Sunecon (2015). This difference is considered to relate to incorporation of statistical uncertainty, which is appropriate for structural design, but provides a high bias when assessing flood mitigation options.

2.1.1.5 Climate change.

Suriname's main disaster risks are very likely to be intensified further by climate change. Observed trends[14] show that average annual temperatures have increased by 0.2°C since 1960, an average rate of 0.05°C per decade (which is less rapid than the global average) with particular increases in the

[13] Sintec & Sunecon (2015) Updated Ring-dyke Engineering Studies. {In Dutch}
[14] Mc Sweeney, C., New, M. & Lizcano, G. 2010. UNDP Climate Change Country Profiles: Suriname. Available: http://country-profiles.geog.ox.ac.uk/

number of hot days and hot nights. Future climate change projections suggest that under any one emissions scenario, temperatures will increase by about 1.5°C by 2090s, more rapidly in the south and interior regions than the north, with further increases in the number of hot days and hot nights likely affecting human health and biodiversity. The trends for changing rainfall patterns are less obvious within the observed rainfall records and there is insufficient sub-daily data to determine trends at sub-daily scales. Recent studies looking at observed data for Suriname state:

- Mean annual rainfall over Suriname has not changed with any discernible trend since 1960.
- There is not sufficient daily precipitation data available to determine trends in the daily or sub-daily variability of rainfall.

Similarly, projections from various Global Climate Models (GCM) for mean annual rainfall[15] show a wide range of changes in precipitation for Suriname. Ensemble median values of change by the 2060s, however, are consistently negative for all seasons and emissions scenarios. Projections vary between -65% to +40% by the 2090s with ensemble median changes of -5 to -9%.

There is however, a trend towards higher rainfall totals during extreme events, although this is not conclusive. Similarly, maximum values for 1 and 5 day rainfall events show little consistent change, but tend towards increased rainfall totals for the seasons November to January and February to April, particularly in the southern parts of the country.

Although uncertainties exist due to the lack of data, climate change is likely to have a significant impact on Suriname, especially if the hydrological cycle intensifies leading to more intense rainfall events[16]. For the purpose of this study, an increase of 20% rainfall intensity was chosen for the year 2050 modelling and risk quantification. Whilst this value may be towards the upper bounds of the likely change, it still provides a realistic forecast of a future scenario which should be planned for.

2.1.1.6 Sea Level Rise.

Sea level rise allowance for Paramaribo by 2050 has been developed as a range, based upon IPCC projections for sea level rise (Church et al. 2015) and regional observations of relative sea levels over the last 30 years. The lower limit for sea level rise of +0.09m is based on the IPCC lower estimate of global sea level rise. The upper limit of +0.27m rise by 2050 is based on the IPCC upper estimate of global sea level rise plus a 2.5 mm/yr regional trend.

Available information regarding regional behaviour includes satellite altimetry[17] and tide gauge records from the Guiana region. The relative difference between regional and global changes may be related to interdecadal climate variability, and therefore it may not be sustained for forthcoming decades.

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[15] Mc Sweeney, C., New, M. & Lizcano, G. 2010. UNDP Climate Change Country Profiles: Suriname. Available: http://country-profiles.geog.ox.ac.uk/

[16] Gloor M, Briensen R.J.W, Galbraith D., Feldpausch T.R., Schongart J., Guyot J.L., Espinoza J.C., Lloyd J., Phillips O.L. Intensification of the Amazon hydrological cycle over the last two decades. Geophysical Research Letters, 40, 1729-1733 doi:10.1002/grl.50377

[17] Willis JK, Chambers DP, Kuo C-Y & Shum CK. (2010) Global Sea Level Rise. Recent progress and challenges for the decade to come. Oceanography, 23 (4). p26-35.

2.1.1.7 *Modelling scenarios.*

In order to understand the existing flood hazard, a set of baseline scenarios to represent the flooding that could occur at varying return periods have been developed. Return periods signify the statistical frequency with which an event is likely to occur. To clarify, if a flood has a return period of 10 years, this does not signify that the flood would occur once every 10 years and if it has already occurred, it won't be repeated for another 10 years. Instead it simply means that statistically, over a very long period of several decades, it would be expected that on average, a flood with a 10 year return period would occur approximately once every 10 years – in other words, there is a 10% chance of the event happening every year. This means that a 10 year (10yr) flood event could occur more than once in any one year. Similarly, a 100-year return period event has a 1% chance of occurring every year.

Multiple scenarios were used to represent the baseline as follows:

- A pluvial flood event was modelled with direct rainfall across the city and surrounding area, under current conditions for a range of 4 rainfall return periods, (i.e. 10yr, 50yr 100yr and 200yr), with an appropriate normal tidal boundary and sluice gate operation (sluice gate opening determined by tidal boundary), with pumping applied at the currently achievable rates.
- A coastal flood event was modelled using an appropriate storm surge, with no pluvial flooding, but for the same return periods of extreme tide levels based on astronomic tidal cycle and combined surge and wind driven wave component.

Sensitivity of the scenarios was assessed based on water levels in the Saramacca Canal – trial runs were carried out with the water levels permanently low in the Saramacca Canal for a sufficient period to check that the overall city drainage system operates as would be expected.

Future scenarios modelled are:

- Pluvial flood event for the year 2050, with appropriate increase in rainfall intensity, and estimated increase in urban growth – all other factors, including the return periods run remain as per the baseline.
- Coastal flood event for the year 2050, appropriate increase in sea level, and incorporating a factor to encompasses increased storm surge and wind as a likely result of climate change. This scenario will include the same increase in population density as applied to the pluvial event.

2.1.1.8 *Outputs:*

The analysis has resulted in the following outputs

- A set of flood hazard maps for Paramaribo, including both current and future scenarios, and current flood risk management processes (i.e. pumping and sluice gate operation etc).
- A configured and tested hydraulic model (using selected freeware specifically with further use and sustainability in mind.
- All technical data, including all input and output files for the scenarios tested, and appropriate GIS software and tools for further model development and use.

2.2 Component 2: Flood risk assessment for Greater Paramaribo.

2.2.1.1 What is flood risk.

The term 'flood risk' is often used as a general expression to mean the extent of flooding, or perhaps the chance of flooding; however in the context of a scientific analysis of flood risk, the term needs to be specifically defined. Figure 2-6 shows the widely-accepted definition of risk, as applied to any type of peril, and is the definition that is used here.

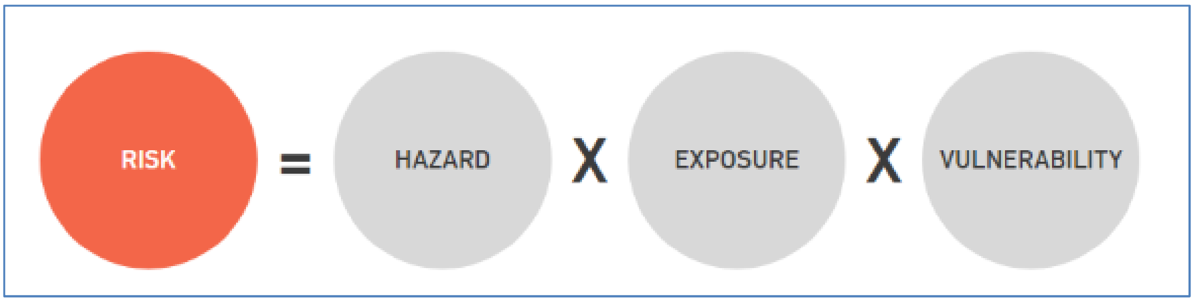


Figure 2-6. Commonly used definition of the term 'risk'.

A flood 'hazard' exists wherever land is liable to flooding and becomes hazardous to people when a flood coincides negatively with human populations, assets or activities. Flood hazard increases with probability of flooding, depth of inundation and velocity of flow which are in turn are affected by climate change and variability, land use change, urban expansion, ageing infrastructure and land subsidence[18]. The consequences of flooding include 'exposure', whereby people, infrastructure or assets are exposed to direct impact of flood waters, and 'vulnerability', which involves an inability to resist a hazard or to respond when a disaster has occurred. Vulnerability is affected by several factors such as socio-economic conditions (e.g. age, health, local sanitary conditions, and economic status) and physical factors (e.g. location and conditions of buildings), as well as flood prediction capability (e.g. whether flood warnings and emergency response procedures are in place). Flood Risk can be reduced by decreasing the magnitude of the hazard, reducing the exposure of people to flooding, and diminishing the vulnerability of flood-prone communities.

The term 'risk' therefore not only incorporates the concept of hazard, i.e. how severe flooding might be in terms of depth and extent, but also includes the scale of the impact the flooding might have on the communities affected. To be meaningful, the use of the term 'risk' also needs to include an indication of the frequency (or probability) with which the level of damage might occur, and to be useful for comparing different mitigation scenarios, it needs to include both current and future conditions under the different management options. Flood Risk can often be simplified and expressed as a single value of annualized damages. This provides a measure of the average cost of flood damage per year based on the probability of a flood event of a particular severity occurring, and the damage that would be incurred if it did happen. It accounts for the situation that occurs most years where very little damage occurs, but includes the possibility of a major, very damaging flood event occurring at some point in the future.

[18] Abhas Jha et al 2011 "Five Feet High and Rising: Cities and Flooding in the 21st Century" Policy Research Working Paper 5648, The World Bank, East Asia and Pacific Region, Transport, Energy & Urban Sustainable Development Unit. May 2011 http://www-wds.worldbank.org/servlet/WDSContentServer/WDSP/IB/2011/05/03/000158349_20110503095951/Rendered/PDF/WPS5648.pdf

In component 1 of the study, flood hazard under a range of probabilities was explored, and flood depth maps for each return period were produced. Component 2 assesses the impact that these various flood events would have. In order to do this, a dataset of the buildings and contents that could be affected by the flooding is required (as a measure of 'exposure'), as well as an indication of the damage that they may suffer when exposed to flooding (as a measure of 'vulnerability'). The process of quantifying the flood risk though this approach is described briefly in the following sections, but is set out in detail within the technical report in Appendix A.

2.2.1.2 Developing exposure and vulnerability data.

A full and detailed flood risk assessment would require an inventory and classification of everything that would be adversely affected by flooding. This could include all direct, tangible assets such as buildings, infrastructure, property, vehicles etc., as well as indirect damages such as disruption to the economy, environmental impacts and social wellbeing including injury or loss of life, loss of personal possessions, disruption etc. At a city-wide scale study however, capturing every aspect of the exposure and vulnerability across an entire city is unrealistic. To meet the strategic objective of the study, only the main elements of the exposure and vulnerability are needed, but with sufficient confidence and granularity to provide useful decision support data and tools for flood risk management and planning, and to allow sensible comparisons between different risk mitigation options. Research however, has suggested 30% is a typical factor to estimate indirect flood damages from direct damages, and could be used here as an indicative figure.

The exposure and vulnerability data focussed on for this study, has been buildings of varying structure and uses, including different types and construction of residential properties, commercial and industrial buildings, as well as building contents, possessions, and services, and agricultural land-use data. Unfortunately, this data is not readily available, and certainly does not exist in a usable form and at an individual property level. However, using local guidance, satellite imagery, the small amount of detailed 'open street map' available, and land parcel information received from GLIS, a city zoning (8 zones including rural agricultural land) was derived, each with different percentages and densities of the most common types of buildings (6 types of residential and 3 types of commercial or industrial) and land uses. Costs for typical residential building contents, fixtures and fittings were also derived, and using information on similar studies elsewhere, commercial and industrial building contents and services costs were obtained. Satellite imagery (Google Earth) was then used to sample each zone to estimate the roof area of the different building types, and then each of the zones were subdivided into a 100m by 100m grid, applying the estimated property type distribution by area and size, or land use (i.e. agriculture) for the zone to each grid cell. This then allowed the previously derived flood maps to be applied to estimate the average depth of flooding across each cell, and therefore the average depth of flooding that would affect each of the different buildings.

The amount of damage likely to occur to each of the different building types and uses for a given depth of flooding clearly differs, as does the amount of damage to their contents. There are fortunately, many sources of depth/damage curves available derived for a wide range of situations that reflect the way different building types or assets are affected by flood water. Again, using the information gathered during previous local discussions and workshops, depth damage curves derived for other parts of the Caribbean were selected and adjusted to local costs and values as recommended in the CHARIM Handbook[19]

2.2.1.3 Assigning and quantifying flood risk.

The final step in the process to derive a sensible and useful measure of flood risk, at a meaningful resolution, was to combine the various depth/damage per unit area curves for the various exposure types, and calculate the likely damage for each 100m by 100m grid cell. This process was carried out using GIS tools, allowing spatial analysis and visualisation of damages resulting from different return periods events and flood sources. The data was then exported to spreadsheets for further analysis, and using the results for the different event probabilities (return periods), the Annual Average Damage (AAD) at a spatial resolution of 100m by 100m across the whole city and surrounding areas was calculated. The data could also be summed to provide a single value of total economic flood damage (for the selected exposure) for a particular scenario.

2.2.1.4 Outputs:

Outputs from this component are as follows:

- Economic flood damage data for a range of return periods, flood types and baseline and future scenarios – both distributed at a resolution of 100m by 100m, or as a single value, or any sub-division in-between.
- Quantified (costed) risk data for a range of return periods, flood types and baseline and future scenarios – both distributed at a resolution of 100m by 100m, or as a single value, or any sub-division in-between.
- Sets of depth/damage per unit area curves, with a basis in local knowledge, and best practice guidance.
- Initial derived data sets for property types, distribution, value, size and uses – suitable starting point for further data acquisition and more detailed analysis.
- Tools and methodology for carrying out GIS analysis of flood damages and risk

[19] Caribbean Handbook on Risk Management - developed by a consortium of five international institutions: University Twente, Faculty ITC (UT-ITC), the Netherlands; The University of the West Indies, Faculty of Engineering (UWI) Trinidad and Tobago; Asian Institute of Technology (AIT), Thailand; SSBN – Flood Risk Solutions, United Kingdom; Envirosense, The Netherlands. (http://www.charim.net/)

2.3 Component 3: Mitigation Options Analysis.

2.3.1.1 Option considerations.

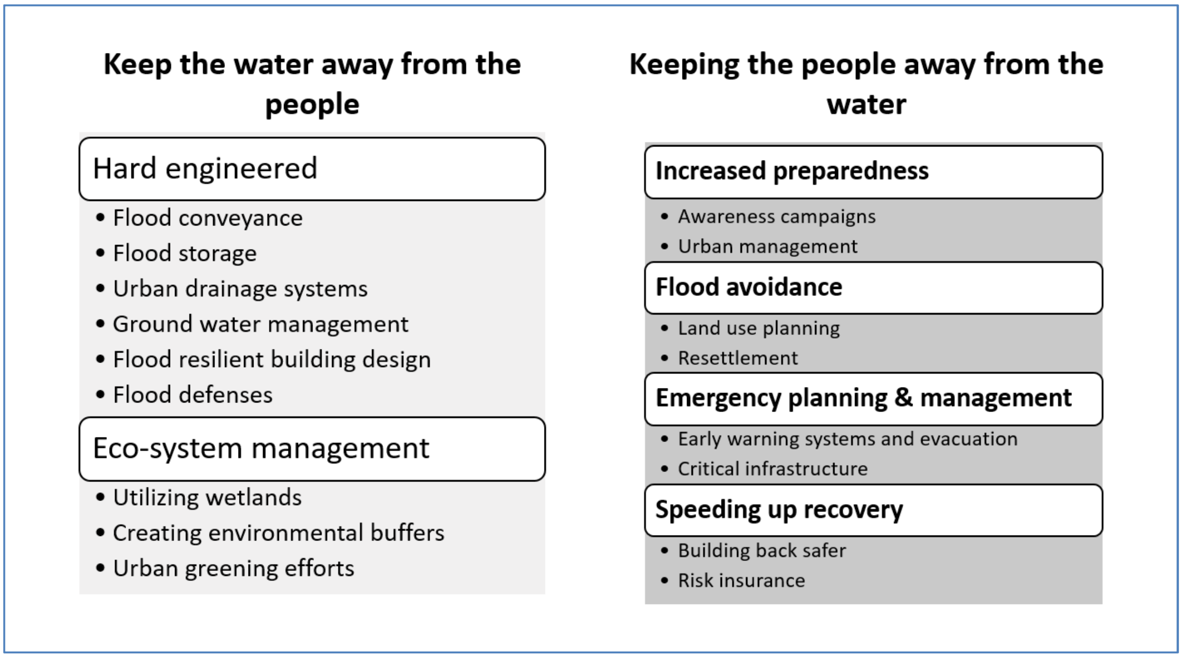


Figure 2-7. General flood mitigation option.

The main objective of this project is to identify the most cost effective, achievable and sustainable options for reducing the overall flood risk in Paramaribo. By developing an understanding the flood mechanisms and sources of flood risk through discussions with local knowledge holders, and bringing experience of what has been successful elsewhere, a list of mitigation actions that are potentially effective and feasible have been determined. Figure 2-7 highlights the general principles behind the selected mitigation strategies, and defines the general measures to be considered in the analysis. In practice, not all measures are suitable for all flooding problems, and the most effective and sustainable solutions are often a mix of approaches, utilising a range of structural and non-structural (or nature-based) interventions.

A total of 14 options (11 structural and 3 non-structural) have been selected for assessment and will be described in detail in later sections.

2.3.1.2 Process for assessing the options and quantifying the benefits.

To meet the overall study purpose, the various options need to be assessed in a comparable way against the key drivers of flood risk reduction. Their relative effectiveness in terms of a quantifiable reduction in flood risk against a baseline, both now and in the future need to be determined. A key consideration for the analysis is therefore how to represent the various options within the hydraulic model, and whether there needs to be an alternative or additional consideration to qualify the benefit.

A clear advantage of using the hydraulic model for testing structural scenarios is that it provides a consistent measure against the baseline, and shows an immediate tangible and quantifiable result. An improvement in drainage, for example, will provide a clear benefit in terms of reduced flood hazard depth and extent. When quantifying the risk under this new 'better drainage' scenario, even though flooding may still occur to some degree, the overall damage value will be reduced and the risk measure will be lowered.

Testing non-structural measures such as flood forecasting and warning is not as simple, as there is no measurable change in flood extent or depth. However it is known that overall damages can be reduced by taking appropriate action to protect belongings or temporarily increasing the resilience of properties. Similarly, there can be a change in the overall flood risk through land use planning and perhaps regulatory powers, or changes in building regulations where flooding hazard remains the same but the impact is reduced. In these instances, the benefits of these options can be reflected through changes in the vulnerability (depth/damage curves) for the buildings, assets and contents, and still calculate a comparable risk value through essentially the same modelling process.

2.3.1.3 Outputs:

Outputs from this component are as follows:

- A set of flood hazard maps for Paramaribo showing the impact of the various options for the same return periods as the baseline, and for the current and future scenarios.
- A set of tables of damage values for each of the options – both structural, and none structural for comparison against the baseline, and calculation of benefit-cost ratios.
- Series of capacity building initiatives, technical handover and training documentation to support future use and development of the system to analyse benefit-costs for future improvement proposals.

2.4 Component 4: Development of a Flood Management Investment Plan.

2.4.1.1 Investment Plan.

Based on the flood risk assessment and options analysis described above and with the necessary information from the GoS, the project has begun to develop a prioritized and targeted flood risk reduction investments plan. This plan includes improvements, developments or changes that could be implemented with confidence, and with little additional investigation or justification. The plan also identifies where detailed further studies and design contracts for large capital expenditure is required, or where uncertainty or complexity is high. In addition, recommendations are made for operational changes and improvements, and long-term strategic improvements and policy development, with likely time frame, and expected outcome.

2.4.1.2 Background and strategic alignment

Under this component an investment plan for prioritized flood risk management investments has been developed through consultation and close involvement with the GoS and stakeholders, and is built upon on a solid evidence of quantified risk and benefit-cost relationships. The investment plan builds on the options tested, and with the benefit of the modelling analysis and following further technical deliberation and feasibility considerations, they have been refined into practical proposals. The plan retains options for the rehabilitation of the Saramacca Canal, a key structural element within the city of Paramaribo drainage system and one of the top priority investments identified by the Government. It also includes soft measures such as nature-based solutions (e.g., future land use planning and regulation) to alleviate flood risks as well as non-structural measures such as improved flood monitoring and forecasting, improved planning (emergency response as well as urban development), and more effective emergency response. The plan will define a selection of measures, some of which will require detailed design with further high-resolution analysis as part of the next steps, whilst many of the more operational recommendations will be sufficiently well defined to allow immediate implementation or procurement.

2.4.1.3 Activities

The investment plan will focus on reducing the impact of recurrent flooding while taking into consideration environmental and social aspects. However, the investment plan will need to remain a live document, and further, more detailed studies carried out to resolve issues such as land acquisition, involuntary resettlement, etc. This component will include workshops with all stakeholders to agree on the proposed plan and to ensure effective participation and contributions.

2.4.1.4 Outputs:

Outputs from this component are as follows:

- A standalone evidence-based investment plan for the Suriname Government to use to support flood risk reduction measures in and around Paramaribo
- A roadmap for future work to build on both the flood risk assessment, and improve the level of analysis and increase the certainty within the investment plan
- Training and capacity building in order to further the overall aim of reducing disaster risk in the Greater Paramaribo area.

This component also contributes towards improved future flood risk-related data and encourage data sharing. All data, including the digital topographic information and data have been acquired and provided freely to be used in any future analysis. Modelling and GIS software are Freeware packages, and can be used for further development of the investment plan and any associated studies.

3 Flooding in Paramaribo.

3.1 General description.

Paramaribo is the capital of Suriname, located on low lying coastal plain on the left bank of the Suriname River approximately 10 km from the Atlantic coast to the north. The city covers an area of approximately 70km^{2}, and is home to a population of over 300,000 people. The area is generally flat and close to sea level, ranging from less than 1m to 2m (relative to datum WGS84).

The old historic part of the city developed along relatively high and sandy areas close to the river, surrounded by slightly lower land that became occupied by large plantations. These areas, often prone to flooding, were drained using a network of canals and sluices to improve the productivity of the surrounding land. Since these early days, constrained by the Suriname River, the city has gradually expanded westwards, southwards, and to the north, occupying land formerly used for agriculture.

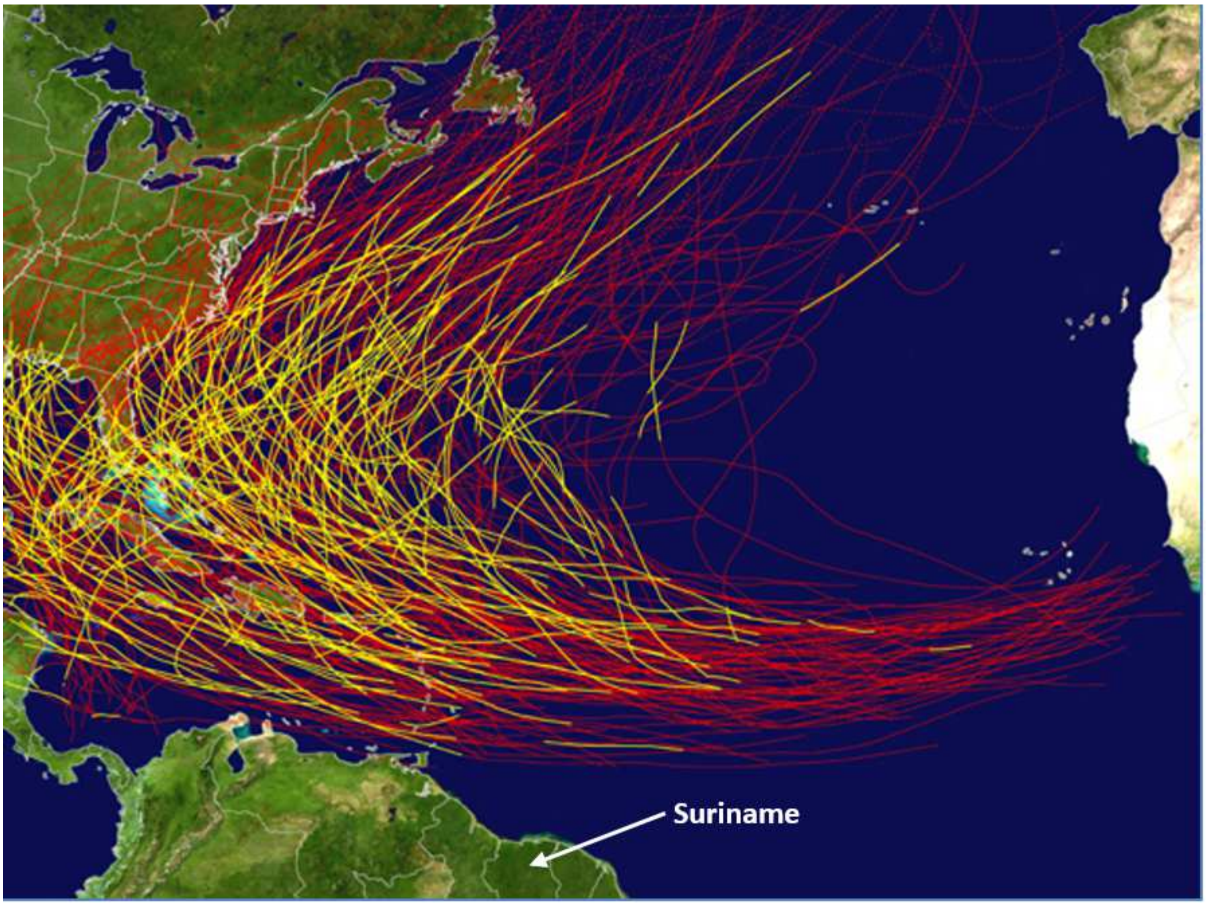


Figure 3-1. Major hurricane tracks across the Atlantic (1851 to current - Ref NOAA).

The city is dominated by a tropical climate, and being only a short distance north of the equator has two distinct wet seasons, December to January, and April to August. Being outside the main hurricane zone (see Figure 3-1) means that hurricanes are very unlikely, and when compared to the Caribbean further to the north, Suriname has a relatively benign climate. However extra-tropical cyclones can result in strong winds and periods of prolonged and heavy rainfall, with daily totals in the order of 200mm or more. With sea temperatures set to rise in the future, these local storms and associated rainfall events are likely to become more intense.

3.2 River flooding.

The city is protected from potentially frequent flooding from the Suriname River by low river walls and raised ground along the majority of the river frontage. The river at this point is wide and flat, and is tidal some distance upstream of Paramaribo. The flow in the river from upstream is largely controlled by the hydro-power generation dam at Afobaka on the Brokopondo Reservoir, some 75km to the south of the city. Although additional flows from tributaries downstream of the dam will add to the Suriname River discharge, run-off from the majority of the contributing catchment area is stored within the Brokopondo reservoir and released at a controlled rate to produce electricity. The likelihood of flooding in Parimaribo as a result of extreme river flows is therefore is negligible. However, the tidal influence is significant and an extreme high tide will raise water levels in the river resulting in some inundation of areas along the river side, particularly the old historic part of the city. In addition, high tides in the river prevent natural drainage from the city and surrounding land, which can frequently result in short periods of localized flooding.

The main risk associated with flooding in Greater Paramaribo is therefore through inundation from the open sea to the north, and extreme rainfall events over the area combined with poor drainage.

3.3 Pluvial flooding.

3.3.1.1 Sources and causes of pluvial flooding.

The city of Paramaribo and surrounding area is relatively flat with naturally poor drainage, and flooding due to heavy rainfall (pluvial flooding) occurs frequently throughout the two rainy seasons. The severity and distribution of flooding across the city depends on the intensity, duration and distribution of the local rainfall, which due to the convective nature of the storm cells producing much of the rainfall over the area, can be localized with relatively rapid onset. However, the less frequent but more severe flood events are more likely to be caused by prolonged and wide-spread heavy rainfall resulting from major weather event, such as a tropical depression or storm. Figure 3-2 shows the areas prone to flooding identified by the 2001 Masterplan. As the city has changed and expanded over the subsequent 15 years, the extent and distribution of flood prone areas with a significant impact will also have increased.

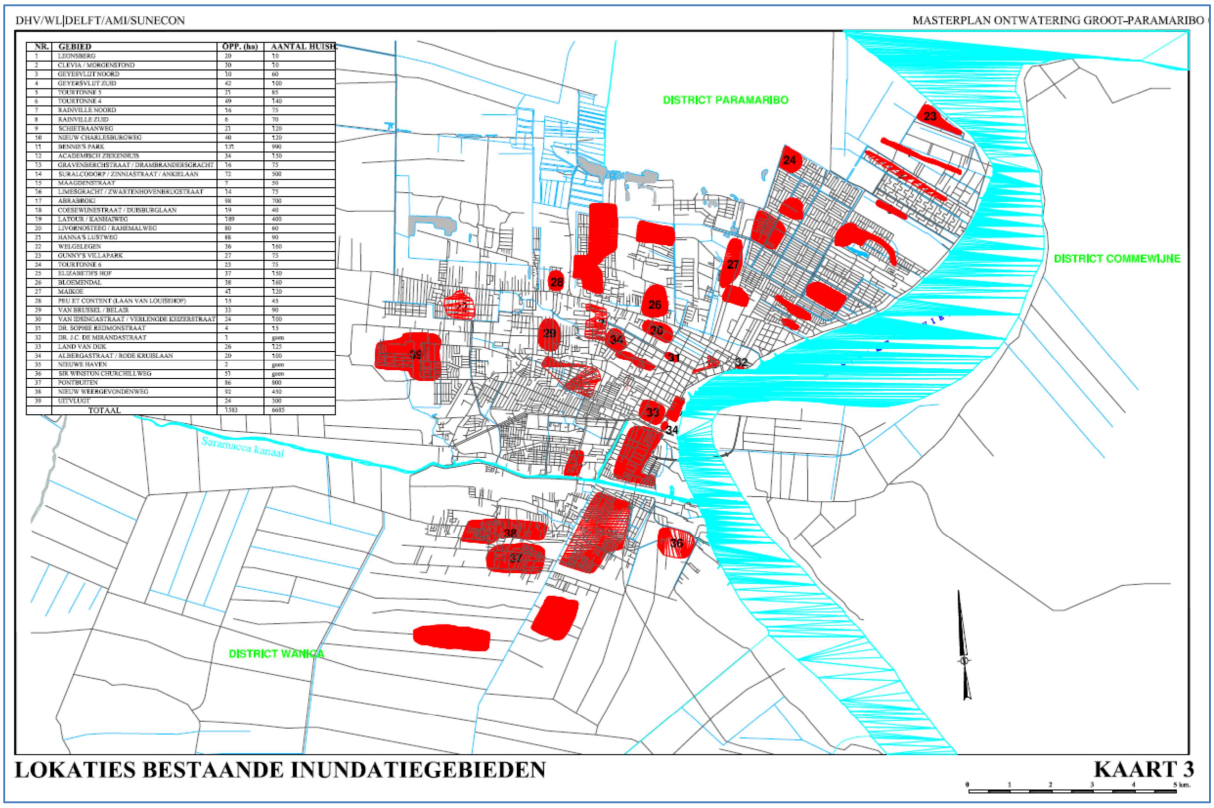


Figure 3-2. Existing areas with known flood hazard (MOGP 2001).

The geology of the area is a relatively recent formation of sedimentary deposits (Holocene Epoc – last 12,000 years) and is a mix of clays, sands and shell beds. The harder sands and shell beds (referred to as zippers) tend to form slightly raised areas with greater permeability than the surrounding land, although these features tend to be small and only surface deposits and therefore do not retain large amounts of water. Permeability of the soil is therefore variable, but with extensive clay in the lower elevation areas, infiltration is generally poor and surface water ponding following heavy rainfall is common, made worse due to the lack of any significant gradient. This is a key factor in the flood risk associated with the area, and needs to be taken into account when considering flood risk mitigation options.

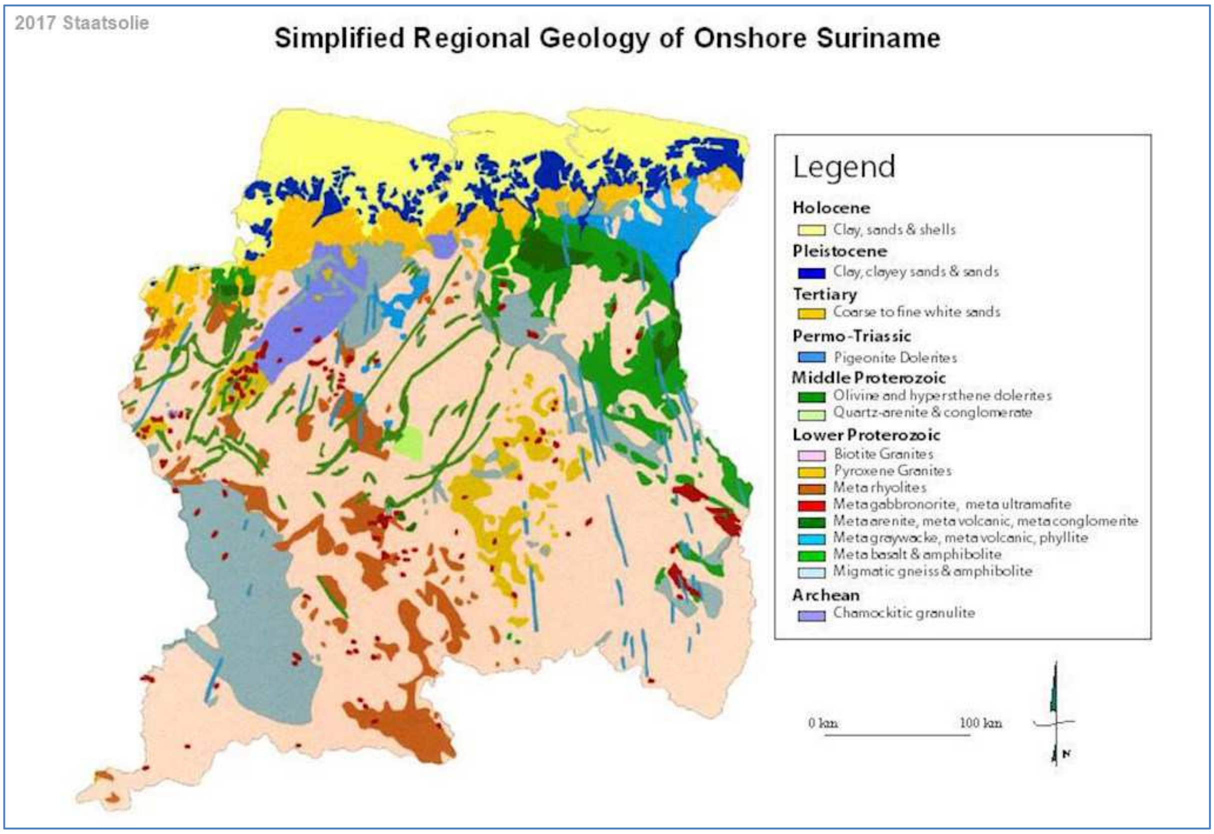


Figure 3-3. Suriname geology map (Source – Staatsolie).

Although the older central area of Paramaribo city has sub-surface piped drainage with gullies collecting surface water run-off, the area is relatively small and the majority of greater Paramaribo relies on an extensive network of canals for storm water drainage. These canals drain the central and southern parts of the city towards the Saramacca Canal, which is a large historic navigation waterway that runs from east to west, joining the Suriname River to the Saramacca River. As the city has grown over the last century, the role of the Saramacca Canal has become ever more important in the drainage of rain water from an area of approximately 190km^2, with approximately 70km^2 from the more heavily urbanized city areas to the north of the canal, and 120km^2 from the less densely populated areas to the south (see Figure 3-4).

An area of approximately 50km^2 towards the north east of the city drains through canals to the Suriname River, and the remaining land to the north of the main coastal highway, an area of nearly 150km^2, drains northwards towards the Atlantic Ocean. A small polder area of around 40km^2 to the west of the study area drain towards the Saramacca River and is discharged through a large pumping station.

The majority of the network drains under gravity through sluice gates and tidal flaps which prevent inundation when the tide is high, but in several locations drainage is augmented using pumps. The total extent of this complex drainage network that falls within the study area is more than 500km^2.

Figure 3-4. Saramacca Canal drainage area.

As well as providing drainage through the interconnected canal network that runs along the side of most roads, the canals themselves provide considerable storage capacity for run-off during a rainfall event. During a significant rainfall event, however, this capacity can be overwhelmed, and flooding will occur with inundation of roads and roadside properties.

The Saramacca Canal is approximately 25km in length, and ranges from around 50m wide at the eastern end to less than 30m wide towards the more rural western end. There are large sluice gates with navigation locks at both ends of the canal to allow shipping access from the Suriname and Saramacca Rivers (see Figures 3-5 and 3-6), however vessel traffic is minimal at present due to the poor condition of the canal. The sluice gates on the western end of the canal are currently not functioning and are permanently closed, and the navigation lock is used to regulate local water levels on the canal. The sluice gates at the eastern end of the canal on the Suriname River are operational, although only four of the five 5m gates can be opened to allow release of storm water when river water levels allow (see Figure 3-7). They can then be closed to maintain water levels in the canal during dry periods when the tide levels in the river are low, or conversely, when tides in the river are high, they prevent ingress of saline river water into the canal, and potential flooding. When water levels are particularly high, the lock gates are also opened to increase discharge rates into the Suriname River. The sluice gates on the eastern end of the canal therefore provide the main discharge capacity from the city's drainage system, and can remain open for typically around 5 hours, before the tide levels in the river prevent discharge, and the gates need to be closed. The timing of high tides is slightly different at either end of the canal, and so during a flood event, the Suriname River sluice gates can be opened half an hour earlier than the Saramacca River end, which is only normally opened for around 3 hours during the rainy season.

There is a slight gradient along the canal in both directions from a watershed location approximately 15km from the Suriname River end and 10km from the Saramacca River. Water movement through the canal is therefore relatively complex, controlled by subtle changes in water elevation along its length. The general principle however is for the majority of surface water from the city and surrounding area discharges towards the Suriname River, whilst the less urban areas to the west, drain towards the less effective western end of the canal, and into the Saramacca River. The western end of the canal however does play an important role in allowing fresh water from the Saramacca River to enter the canal during dryer periods, and by leaving the gates open at high tide, drives the fresh water through the system towards the eastern end of the canal – providing fresh water for irrigation, maintaining water levels for navigation, and reducing water quality problems in the eastern end of the canal.

Figure 3-5. Navigation lock at western end of Saramacca Canal.

Figure 3-6. Navigation lock on eastern end of Saramacca Canal.

Figure 3-7. Sluice gates at eastern end of Saramacca Canal.

As an essential part of the Paramaribo drainage system, it is important that the Saramacca Canal provides sufficient capacity and conveyance during a flood event. However, the dual role of providing navigation as well as flood relief means that the canal cannot be kept drained down to its lowest level in order to provide maximum storage for flood water. In practice, there is an optimal operating range of approximately 1 to 2 meters which provides an active storage layer in the canal. Excessive vegetation build up will have some effect on the overall active storage volume, but will have a larger, more significant impact on conveyance of flood water towards the sluice gates. Excessive vegetation will also result in a loss of capacity through increased sedimentation and material build up on the canal bed.

Figure 3-8. Saramacca Canal towards more rural western end, showing weed growth.

The capacity of the Saramacca Canal and its ability to discharge excess surface water into the tidal Suriname River are clearly extremely important in determining flood risk, and must therefore be one of the main considerations when addressing flood risk.

The condition of the general canal network that drains the city and surrounding area is also considered a major factor in determining the occurrence and severity of flooding. The canal network provides both storage for rainwater and conveyance capacity to collect and transport surface water from the city and surrounding areas through the network and ultimately into the sea. Maintenance is therefore essential to keep the canals free from the build-up of vegetation and sediment, and the multitude of small culverts and road crossings clear. Figure 3-9 shows examples within the city of a well-maintained canal, and a canal in need of some clearance. The vegetation mats that develop in the waterways may be confined to the water surface initially and probably have little impact on the overall flow capacity, however the vegetation mats encourages build-up of material on the canal bed and the waterways can become significantly choked over time.

Figure 3-9. Maintenance requirements – recently maintained (left), maintenance required (right).

Figure 3-10 shows the impact of sedimentation on a culvert linking sections of the canal together. If these become blocked the canal system becomes a series of poorly connected ponds, and the ability of the system to discharge is significantly reduced.

Figure 3-10. Sedimentation reducing conveyance on canal drainage system.

3.3.1.2 Impact of pluvial flooding.

Urban, or surface water flooding that results from the drainage system being overwhelmed by heavy rainfall is generally referred to as 'pluvial' flooding. It tends to occur in the general vicinity of where the rain has fallen, and is not normally associated with flood discharges from river or large drainage basin. As a result, pluvial flooding can be localised in response to local heavy downpours, it can be unpredictable and occur quite rapidly, but would not normally be deep or pose a serious threat through high water velocities. Nevertheless, this flooding can be deep enough to cause significant damage to low lying property, and can cause serious disruption through road closures and damaged vehicles. Although the local drainage network is temporarily overwhelmed, with adequate conveyance and storage within the overall network, the floodwater will quite quickly subside. This is the kind of flooding that occurs relatively frequently during the rainy season. Some areas will be more prone to this type of flooding than others due largely to the local topography and natural drainage, but also to the capacity or condition of the local drainage, and on occasions, the coincidence with high tide and resulting tidal locking.

Pluvial flooding however can also be the result of more widespread and prolonged rainfall, perhaps over several days, which gradually saturates the drainage network as a whole becoming inundated and unable to cope with any bursts of high intensity precipitation. Under these conditions, the flooding will be extensive, and potentially relatively deep in places, with more than 0.5m depth of flooding being widespread. Considerable damage to property will occur under these conditions, and the floodwaters are likely to take at least 24 hours to recede to manageable levels. The impact on infrastructure, services and commerce will be major, and emergency response and incident management will be challenging due to the potentially widespread nature of the impact, and potentially prolonged nature of the flooding. Although this is less likely to occur than the localised flooding described above, and which the local population are used to dealing with, the rainfall conditions have been shown to occur historically in other parts of Suriname, and so could happen at any time in Paramaribo, with impacts many orders of magnitude greater.

3.4 Coastal flooding.

3.4.1.1 Sources and causes of coastal flooding.

Flood risk and coastal erosion are closely linked, and are part of the same complex problem associated with the highly dynamic, muddy Suriname coastline, which has led to increased erosion in areas such as Coronie and Weg naar Zee. Although not directly subject to hurricanes which pass further to the north, extra-tropical storms can create strong wind and, on occasions, a storm surge component to the tides. Fortunately, the very gently sloping, muddy coastline protects the shore to some extent, by reducing the impact of waves as they lose energy in crossing the shallow off-shore mud flats. Wave heights of several metres however, are still possible during high tide, which can still be very damaging and will contribute to the severity of flooding.

In some locations along the coastal area to the north of Paramaribo, such as Weg naar Zee, dykes have been erected and makeshift defences built along the coast in the past. At North Coronie, a coastal seawall was installed to provide protection to the coastal access road to Nickerie, which had been subject to both inundation and erosion. In these locations, wave-induced flooding occurs through wave overtopping, a complex process controlled by the state of the sea (depth, wave properties) and the geometry of beaches and local flood defences. As recently as February 2015, significant flooding occurred in the Weg naar Zee area as a result of high spring tides and heavy wave action, overtopping and damaging the sea wall, and inundating a number of sites including the crematorium and the Hindu Temple. Figure 3-11 shows images of the existing flood protection along the Weg naar Zee coast, clearly showing the vulnerability of the coastal area to high tide and extreme weather events.

Figure 3-11. Current flood protection along the Wag Naar Zee coast north of Paramaribo.

Coastal flooding and erosion along this section of coast is extremely complex, and will be dealt with in more detail in Part 2. Nevertheless, the extent of the hazard posed by flooding from the sea and an assessment of the impact has been carried out as part of the strategic flood risk assessment study, and is therefore included within this report.

3.4.1.2 Impact of Coastal Flooding.

The frequency of coastal flooding has increased significantly in recent years, however these have generally been relatively minor in terms of scale and impact. They have mainly affected the northern coastal fringe, and areas along the river frontage of the Suriname River. Although the depth of tidal flooding may be small, there is an almost infinite volume within the ocean, and so the extent of flooding across a flat expanse of land can be large. Wave overtopping can contribute a significant volume of water to a flood event, or can even be the sole cause of flooding due to the volume of water thrown onto the land on each successive wave. For a similar extent of flooding, coastal flooding is generally far more damaging than pluvial flooding due to the salt water. This will result in considerably more damage to infrastructure, buildings and contents due to the waters corrosive properties and high sediment loading. It will also impact agriculture to a much greater extent than fresh water flooding, in terms of damage to the crops, which is likely to result in complete crop failure, and may result in longer term damage to the soil which can reduce productivity for up to a year or more for some crops.

A large scale coastal flood event has not been experienced in the area in living memory, nevertheless, the possibility exists, and because of the low lying flat topography of the area, flood levels would not need to be particularly high to create rapid and extensive inundation. Damage along the coast and to the land behind coastal protection would be considerable due to the erosion from relatively fast flowing sea water. Long lasting impacts will also occur due to the saline water flooding into the canal network, and salt deposition across the land, both on the land and vegetation surface, but also within the soil itself. Damage to property and buildings would be considerable, and fixtures and fittings can suffer irreparable damage from sea water. Loss of life is also a possibility due to the rapid onset of flooding, and potentially high velocities and depth of flooding in low lying areas. Evidence from around the world has shown that fatalities from flooding, more often than not, occur when people are traveling through flooded areas, frequently in vehicles, when trying to navigate submerged roads or bridges and ending up in deep water. Lack of risk awareness within the population at large, and the absence of an effective early warning system contributes strongly to this risk.

4 Risk assessment and key findings

4.1 Results of the flood modelling

4.1.1.1 Current and future scenarios

In order to understand the risk from flooding, a hydraulic model for Greater Paramaribo has been developed that allows the simulation of flooding from different sources. As discussed in Section 3.2, river flow in the Suriname River is controlled upstream by the Afobaka hydro-power dam which prevents high flows affecting the lower reaches of the river through Paramaribo. The main sources of flooding that have been analysed are therefore heavy rainfall events across the city, and tidal flooding from the coast and along the river frontage.

The technical detail of the modelling is provided elsewhere within this report (Appendix A); however a summary of the simulation scenarios is provided here for completeness:

- All scenarios have been simulated for a range of return periods (10yr, 50yr 100yr and 200yr)
- Coastal flood inundation has been modelled for the current (2017) extreme tide levels (including storm surge and wave component), and a future scenario for the year 2050 – including sea level rise, increased population and urbanisation of coastal areas
- Tidal flooding includes three consecutive tidal cycles applied to the model at the coast, along the Suriname River frontage, and at the Saramacca end of the Saramacca Canal (delayed by 0.5hr.)
- Pluvial flood inundation has been modelled for the current (2017) and a future scenario for the year 2050 – including climate change, sea level rise, increased population and continued urbanisation of surrounding rural areas.
- Pluvial events were derived from local daily rainfall records, but applying a generic regional storm profile to capture the intensity of the rainfall over a short period. This resulted in a relatively peaky storm profile, with much of the rainfall occurring within a relatively short period of around 4 hours. Average tidal water levels were applied as a model boundary condition for these simulations.
- Results have been analysed and tabulated to provide a baseline for comparison against a range of mitigation options.

The models have been run for sufficient time to allow the flooding to reach its peak, and in some cases, sufficiently long to allow the flooding to dissipate. For both coastal and pluvial events, this has meant running the model for a period of 36 hours, allowing a sequence of three high tides, with the middle one being the largest, and allowing the system time to fully drain following a 24 hour rainfall event.

The current scenario is taken as the baseline, against which, all other options can be compared. The future scenario (i.e. 2050) is effectively the 'do-nothing' scenario, where everything carries on as before, except that climate change, sea level rise, and population increase will result in an increased flood risk.

4.1.1.2 Results of the flood hazard modelling

The results of the modelling process consist of a sequence of digital snapshots of the inundation as it develops across the study area, recorded at 15 minute intervals. Each snapshot is a file containing the water depth on each and every cell of the model. When viewing or processing this data, it is normal to ignore the water depths of less than 150mm (15cm), as this represents puddles and shallow ponding which can occur virtually anywhere, and in reality, would not be considered flooding. Each 15 minute snapshot is stored, and can be visualised as an animation over the period of the model run, which can include the flood recession as the water drains away, and is extremely useful in understanding the dynamics of the flood mechanisms, highlighting any pinch-points or restrictions in the system. When mapping or analysing the flood hazard for a given event, a compilation of the maximum water level reached on each cell throughout the flood simulation period is used. Although clearly the maximum flood depth on each cell of the model would not occur all at the same time, it captures the worst-case flooding at each location, and it allows the calculation of the total damages that would occur throughout the duration of that particular storm event. This is the main data that has been used for the analysis and has been used for all flood depth and flood difference maps.

The tabulated and mapped data presented here are the maximum depth data with Table 4-1 showing the area of flooding for a range of flood probabilities (return periods), where the depth of water exceeds 150mm (15cm). This is a relatively arbitrary depth threshold, but often selected to indicate flooding that will begin to cause significant damage, and may pose a risk to life if combined with high water velocities (not a significant factor in this instance).

All flood maps for both the current and future scenarios, and for the complete range of return periods are provided in Appendix A, however examples are presented here for completeness. Figures 4-1 to 4-4 show the 10yr return period events for the current and future (with climate change) pluvial and tidal flood events.

Scenario	Area of inundation > 150mm (km^2)			
	10 Year	50 Year	100 Year	200 Year
Baseline pluvial flood event	431	452	458	462
Future pluvial flood event (2050)	441	459	464	468
Baseline tidal flood event	97	122	132	142
Future tidal flood event (2050)	151	168	177	190

Table 4-1. Baseline and future scenario flood area.

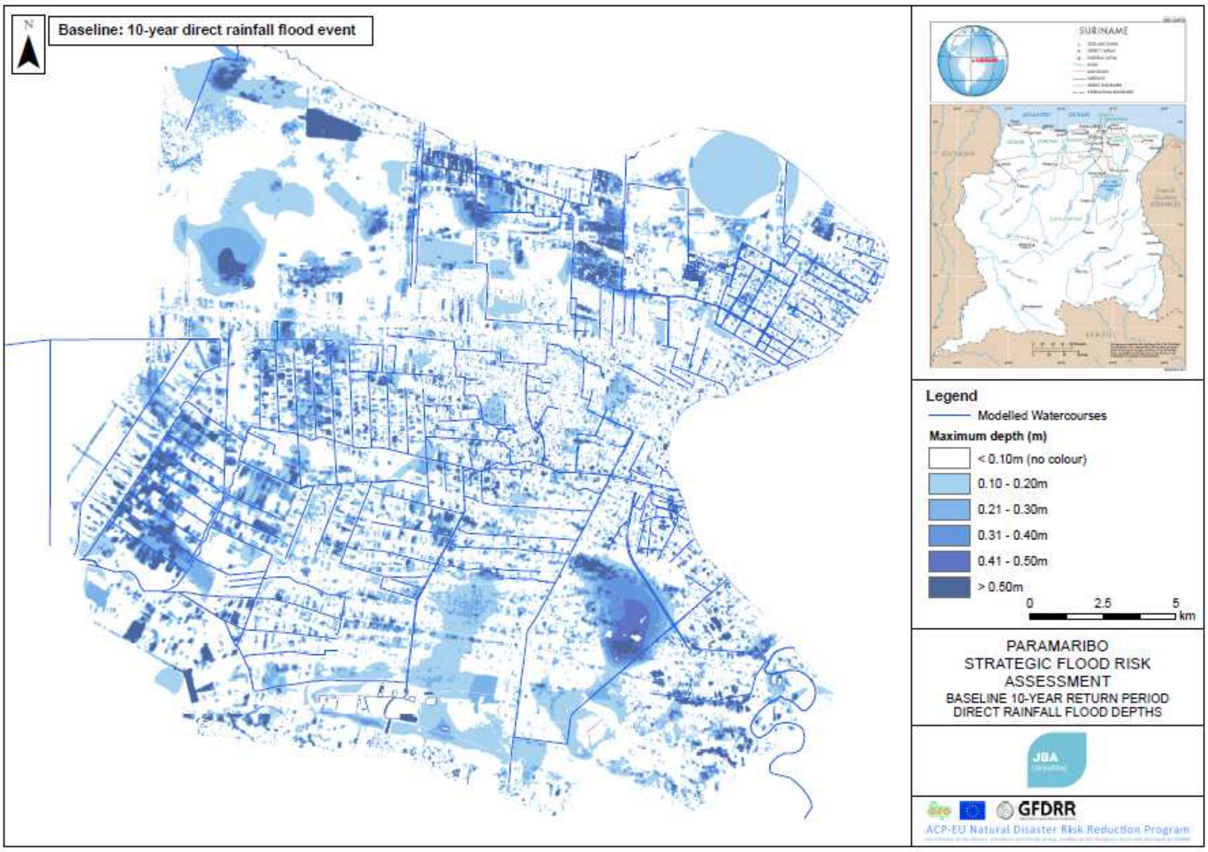


Figure 4-1. 10yr Return Period Pluvial flood depth grid.

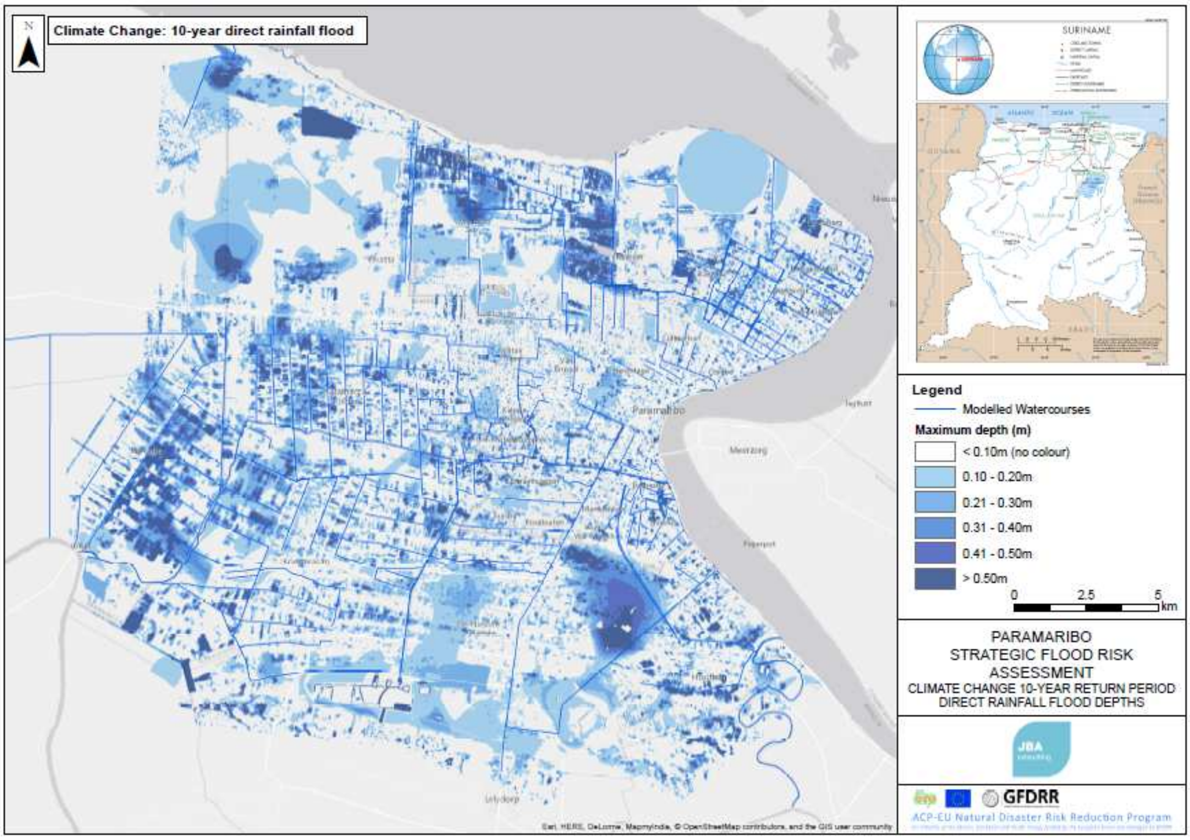


Figure 4-2. 10yr Return Period plus Climate Change Pluvial flood depth grid (for the year 2050).

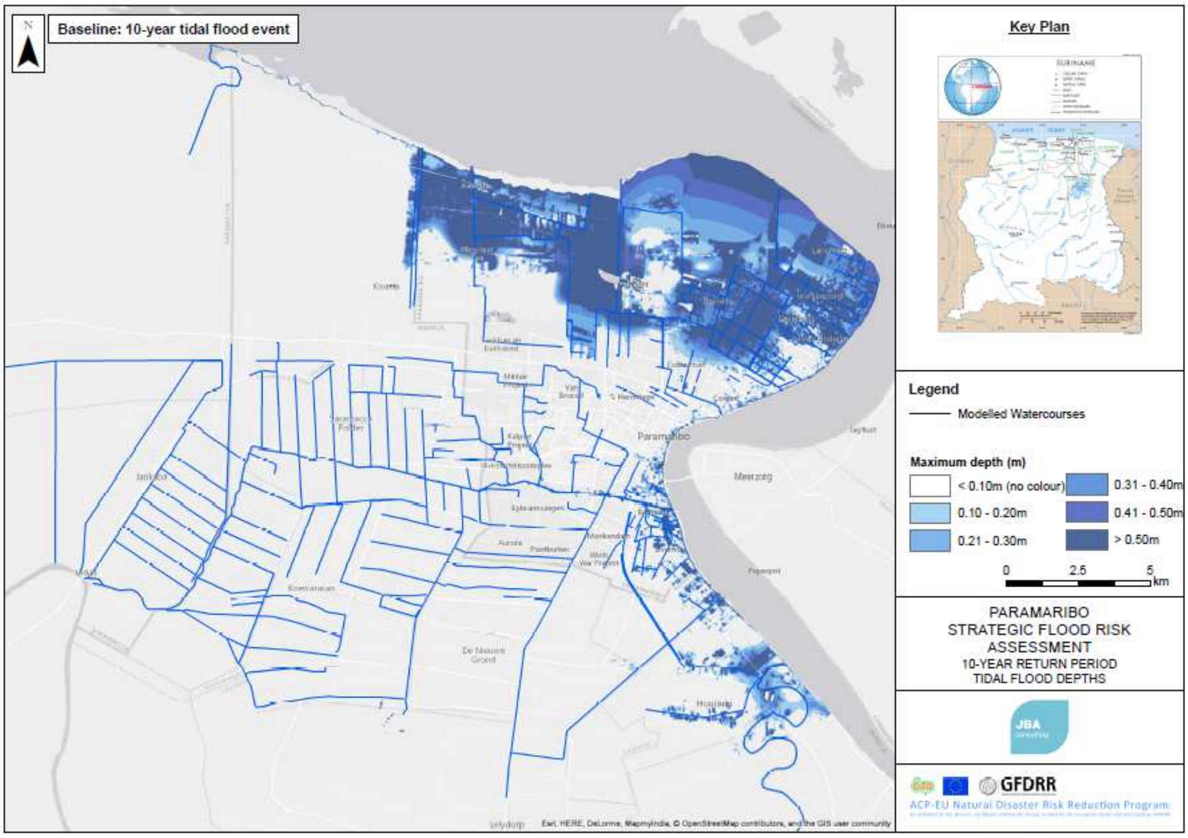


Figure 4-3. 10yr Return Period Tidal flood depth grid.

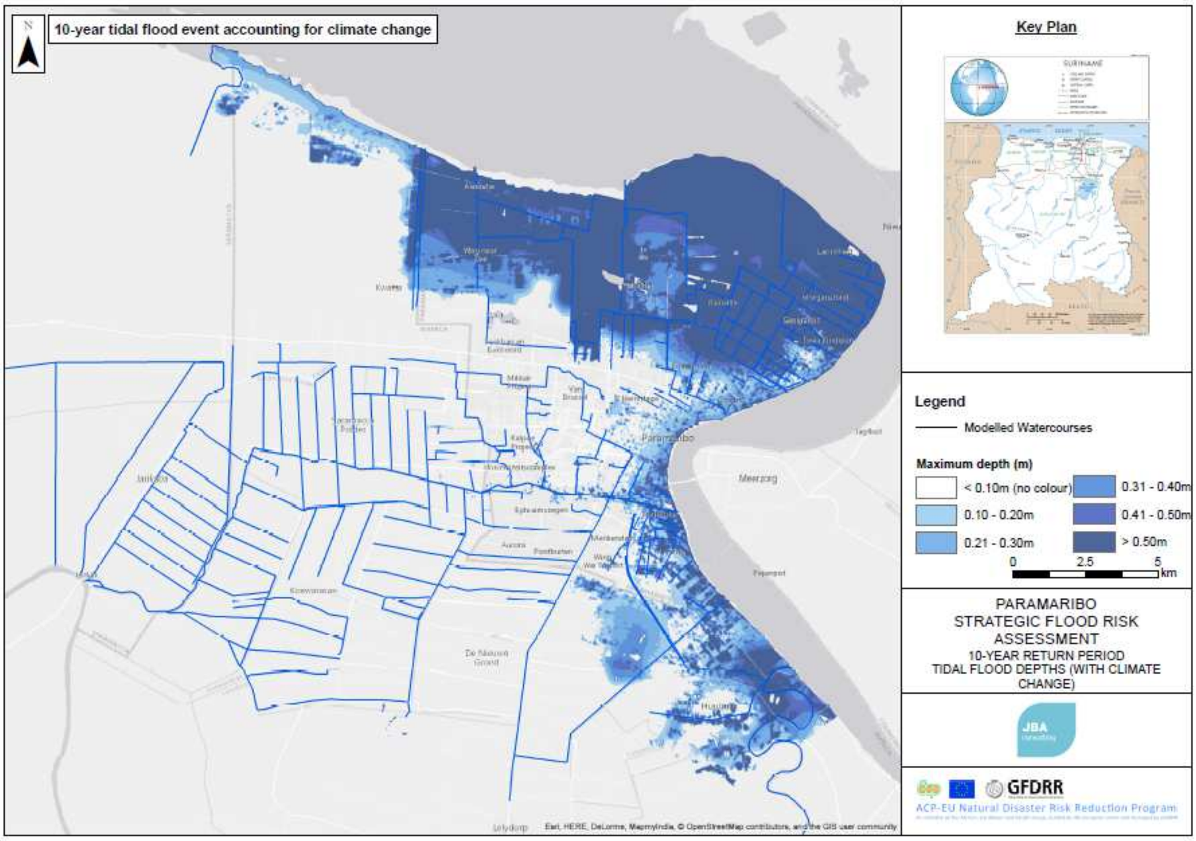


Figure 4-4. 10yr Return Period plus Climate Change Tidal flood depth grid (for the year 2050).

The difference between coastal and pluvial flooding events is clear to see from these maps, and although the pluvial flood hazard is far more extensive than the tidal flood event, the depth of coastal flooding is significantly greater. As a consequence, the damages caused are likely to be very much greater, not only due to the greater depths, but also due to the damaging effect of the saline water and heavy sediment load, the rapid onset of flooding, and the relatively higher velocities and potential for entrained debris. The increase in flood depth and extent due to climate change is also evident for both, however the increase in tidal flooding due to sea level rise is considerably greater. This is considered in more detail in the next section on damages and risk associated with the different flood sources.

4.2 Results of the flood risk analysis

The results from the flood risk analysis are summarised here as a cost of the damages likely to result from a flood of a given probability (or return period), and, more usefully, as a single annual average damage calculated from the integration of damages for events of different probabilities. These costs are calculated from depth/damage curves developed using readily available estimates of replacement costs and likely percentage damage for a range of types of buildings, land use, building contents, services etc. These depth damage curves have been derived using data from previous detailed studies, transferred to the Suriname situation, with some baseline information and professional judgement. The details of this process are provided within the technical report attached in Appendix A.

As with the flood hazard data, it is common practice to map the maximum flood damage as a gridded value for each return period, or, more usefully, the gridded value of Annual Average Damages (AAD). This highlights not just where the flooding occurs, but also where the risk from flooding is likely to be highest. The full set of flood risk maps are provided in Appendix A, but the AAD risk maps for the baseline and future scenario for both pluvial and tidal events are presented in Figures 4-5 to 4-8 highlight the way flood risk is likely to increase over the next 30 years, Figures 4-9 and 4-10 show the change in AAD over the same period. Tabulated summary data for the changing risk is provided here in Table 4.2.

Scenario	Calculated total damages (US$)				
	10 Year	50 Year	100 Year	200 Year	Total AAD
Baseline pluvial design event	266	430	508	590	91
Future pluvial design event (2050)	326	527	622	722	112
Baseline tidal design event	1,069	1,488	1,684	1,886	350
Future tidal design event (2050)	2,185	2,747	3,001	3,256	695

Table 4-2. Baseline and future flood damage estimates.

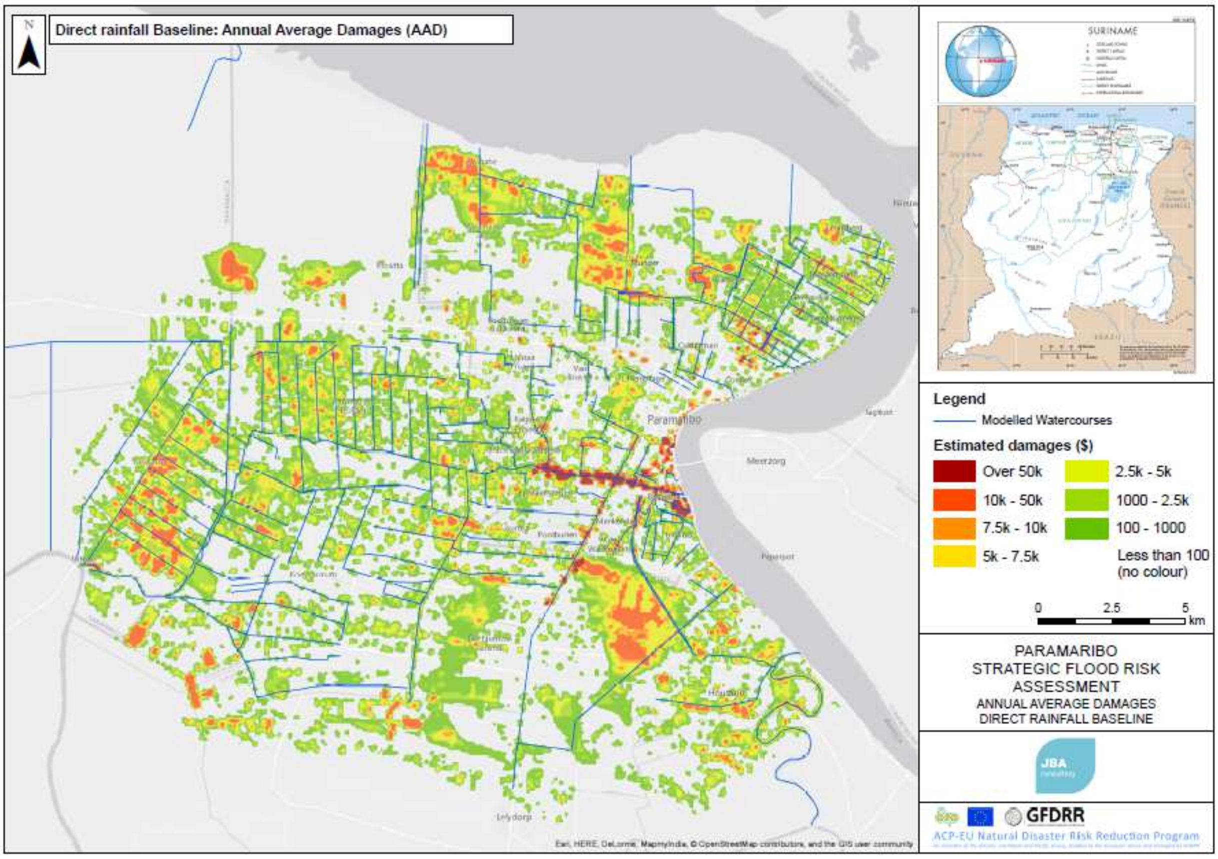


Figure 4-5. Pluvial Annual Average Damages values for the current scenario.

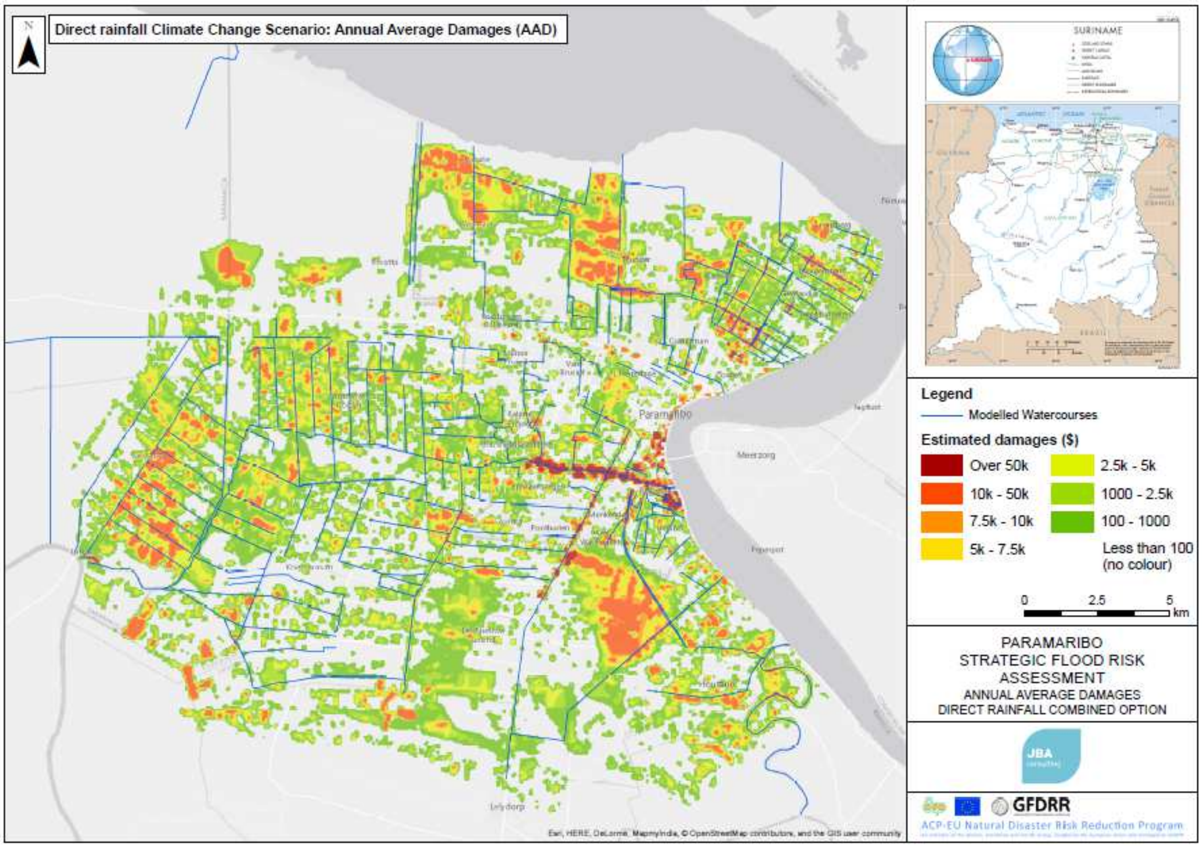


Figure 4-6. Pluvial Annual Average Damages values for the future scenario (2050).

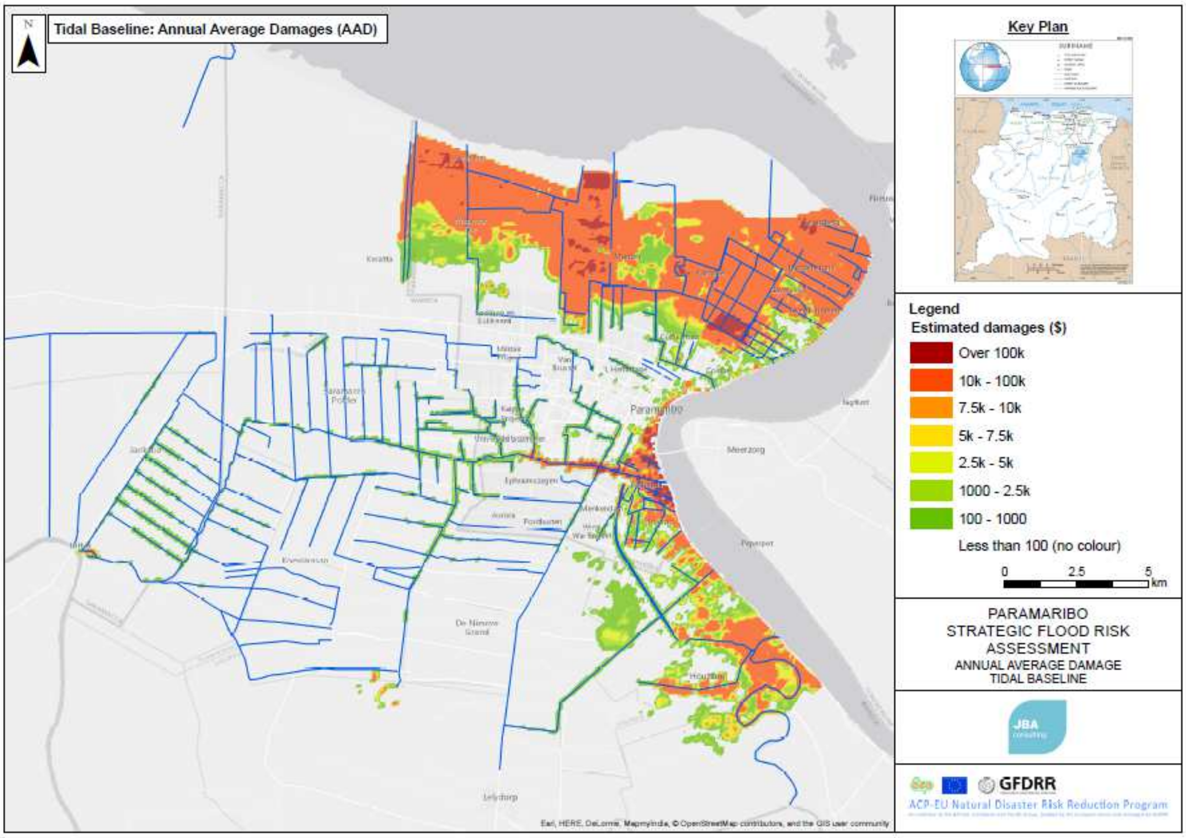


Figure 4-7. Tidal Annual Average Damages values for the current scenario.

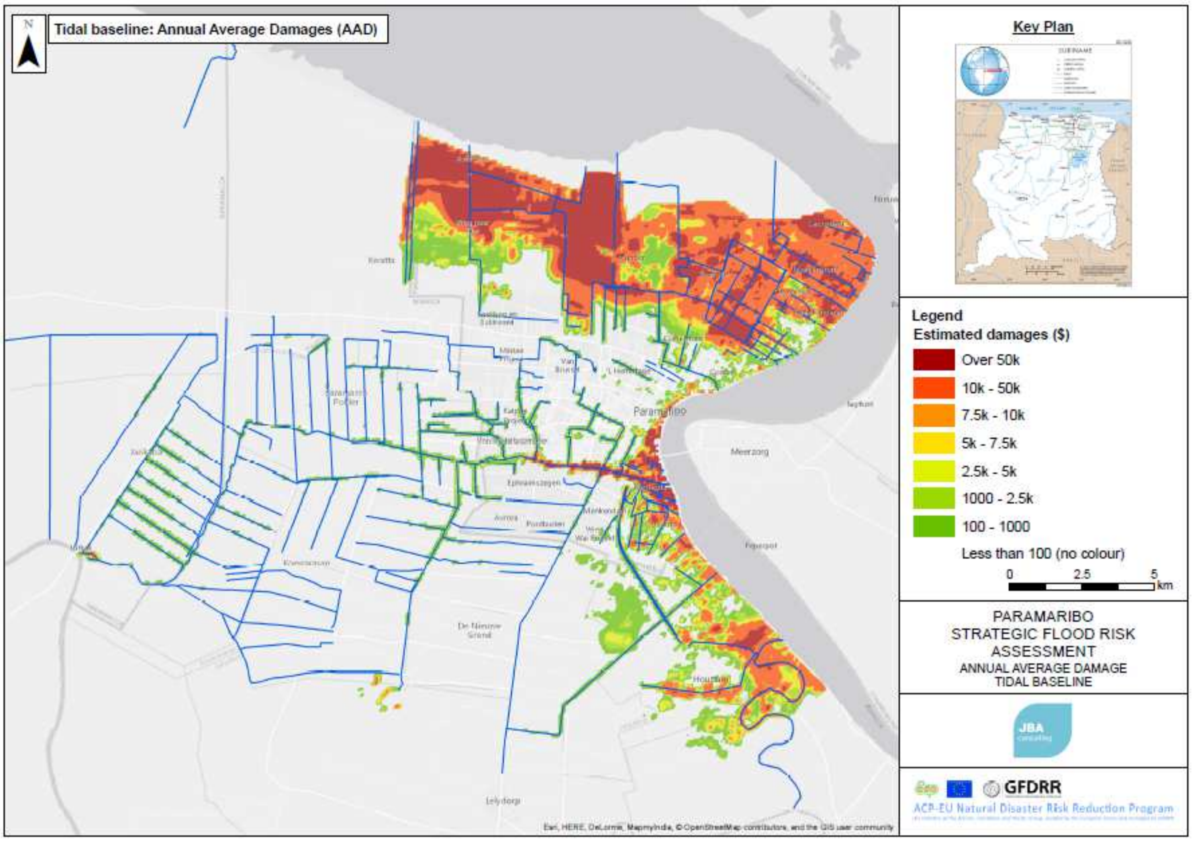


Figure 4-8. Tidal Annual Average Damages values for the year 2050.

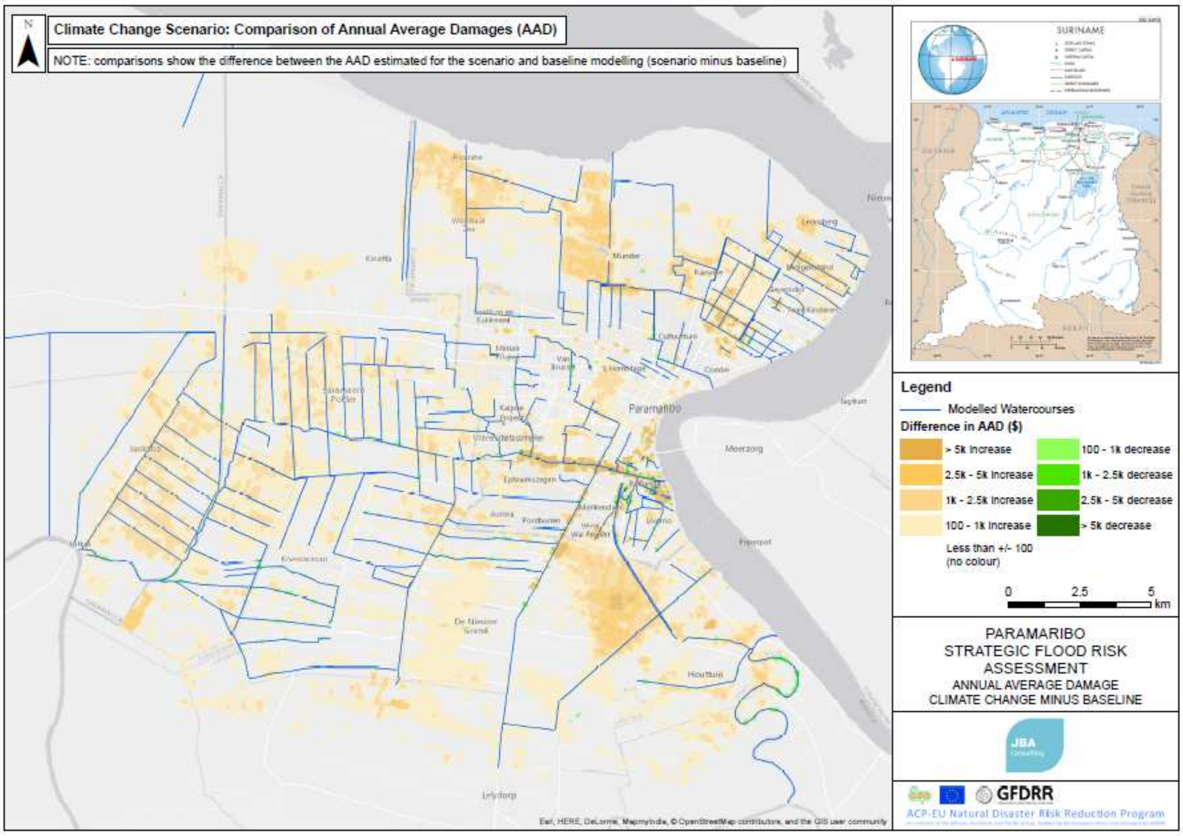


Figure 4-9. Change in pluvial AAD between current baseline and future scenario (2050).

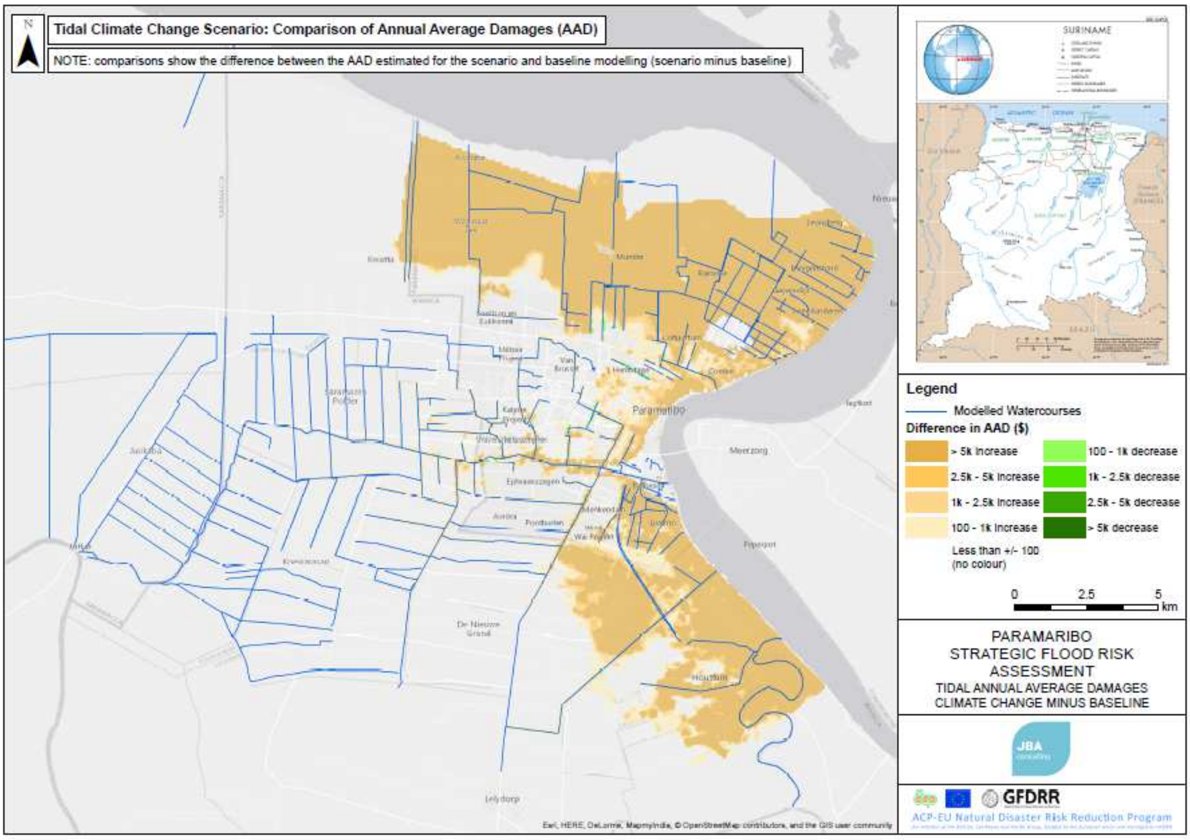


Figure 4-10. Change in tidal AAD between current baseline and future scenario (2050).

4.2.1.1 Key issues affecting flood risk

From the preliminary flood risk assessment carried out through field visits and discussions with local experts, and analysis of the results from the broad scale modelling analysis, the following main drivers of flood risk within the city have been identified:

1. Extreme rainfall: The flood hazard mechanism associated with extreme rainfall is principally attributed to the intensity of the rainfall, the largely clay soils, and the lack of gradient. This means that the heavy rainfall does not have time to fully percolate into the poorly permeable clay soils, and so the only way of preventing flooding is to locally store all the surface water, or remove it as quickly as it arrives.
2. Expansion of the city from its original historic centre on relatively elevated land, into low lying formerly agricultural land throughout the last century: The canal system was designed to support both irrigation during the dry season and land drainage during the rainy season. Drainage of this land has always been poor, but was generally considered acceptable for the intended agricultural purposes.
3. Continued and still poorly controlled development in areas likely to be prone to flooding: Reducing flood hazard in these areas by land raising and increased drainage, simply displaces the problem to somewhere else.
4. Inadequate and poorly maintained drainage system (canals, pumps, sluice gates etc): These have elements which are not optimised to operate as part of an integrated system, i.e. pinch points within the network preventing the whole system from operating efficiently and effectively.
5. Rapid and often uncontrolled run-off from the built environment: Drainage from the roof areas and other impermeable surfaces often discharges directly into the road drainage or roadside canal with no mechanism to attenuate the run-off.
6. Very little slope within the area of Greater Paramaribo: This means that the flow of water relies heavily on a difference in head from one part of the system to another. If the drains and canals are not free flowing, water levels in some part of the city may become unacceptably high before sufficient water movement occurs towards the discharge points.
7. High vulnerability to damaging floods: Low impact flooding occurs relatively frequently, and as a result, people are used to dealing with it and resilience against this frequent flooding is relatively good. Vulnerability to the less frequent but potentially very damaging floods however remains high. There is limited public awareness of the risks associated with severe flooding and how to respond, which is linked to the need for improved preparedness, both at government level (with currently limited civil contingency planning), and at a local level (with currently limited community awareness). This means that response to a major flood event may be difficult to coordinate and actions taken are not as effective in reducing impacts as they could be.
8. Lack of flood warnings: This vulnerability to severe flooding is compounded further by to the lack of an effective flood forecasting and warning capability for the Greater Paramaribo area. The potential for flood damage prevention could be substantial with the introduction of a decision-making data such as flood forecasting and an early warning service.
9. Coastal vulnerability: Mangrove deforestation and the loss of the natural protection against erosion along the coastal strip means that the area is more susceptible to flooding from the sea.

Combined with increased drainage of the land behind the coastal strip, which has the effect of lowering the land surface due to shrinkage of the soil, any coastal flood event that does occur will result in greater inundation, deeper and faster flowing flooding, and more damage.

10. Extreme intense rainfall events: These are likely to become more frequent in the future as a result of climate change.
11. Sea level rise: This will reduce the length of time when free drainage of the low-lying parts of Greater Paramaribo can occur, with greater reliance on rapid discharge at low tide and pumped drainage during high tide.

4.2.1.2 Scale and nature of the risk from flooding

The modelling has confirmed that:

- Economic risk is driven in part by the value of the assets at risk, but more specifically by the relatively high frequency of pluvial flooding, and the potential severity of the coastal flooding.
- The total annual average damage attributed to flooding from a tidal flood event is approximately US$350m.
- The total annual average damage attributed to flooding from a rainfall flood event is approximately US$91m.
- The total combined annual average damage from all sources of flooding is approximately US$441m, potentially rising to over US$800m by 2050 as a result of climate change and sea level rise.

4.2.1.3 Key strategic objective to support the reduction in flood risk

From the flood risk assessment carried out, a set of eight fundamental issues have been identified which need to be addressed in some way in order to reduce flood risk within Greater Paramaribo. Strategic objectives aimed at resolving these issues are:

Pluvial flooding

- Slow the rate of storm water run-off at source (i.e. at individual property, street, or development level) to reduce the impact on the drainage network;
- Increase the available storage within the drainage system (i.e. on canals, or pipework) to minimise flooding whilst the system drains down;
- Increase the rate of discharge through and from the drainage system into the sea.

Tidal flooding

- Improve the coastal resilience to on-going and long-term erosion;
- Reduce the probability and extent of damaging inundation resulting from high tides or wave action along the coast or river wall.

All sources of flooding

- Increase resilience of both people and assets to the impact of flooding;
- Prevent further increase in flood risk due to unplanned and unregulated development;

- Provide flood forecasting and early warning, with an effective response capability.

To determine how these strategic objectives could be met, and the relative priority for the effort and cost of implementation as a solution, they have been conceptualised to form practical representations of the objective. This has been done by interpreting the high-level objectives, which could be implemented in many different ways and at different scales or locations, and developing of a set of potential mitigation options. These options may not represent a specific project, but they reflect the types of schemes, projects or developments that could be implemented, and they capture the likely costs of implementation, and reflect the likely benefits. The options proposed are discussed in more detail in Section 5.

5 Options Analysis

5.1 Mitigation Options Tested

The strategic objectives identified in the previous section have been conceptualised to form a number of technically feasible mitigation options that have been discussed with local specialists and are considered sensible and realistic, and could be implemented. The purpose of this section is to present the analysis carried out for these options and discuss the results. Although at this stage the technical detail of the options has not yet been determined, they represent the types and scales of mitigation measures that could be applied, either locally or more globally, in a way that highlights the areas that would benefit most and the types of interventions that would have greatest effect.

For simplicity, the options have been considered as either structural or non-structural, and generally where structural, can be represented as a physical change within the city wide hydraulic model (e.g. a change made to the DTM, 1-D features, or model parameters). Where the options are non-structural, these have been addressed through other means, such as changing the vulnerability functions to represent an improvement in resilience.

5.1.1.1 Structural mitigation options

A list of the options selected for assessment (in no specific order) and how they were represented within the analysis is given below:

1. Improve road drainage by installing large (600mm) pipes along the roadside instead of the open drains to improve drainage rates, reduce the likelihood of blockage through sedimentation and vegetation growth, and reduce maintenance of the drainage network.
2. Increase the channel capacity of the main canal network throughout the city and surrounding area by approx. 20% volume. This would be achieved through dredging and removal of vegetation, and widening narrow sections where possible.
3. Increase conveyance through culverts under roadways at key locations (identified by the baseline flood hazard modelling). This is achieved within the model by lowering the DTM cell at the road crossing to remove the road as a barrier to flow at that point, allowing more water to continue along the flow path. In practice this would involve replacing the culvert with a larger culvert.
4. Install new and efficient drainage system as part of a potential large new development proposal to the north of the city within the Blauwgrond resort. This would include a number of large drainage canals discharging towards the Atlantic coast and with sluice gates and pumps at the coast. Within the model this is represented by 3 canals of approximately 20m wide at top of bank, and a constant discharge capacity of 10 cumecs .

5. Pumps on all the 5 main river wall sluices (excluding the Saramacca Canal in this instance) to improve drainage at high tide (assume a pumping capacity of 5 cumecs).
6. Double pumping capacity where pumps currently exist (currently baseline model assumes 11 pumping stations along Suriname River, 8 internal pumping stations, and 2 pumping station on the Saramacca River, and 1 on the Atlantic coast).
7. Saramacca Canal improvements – increase conveyance along the entire length of the canal through dredging, removal of vegetation, and re-profiling. Re-alignment will be carried out within the existing boundary of the canal, but may be in the order of several metres where practical, or to remove any pinch points.
8. Increase discharge capacity at eastern end of Saramacca Canal through widened or improvements to the efficiency of the sluice gates, which are currently only partially operational. Tidal locking will still occur, but greater volume of discharge would be achieved at low tide.
9. Increase discharge capacity at eastern end of Saramacca Canal through the installation of large pumps to allow longer period of discharge into the Suriname River (assumed pumping capacity of 20 cumecs for the purpose of the assessment).
10. Install a navigation lock in the middle of the canal (located at the highest elevation point along the canal), allowing higher water levels towards west, and lower levels towards the east prior to flooding events, and greater draw-down possible within the higher priority (for flood discharge) eastern end of the canal.
11. Major drainage improvements to the northwest of Paramaribo through the Kwatta area, reflecting the work that has already been partly done, and apply pumps at the Atlantic coast to allow longer discharge period (assume pumping capacity of 10 Cumecs).

5.1.1.2 Non- structural mitigation options

12. Flood forecasting and early warning – assumes flooding still occurs and will increase as a result of future climate change and sea level rise, but vulnerability can be reduced through effective warning and response. This option cannot be directly modelled within our analysis, however it can be represented within the analysis by changing the amount (and therefore cost) of damages associated with flooding to various land use types and building contents for a given depth of inundation.
13. Land use planning and building codes – assume flood hazard remains largely unchanged (increasing as a result of future climate change and sea level rise), but vulnerability can be reduced in the future, i.e. reflected through the expected increase in urban growth having a zero or beneficial impact on flood risk. This option is reflected in the study through a reduced increase in flood damage that would occur in the future as a result of climate change and urban growth.
14. Storage, on site usage where applicable, and attenuation of surface water run-off from the built environment (sustainable drainage systems), prior to any controlled release to the drainage infrastructure. This approach deals with flood risk at source, by dealing with surface water run-off at a property or development level. Successful implementation of this option requires institutional and statutory processes and procedures for specifying, administrating, and enforcing the necessary technical components of the requirements, and will be closely linked to the ‘Planning and Building Regulations’ strengthening initiatives. This option is reflected in the study through a reduced increase in flood damage that would occur in the future due to climate change and urban growth

5.1.1.3 Results of options modelling

Each of the options described above have been incorporated into the hydraulic model, which has been re-run using the same hydrological inputs and boundary conditions as in the baseline. The resulting flood hazard maps and risk data has been processed and collated in the same way as the baseline, and is presented here in Table 5-1. A direct comparison can then been made between the results for each of the options tested and the baseline, and the resulting reduction in damages are shown in Table 5-2.

Mitigation Option	Area of inundation > 0.3m				Calculated total damages (US$m)				
	10 Year	50 Year	100 Year	200 Year	10 Year	50 Year	100 Year	200 Year	Total AAD
Option 1 – Install sub-surface roadside drainage in heavily urbanised areas	426	448	455	460	267	429	505	584	92
Option 2 - Increase the capacity (volume and conveyance) of the canal network	428	450	456	461	257	411	485	564	88
Option 3 - Increase conveyance through culverts and improve connectivity	431	452	458	462	264	428	506	588	91
Option 4 - Extensive drainage network from Blauwgrond area to the north coast	426	447	453	458	261	418	491	569	89
Option 5 - New pumps on the 5 main river wall sluices	428	450	456	460	234	381	454	506	81
Option 6 - Double pumping capacity at the 22 existing sites.	430	451	457	462	263	422	498	579	90
Option 7 - Saramacca Canal improvements – re-profiling and clearing	428	450	456	461	238	396	471	550	83
Option 8 - Increase discharge capacity through the tidal gates at eastern end of Saramacca Canal	430	452	457	462	250	415	492	575	87
Option 9 - Increase discharge capacity through addition of pumping at eastern end of Saramacca Canal	429	451	457	461	228	392	471	538	80
Option 10 - Navigation lock in the middle of the canal to improve water level management	431	452	458	462	265	428	506	588	91

Mitigation Option	Area of inundation > 0.3m				Calculated total damages (US$m)				
	10 Year	50 Year	100 Year	200 Year	10 Year	50 Year	100 Year	200 Year	Total AAD
Option 11 - Major drainage improvements to the north west of Paramaribo through Kwatta area	428	449	455	460	263	424	501	582	90
Option 12 - Flood forecasting and early warning	431	452	458	462	225	366	434	504	78
Option 13 - Land use planning and building codes	431	452	458	462	259	419	495	575	89
Option 14 - Run-off attenuation to greenfield rates for all new development	431	452	458	462	263	425	502	582	90

Table 5-1. Flood risk under different options.

Mitigation Option	Change in total damages (US$m)				
	10 Year	50 Year	100 Year	200 Year	Change in Total AAD
Option 1 – Install sub-surface roadside drainage in heavily urbanised areas	1.2	-1.2	-2.9	-5.5	0.2
Option 2 - Increase the capacity (volume and conveyance) of the canal network	-9.2	-19.0	-22.8	-25.6	-3.4
Option 3 - Increase conveyance through culverts and improve connectivity	-2.1	-2.0	-1.9	-2.0	-0.6
Option 4 - Extensive drainage network from Blauwgrond area to the north coast	-5.1	-12.4	-17.0	-20.9	-2.1
Option 5 - New pumps on the 5 main river wall sluices	-32.1	-49.3	-54.5	-83.4	-10.9
Option 6 - Double pumping capacity at the 22 existing sites.	-3.3	-8.0	-9.9	-10.7	-1.3
Option 7 - Saramacca Canal improvements – re-profiling and clearing	-28.2	-34.5	-37.6	-40.1	-8.9

Mitigation Option	Change in total damages (US$m)				
	10 Year	50 Year	100 Year	200 Year	Change in Total AAD
Option 8 - Increase discharge capacity through the tidal gates at eastern end of Saramacca Canal	-16.4	-15.5	-16.3	-14.7	-4.9
Option 9 - Increase discharge capacity through addition of pumping at eastern end of Saramacca Canal	-38.3	-38.0	-37.1	-51.7	-11.6
Option 10 - Navigation lock in the middle of the canal to improve water level management	-1.5	-1.6	-1.8	-1.9	-0.5
Option 11 - Major drainage improvements to the north west of Paramaribo through Kwatta area	-3.2	-6.3	-7.4	-7.8	-1.2
Option 12 - Flood forecasting and early warning	-41.2	-63.7	-74.3	-85.5	-13.9
Option 13 - Land use planning and building codes	-14	-22	-26	-30	-5
Option 14 - Run-off attenuation to greenfield rates for all new development	-7	-11	-13	-15	-2

Table 5-2. Comparison of benefits from mitigation options and baseline.

The key metric used for assessing the effectiveness of a particular mitigation option is the Annual Average Damage (AAD). This allows a direct comparison between the baseline and the mitigation option, and incorporates both probability and scale of the damages within a single value. Additionally, the difference between the baseline AAD and the option AAD is referred to as the Annual Average Benefit (AAB) from the proposal. Furthermore, this AAB can be distributed across the lifetime of the proposed mitigation option, and can then be directly compared with the lifetime cost of the mitigation option. This is how the cost-benefit ratio of a particular set of expenditure and actions has been calculated, which can help guide planning decisions and investments. This is discussed in more detail in section 5.2.

5.1.1.4 Cost estimates

High level cost estimates have been made from available regional information for each of the key options tested, with some general assumptions regarding the likely scale and therefore cost of the works and materials. It should be recognised that these costs are simply budgetary, and are to be used to help prioritise the mitigations as part of the cost-benefit analysis. Where cost-benefit ratios are high, reasonable confidence may be attributed to the results. Where the ratio is close to unity, the relative uncertainty may be significantly large and the results need to be treated with caution. A description of data and costings for each option is provided in Table 5-3.

Mitigation option	Costing criteria/metric	Investment cost estimate	Annual operational and maintenance costs
Structural mitigation options			
Option 1: Install sub-surface road drainage by installing large (600mm) drainage pipes along the roadside instead of the open drains to improve drainage rates, reduce the likelihood of blockage through sedimentation and vegetation growth, and reduce maintenance of the drainage network.	Cost per km for laying a 600mm pipe along the edge of a road, and re-surfacing with adequate surface drainage and gully pots, and sediment traps and petrochemical interceptors if necessary.	Cost per km = US$0.5m Total length of road where this is applied is approximately 100km of road Total cost of option is US$**50m**	Additional annual cleaning of sediment from gully traps and routine maintenance = **$100,000 / yr**
Option 2: Increase the capacity of the main canal network throughout the city and surrounding area by approximately 20% volume, which would be achieved through dredging and removal of vegetation, and minor widening where necessary (no requirement for additional land)	Cost per km of roadside canal clearance (assume a average canal width for the city of 10m at top of bank)	Cost per km of canal clearance = US$23,000 Machinery costs = US$250,000 Total length of canal where this is applied is approximately 450km Total cost of option is approximately US$**11m**	Additional annual maintenance to keep this level of canal capacity @$1,000/km (assume whole network cleared once per year) = US$**0.5m**
Option 3: Increase conveyance through culverts under roadways at key locations to improve overall drainage system conveyance.	Average cost per road crossing to replace the existing culvert with a larger one or extra one – assume a standard cost for the culvert for a length of say 10m, but including costs for the works for digging up the road, road closure and re-instating road surface	Cost per road crossing is US$50,000 Total number of road crossings where this would be applied is approximately 480 along 225km of road. Total cost of option is US$**9.6m**	Additional annual maintenance to keep channels clear will be approximately = US$**80,000**

Mitigation option	Costing criteria/metric	Investment cost estimate	Annual operational and maintenance costs
Structural mitigation options			
Option 4: Install new canal network in a potential large new development proposal to the north of the city within the Blauwgrond resort, with large drainage capacity discharging northwards towards the Atlantic coast, with sluice gates and pumps at the coast to ensure adequate drainage (assume pumping capacity of 10 cumecs required).	Cost per km to construct 3 new large canals (assume 20m wide at top of bank, 4m deep), and cost for a single pumping station with 10 cumec pump at the coast and a tidal gate.	Cost per km of canal = US$140,000 Total length of canal where this is applied is approximately 3 x 3km = 9km Cost of canal = US$1.26m Cost of single 10 cumec pumping station = US$7.0m Cost of single tidal gate = US$0.2m Total cost of option is approximately = US$**8.5m**	Channel annual maintenance @ US$1,000/km = US$9,000 Tidal gate annual maintenance = US$25,600 Annual pump maintenance (including estimate for power) = US$194,000 Total annual costs = US$**230k**
Option 5: Pumps on the 5 main river wall sluices to improve drainage at high tide (assume a pumping capacity of 5 cumecs at each).	Cost per site to add a new pumping station where currently only a sluice gate – include cost of pump and pipework, peripheral control and power equipment, and housing.	Average cost per site = US$3m Number of locations with pumping added = 5 Total cost of option = US$**15m**	Additional annual pump maintenance and running costs = US$**100,000**
Option 6: Double pumping capacity at the 22 sites where pumps currently exist.	Cost per site to add additional pumps to existing station (includes cost of pump and pipework, peripheral control and power equipment). Pumps range in size from 0.2 cumecs up around 5 cumecs. The costs for pumping stations are none-linear, so for the purposes of this study they have been grouped into general size categories.	Cost for 0.2 to 0.5 cumec pumps = US$0.35m, Number of pumps = 4 Cost for 0.5 to 1.0 cumec pumps = US$0.71m, Number of pumps = 6 Cost for 1.0 to 2.5 cumec pumps = US$1.4m, Number of pumps = 5 Cost for 2.5 to 5 cumec pumps = US$2.3m, Number of pumps = 5 Cost for pumps > 5 cumec = US$5.0m, Number of pumps = 2 Total cost of option = US$**34m**	Additional annual pump maintenance and running costs = US$**1.1m**

Mitigation option	Costing criteria/metric	Investment cost estimate	Annual operational and maintenance costs
Structural mitigation options			
Option 7: Saramacca Canal improvements – increase conveyance along the canal through dredging, re-profiling and removal of vegetation.	Cost per km for dredging the Saramacca Canal and removal of silt to significantly deepen and widen (up to 5 or 10m where necessary and land availability allows – no additional land acquisition required).	Cost per km of dredging and excavation on the Saramacca Canal = US$1m Total length of canal = 25km Total cost of project = US$**25m**	Additional annual maintenance (assume 10% of initial dredging) = US$**2.5m**
Option 8: Increase discharge capacity at eastern end of Saramacca Canal by refurbishing and widened (or greater number) of tidal gates (currently 5, but not all are operational). Tidal locking will still occur, but discharge during low tide will be greater.	Cost to re-furbish and widening or improving existing tidal sluice gates to provide greater discharge capability.	Estimated cost to refurbish and improve existing gates @ US$2m each = US$10m Total cost of option = US$**10m**	Additional operation and annual maintenance costs = US$**40,000**
Option 9: Increase discharge capacity at eastern end of Saramacca Canal by add pumping to allow longer period of discharge. Assume a pumping capacity of 20 cumecs that will allow discharge throughout the tidal cycle.	Cost to install large capacity pumps, including cost of pump and pipework, peripheral control and power equipment, and housing and civils works.	Cost of 20 cumec pumping station = US$25m Total cost of option = US$**25m**	Additional operation and annual maintenance costs = US$**380,000**
Option 10: Navigation lock in the middle of the canal (located approximately at the watershed), allow higher water levels towards west, and lower levels towards the east prior to flooding events (assuming the canal is 2m lower at the start of an event).	Cost to build a new navigation lock in the Saramacca Canal – including dewatering works, excavation, installation, lock gates, equipment, concrete channel, etc and civils works.	Cost of 2 pairs of lock gates @ US$1.2m per pair = US$2.4m Cost of lock structure and civils works = US$5m Total cost of option = US$**7.4m**	Additional operation and annual maintenance = US$**30,000**

Mitigation option	Costing criteria/metric	Investment cost estimate	Annual operational and maintenance costs
Structural mitigation options			
Option 11: Major drainage improvements to the north west of Paramaribo through Kwatta area by improving and extending the existing canal network to significantly increase drainage capacity to the north towards the Atlantic coast. Pumps would be required to allow longer discharge period (assume total pumping capacity of 10 cumecs).	Cost per km of canal, tidal gates (3 x 4m wide sluice gates), and a 10 cumec pumping station	Cost per km of canal = US$140k 9km of canal required therefore cost = US$1.26m Cost for single sluice gate = US$170k Cost for 3 sluice gates = US$0.58m Cost for single 10 cumec pumping station = US$7m Total cost for option = US$**9.2m**	Channel annual maintenance @ US$1,000/km = US$9,000 Tidal gates annual maintenance = US$25,000 Annual pump maintenance (including estimate for power) = US$194,000 Total annual costs = US$**230,000**
	TOTAL	US$ **204.7m**	US$ **5.29m/yr**

Mitigation option	Costing criteria/metric	Investment cost estimate	Annual operational and maintenance costs
Non-structural mitigation options			
Option 12: Flood forecasting and early warning system development and implementation – covering pluvial and tidal flood hazard	Cost to develop and implement a flood forecasting system for surface water flooding, and tidal flooding for the Greater Paramaribo area.	System hardware, including computers and peripherals = US$50k Data interface (Hydro-met, weather radar and weather forecasts) = US$50k Software development and implementation = US$50k Rainfall run-off and tidal model development and integration = US$200k System configuration with alert thresholds and warning management = US$75k Procedures development and institutional process integration = US$75k Total option cost = US$**0.5m**	Cost for annual running, upgrades and improvements = US$**200,000**
Option 13: Land use planning and building codes to help manage flood risk by reducing the impact of flooding. This assumes that flooding still occurs, and indeed is likely to increase with sea level rise and climate change, but flood resilience can be increased through better zoning, ensuring vulnerable development does not take place in flood prone areas, and appropriate design of all development to reduce flood risk.	This has been costed as an initial cost of implementing a legal framework and set of policies for land use planning, followed by an annual cost of implementation and regulation of the policies.	One-off cost to establish the legal framework, and planning laws and policies, and setting up the procedures and processes = US$**0.5m**	Annual cost of running the land use planning and regulation team = US$**300,000**

Mitigation option	Costing criteria/metric	Investment cost estimate	Annual operational and maintenance costs
Non-structural mitigation options			
Option 14: Storage and attenuation of surface water discharge from all new developments to reflect the natural rates prior to development.	Cost of additional works to install attenuation ponds or strips with an average surface area of 100m^2 with run-off capture canals – perhaps 100m long 2m wide, and four for each attenuation pond. These types of features will be installed as part of a new development (costs carried by the developer), to meet defined standards.	One-off cost to establish the legal framework, principles and technical requirement is estimated at = US$**0.3**m	Cost to developer during scheme development is estimated to be approximately. US$3,500 per scheme, so with an annual cost of approximately US$350,000 Additional annual costs to administer the scheme = US$200k Total annual costs = US$**0.55m**
	TOTAL	US$**1.3m**	US$ 1.**05m/yr**

Total Structural & Non-structural Mitigation Options			
	TOTAL	US$ **206m**	US$ **6.34/yr**

Table 5-3. Options definition and cost estimation.

The costs attributed to the various options have been derived using a range of sources, but with a large body of evidence coming from UK studies and cost databases. The values used from these sources have however been checked against local data where possible to ensure sensible estimates. In many cases the rates and costs are globally set by the equipment and service suppliers likely to be used.

5.2 Analysis of options

5.2.1.1 Benefit-cost analysis

The approach used here follows the guidance set out in the Caribbean Handbook on Risk Information Management (CHARIM) handbook, and is summarised in Figure 5-1.

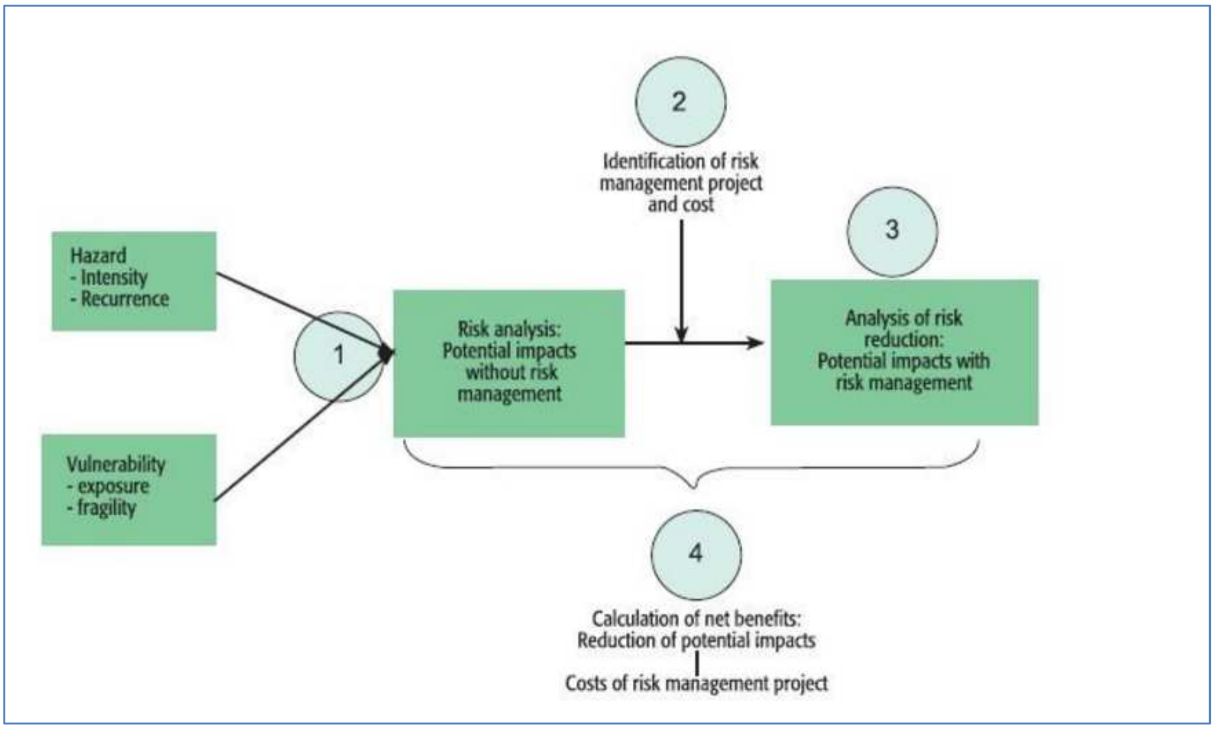


Figure 5-1 Overview of benefit-cost analysis for disaster risk reduction (Source: CHARIM Risk Reduction Planning 6.1).

The study has used a period of 15 years for the analysis as a pragmatic time-frame to avoid the uncertainty in both the economic analysis and changing risk profiles in the future. Although a relatively short time period, this covers the minimum range of expected asset life cycles, although clearly many of the larger engineering works will be serviceable for considerably longer.

The analysis compares the calculated AAD under each of the mitigation options against the baseline AAD, resulting in an annual average benefit (AAB) for each option. In order to compare this value against the cost of the various mitigation options, all the values must be treated in the same way. By applying the costs and benefits across a nominal 15 year period with an appropriate discounted rate to bring both to a present value, they can then be directly compared, and a benefit-cost ratio calculated. The discount rate represents a forecast of the likely inflation rate within a country over a long period (i.e. 15 years in this case), and should be carefully selected as it can have a material impact on the results. In line with common and current global practice, the discount rate selected for this analysis was 3.5%, however a value of 7% was also used as a sensitivity test.

Table 5-4 shows benefit-cost ratios for each option, and presents results using 3.5% and 7% discount rates.

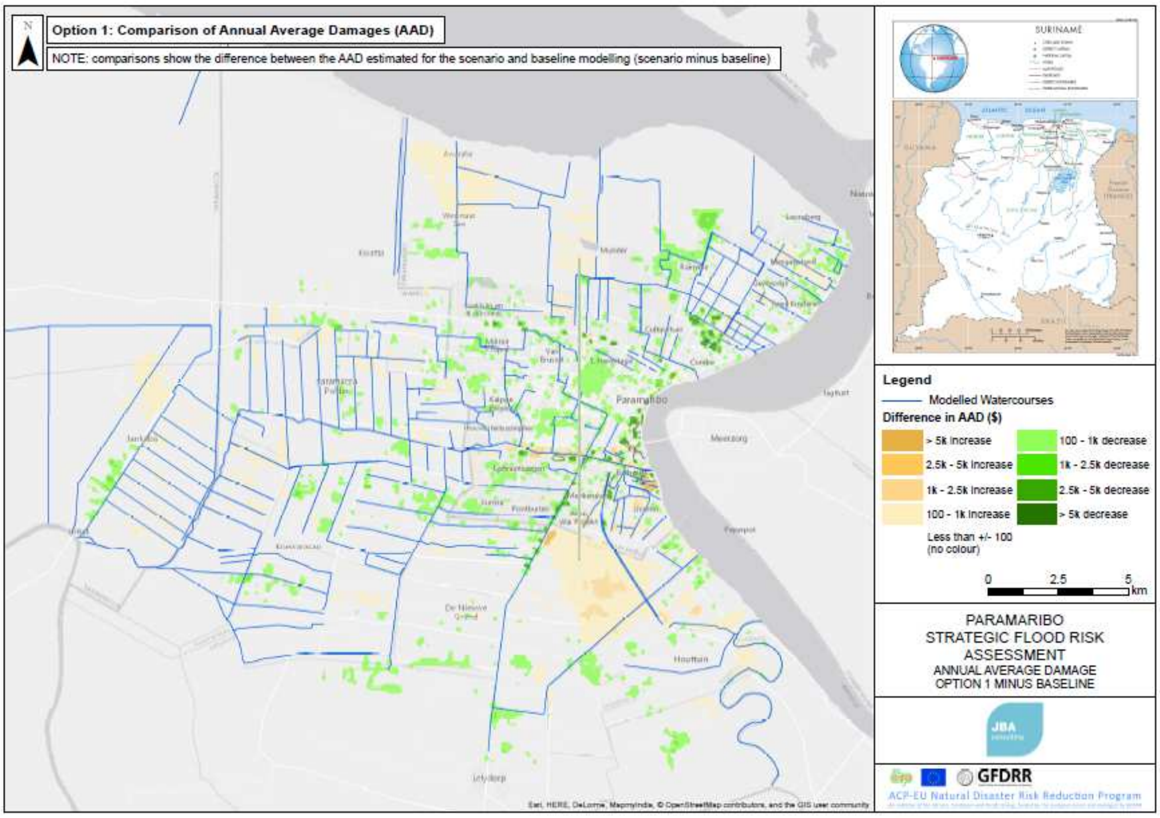
Option No.	Mitigation Option	Benefit-cost ratio (3.5% annual discount)	Benefit-cost ratio (7% annual discount)
1	Install sub-surface roadside drainage in heavily urbanised areas	-0.5	-0.4
2	Increase the capacity (volume and conveyance) of the canal network	4.1	6.0
B3	Increase conveyance through culverts and improve connectivity	1.1	1.6

Option No.	Mitigation Option	Benefit-cost ratio (3.5% annual discount)	Benefit-cost ratio (7% annual discount)
4	Extensive drainage network from Blauwgrond area to the north coast	4.1	5.7
5	New pumps on the 5 main river wall sluices	14.1	19.0
6	Double pumping capacity at the 22 existing sites.	0.6	0.8
7	Saramacca Canal improvements – increase conveyance through dredging, re-profiling and removal of vegetation.	3.3	5.0
8	Increase discharge capacity through the tidal gates at eastern end of Saramacca Canal	9.8	13.1
9	Increase discharge capacity through addition of pumping at eastern end of Saramacca Canal	8.2	11.3
10	Navigation lock in the middle of the canal to improve water level management	1.4	1.9
11	Major drainage improvements to the north west of Paramaribo through Kwatta area	2.1	3.0
12	Flood forecasting and early warning	97.7	157.4
13	Land use planning and building codes	11.4	18.6
14	Run-off attenuation to greenfield rates for all new development	6.8	11.3

Table 5-4. Sensitivity of discount rate used for the benefit/cost ratio.

5.2.1.2 Investment planning

A more in-depth consideration of the modelled options and the results has been carried out in order to prepare a priorities plan for addressing flood risk in Greater Paramaribo. The following pro-forma have been used to collate the key decision data, and summarise the proposed options and actions.

<table>
<tr><td colspan="6">Mitigation Option 1.</td></tr>
<tr><td>Mitigation option assessed:</td><td colspan="5">Install sub-surface roadside drainage in selected heavily urbanised areas by installing covered roadside drains consisting of 600mm culverts and appropriate gully pots at regular intervals to capture the run-off. This was applied to approximately 100km of roadway for the analysis.</td></tr>
<tr><td colspan="6">
</td></tr>
<tr><td>Estimated capital investment:</td><td>$50m</td><td>Economic benefit (Reduction in AAD):</td><td>$-0.2m</td><td>Benefit:Cost ratio (Reduction in AAD:Total capital and revenue costs discounted at 3.5% over 15 years):</td><td>N/A</td></tr>
<tr><td>Overall benefits:</td><td colspan="5">

- Slight reduction in local flooding across a relatively wide area within the city, with some small pockets of greater benefit.
- Reduction in space required by the drainage system.
- Less prone to being used for waste disposal.

</td></tr>
<tr><td>Overall disadvantages:</td><td colspan="5">

- Increase in flooding in certain suburban parts of the city – particularly a small area to the north-eastern area where the damage values are high, and areas around the Saramacca Canal, resulting in an overall increase in estimated annual average damages of 0.2m (essentially zero given the levels of uncertainty within the data).
- Negative (or zero) benefit-cost ratio
- Can be prone to sedimentation and blockage in low head situations
- Loss of aquatic habitat, and reduction in bio-retention and biogenic water quality improvement (i.e. road surface run-off quality can be

</td></tr>
</table>

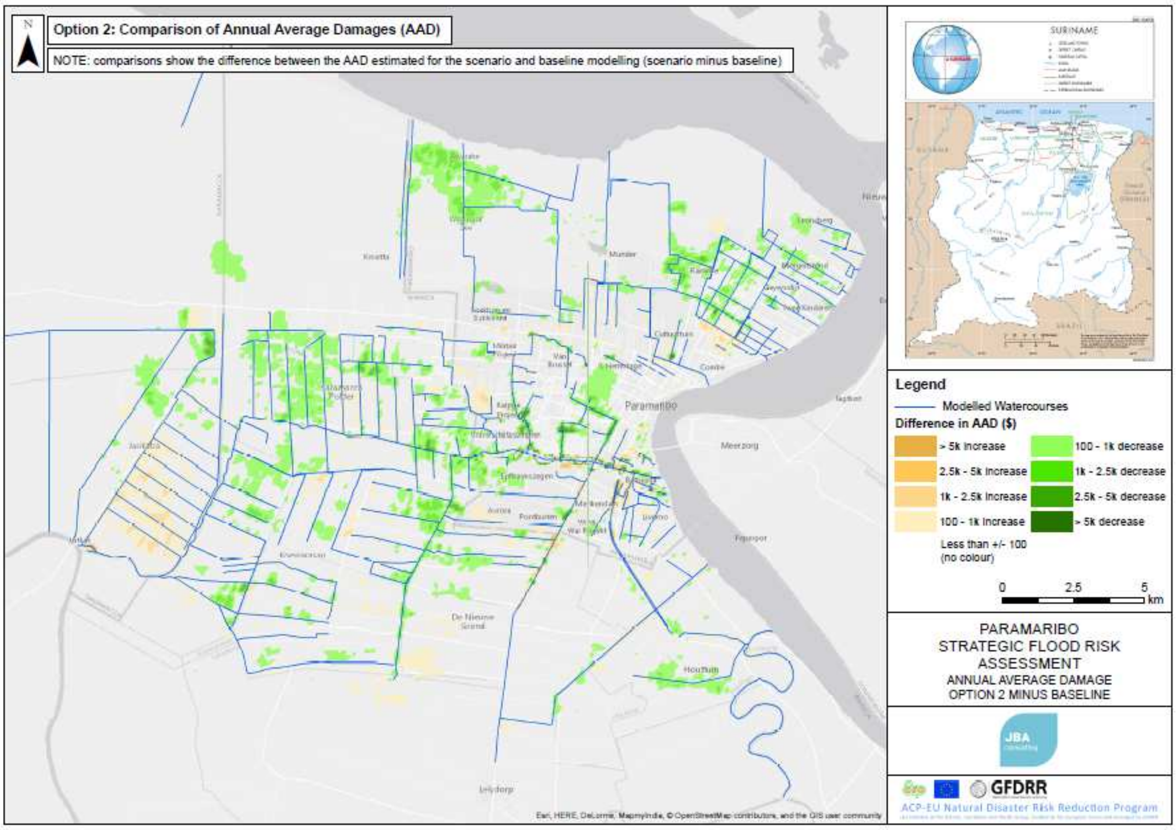
	significantly improved by discharging through open vegetated drainage)
Summary of opportunity:	This option can improve drainage from certain flood prone districts, but with the potential for increasing flooding elsewhere. It could however be incorporated where space is a limitation, however, the benefit-cost ratio is potentially very low, and needs to be looked at carefully for retrofitting this approach to existing locations. It could therefore only be considered where a clear benefit can be demonstrated in new developments.
Refined proposal and cost revision (if applicable):	Covered drainage should only be considered for retro-fitting where there is a clear need, such as heavily urbanised areas where the existing drainage system is under capacity but space for open drainage is not practical. Any negative impact elsewhere must be avoided.

Recommendations and actions.

The benefits of this option have not been demonstrated by the study, and the approach has been shown to cause potential problems. This option is not recommended for widespread implementation, but if required, the following actions area suggested:

- Define locations where the approach is clearly required due to lack of space or other justifiable reasons.
- Pilot the scheme in small area or areas, ensuring increased drainage rate in one location does not cause additional flood risk elsewhere.
- Monitor closely for local increases in flooding, increased maintenance requirement to prevent or clear blockages, and reduction in water quality due to direct road run-off.

This is considered a **low** priority.

<table>
<tr><td colspan="6">Mitigation Option 2.</td></tr>
<tr><td>Mitigation option assessed:</td><td colspan="5">Increase the capacity of the main canal network throughout the city and surrounding area by up to 20% volume, which would be achieved through dredging and removal of vegetation, and minor widening where necessary (no requirement for additional land).</td></tr>
<tr><td colspan="6">
</td></tr>
<tr><td>Estimated capital investment:</td><td>$11m</td><td>Economic benefit (Reduction in AAD):</td><td>$3.4m</td><td>Benefit:Cost ratio (Reduction in AAD:Total capital and revenue costs discounted at 3.5% over 15 years) :</td><td>4 : 1</td></tr>
<tr><td>Overall benefits:</td><td colspan="5">
This option results in more effective drainage and increased capacity.
The increased space for surface water storage within the drainage network will reduce the occurrence of flooding from the smaller more frequent and more intense rainfall events, and reduce the scale of impact from the larger less frequent events.
Improved conveyance will improve drainage rates resulting in a reduction in flooding depth and extent across large areas of greater Paramaribo under all return period scenarios, but more specifically the longer duration less intense events.
Can be targeted to key flood prone areas, however, must be considered as a system and not just individual canal improvement works
The economic benefit through reduction in risk is estimated to be approximately US$3.3m.
</td></tr>
<tr><td>Overall</td><td colspan="5">Increased cost of maintenance</td></tr>
</table>

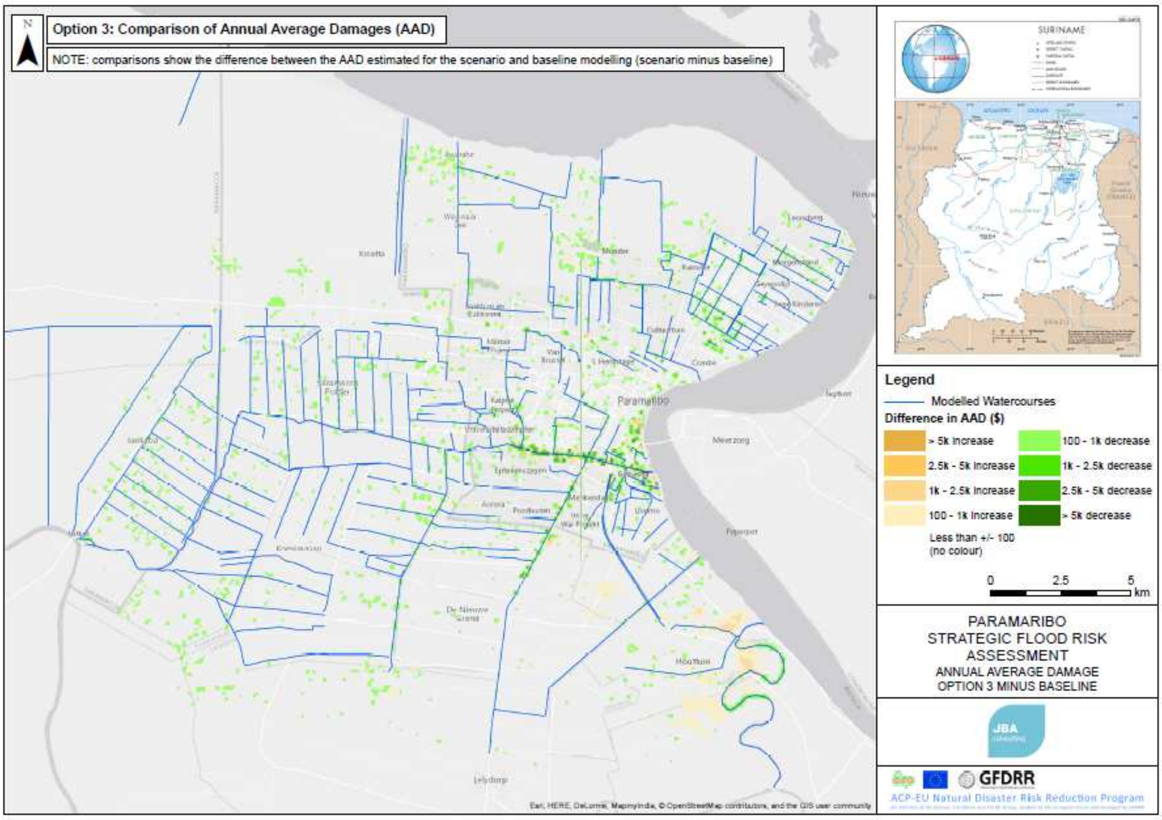
disadvantages:	• Possible reduction in aquatic habitat through removal of vegetation and silt, and increased disturbance due to higher frequency of maintenance.
Summary of opportunity:	The extensive network consisting of several hundred kilometres of canals provides the main drainage system for the entire area. This option takes advantage of the existing infrastructure to improve surface water drainage from the city and surrounding areas through a targeted and strategic widening and dredging programme of work.
Refined proposal and cost revision (if applicable):	The analysis was carried out for the entire main network of 450km of canal, with a cost of approximately US$11m. It is proposed that a targeted project would focus on key canals in main areas of risk (see baseline AAD map in Figure 4-5). The overall capital cost would be reduced to approximately US$6m.

Recommendations and actions.

The benefits of this option have been clearly demonstrated by the study, and the approach has been shown to provide a clear reduction in flood risk. The following actions area proposed:

- Carry out more detailed analysis to define the most effective improvements to individual or groups of canals, assess the scale of the requirement, and develop a detailed scope of works.
- Carry out a more detailed costing exercise once scope and scale of works has been more clearly defined.
- Carry out an environmental impact assessment to identify mitigation solutions for any impact on natural habitats and amenity value (e.g. fishing).
- Building on this investment plan, prepare an economic business case and costed proposal for further consideration and prioritisation.

This is considered a **high** priority.

<table>
<tr><td colspan="6">Mitigation Option 3.</td></tr>
<tr><td>Mitigation option assessed:</td><td colspan="5">Increase conveyance through culverts and improve connectivity along canals intersected by road crossings.</td></tr>
<tr><td colspan="6">
</td></tr>
<tr><td>Estimated capital investment:</td><td>$10m</td><td>Economic benefit (Reduction in AAD):</td><td>$0.6m</td><td>Benefit:Cost ratio (Reduction in AAD:Total capital and revenue costs discounted at 3.5% over 15 years):</td><td>1.1 : 1</td></tr>
<tr><td>Overall benefits:</td><td colspan="5">Improved conveyance through culverts at road crossings improve the efficiency of the drainage network, and reducing the risk of localised flooding due to bottlenecks in the canal system.
The option increases the overall discharge rates, although only to a minor extent, as although local up-stream water levels may be raised by under-capacity culverts, the increase in water level will tend to force water through at a higher velocity and therefore maintain the overall flow rates.
The economic benefit through reduction in risk is relatively small, and is estimated at US$0.6 AAD.</td></tr>
<tr><td>Overall disadvantages:</td><td colspan="5">To implement this option at a scale that would have any wide scale benefit, would result in major upheaval and disruption to the road transport network through the city.
There is a relatively high cost, with a low benefit-cost ratio.
The benefits are largely localised to where the bottleneck is relived.
There is a slight possibility that reducing water levels at one location</td></tr>
</table>

	may increase water levels elsewhere and result in a greater damage overall.
Summary of opportunity:	Many of the culverts connecting canals under road crossings currently constrain free flow of water along the length of the canal. This may be because they are partially blocked with sediment or debris, or are undersized. Testing of this option has investigated the benefits of opening crossings at more frequent intervals, as well as increasing the size of the openings, across a wide area within the city. This option is therefore an over-estimation of what would be implemented in practice, however it is shown to provide very little overall benefit.
Refined proposal and cost revision (if applicable):	Although there are a significant number of undersized culverts within the drainage network, the benefits of carrying out a major overhaul of the culverts at road crossings throughout the city will be small, and the economic as well as social costs will be high. It is likely that simply increasing maintenance and ensuring culverts are kept free of debris and sediment will deliver equivalent benefits, but at minimal capital cost.

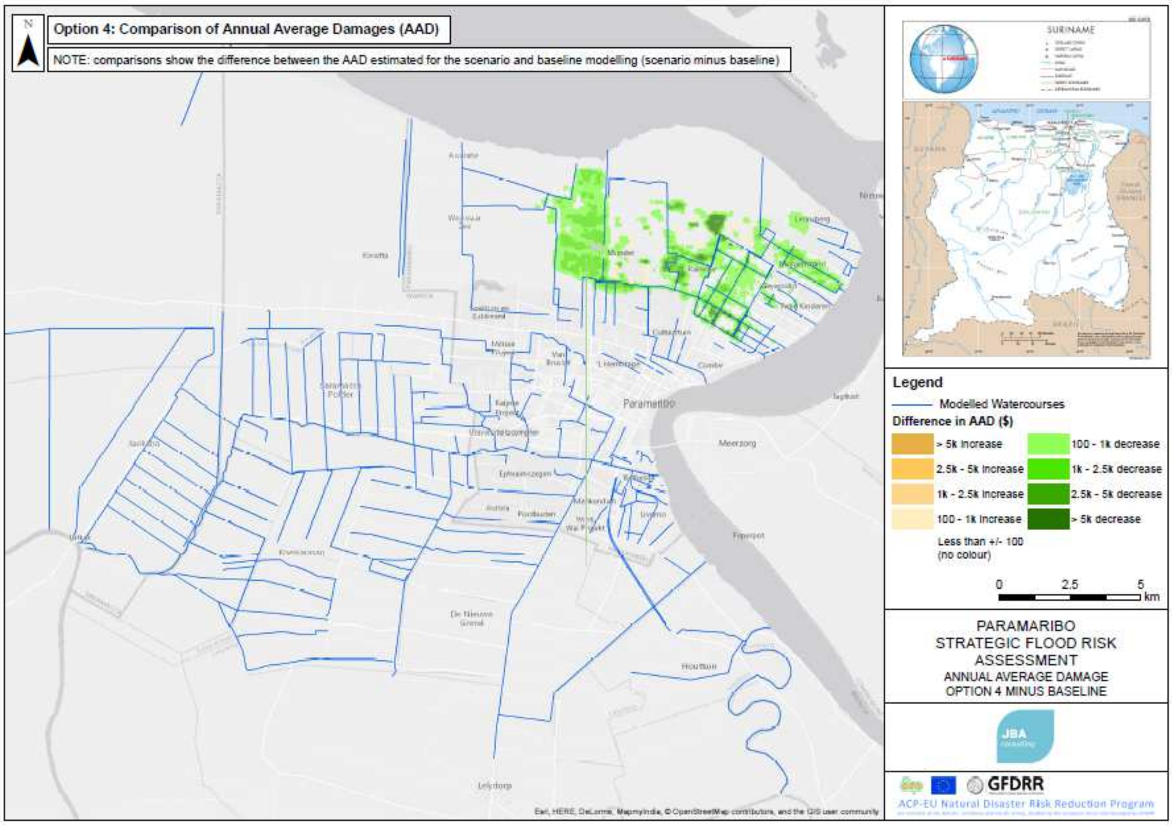
Recommendations and actions.

The benefits of this option are marginal, and the approach would have high costs and result in significant disruption. This option is not recommended for widespread implementation, and the issue of reduced conveyance due to blockages could be addressed in many locations through removal of debris and silt. The following actions area suggested:

- Carry out a survey to assess the full extent of culverts with reduced capacity due to debris and sediment.
- If required, carry out a programme of culvert clearance, integrating the work into a more general canal improvement initiative if possible, to achieve some efficiencies and economies of scale.

This is considered a **low** priority.

Mitigation Option 4.	
Mitigation option assessed:	Install new and efficient drainage system as part of a potential large new development proposal to the north of the city within the Blauwgrond resort. This would include a number of large drainage canals discharging towards the Atlantic coast and with sluice gates and pumps at the coast. Within the model this is represented by 3 canals of approximately 20m wide at top of bank, and a constant discharge capacity of 10 cumecs.

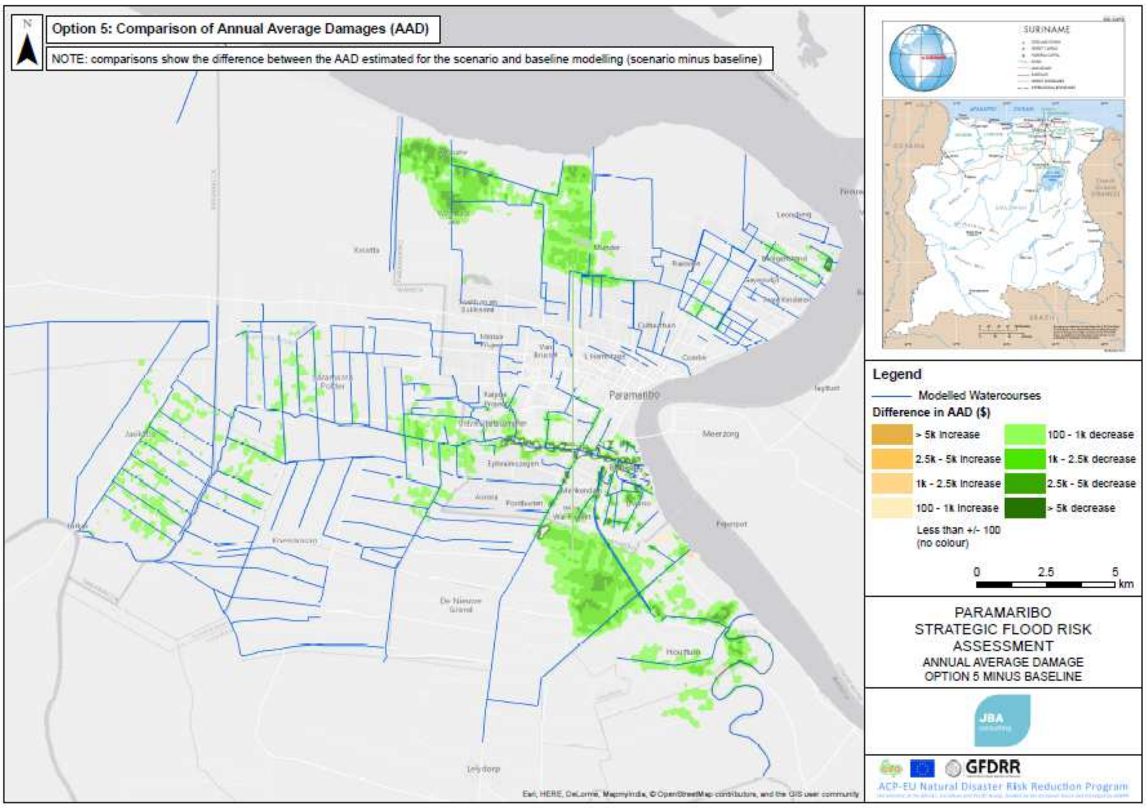


Estimated capital investment:	$8m	Economic benefit (Reduction in AAD):	$2.1m	Benefit:Cost ratio (Reduction in AAD:Total capital and revenue costs discounted at 3.5% over 15 years):	4 : 1

Overall benefits:	• The local improvement in drainage provides a clear benefit within the north-eastern area of the city. • Whilst there is increased discharge from the area where it is applied, it takes some of the pressure from the drainage network that currently drains eastwards towards the Suriname River, and southwards towards the Saramacca Canal, thus reducing pluvial flood risk more widely within the northern areas of the city. • The overall economic benefit through reduction in risk from this option is estimated to be US$2.1 AAD.
Overall disadvantages:	• Additional drainage to the north is shown to be effective locally, however, the associated coastal study discusse in Part 2 of this report has highlighted the unsustainability of establishing hard infrastructure

	for drainage in this area. • The proposed development is likely to result in a significantly increased risk from coastal flooding by placing large numbers of residential properties, and therefore people, in an area of increasing coastal flood hazard. • The drainage canals will pass through important areas of potential mangrove forest towards the north coast, and will significantly change the drainage patterns of fresh water within the area resulting in damage to the fragile ecosystems. • The pumping stations and sluice gates required to ensure drainage of the area are maintained during high tides will be located within an unstable muddy coastal zone, vulnerable to erosion and coastal flooding, and are unlikely to be sustainable in the long term. • Improved short term drainage within this area would increase the likelihood of further urban intensification and would place greater numbers of people at risk from coastal flooding. • Although in part, the drainage will be funded by the new development, the increase in drainage capacity required to provide additional benefit will be significant with high economic costs as well as potentially very high social and environmental impacts from a sustainability standpoint.
Summary of opportunity:	If a large urban development was permitted within the Blauwgrond resort, this Option can improve drainage from flood prone districts, to the northern and central parts of the city but with the potential for increasing flooding elsewhere
Refined proposal and cost revision (if applicable):	This option is not recommended, due to the overall negative impact that drainage to the north would have on the long-term sustainability of the vulnerable coastal zone. If urban development did occur in this area, it is recommended that attenuation and storage of surface water with the creation of fresh, or brackish water wetlands should be investigated as a more sustainable option.
Recommendations and actions. Although the short-term benefits in terms of reduction in pluvial flood risk has been shown, the negative social and environmental impacts of this approach, and the long-term unsustainability are considered to outweigh short-term benefits. No actions are recommended. This option is **not recommended.**	

Mitigation Option 5.					
Mitigation option assessed:	Installation of pumps on the 5 main river wall sluices that do not currently have any form of pumping capacity to improve drainage at high tide. For assessment purposes, an assumed pumping capacity of 5 cumecs was used for each. This was applied at 4 locations along the Suriname River front (i.e. 2 to the north of the Saramacca Canal, and 2 to the south), and a single pump at a location on the north coast.				



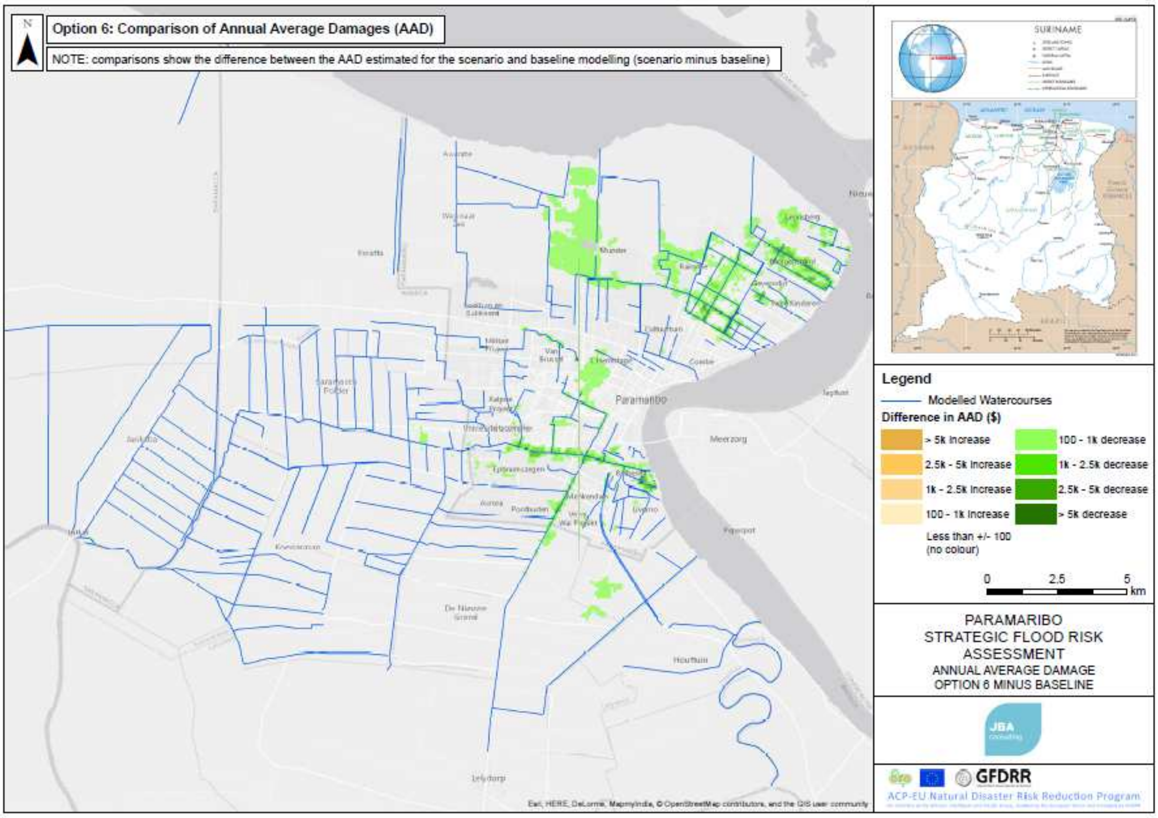
Estimated capital investment:	$15m	Economic benefit (Reduction in AAD):	$10.9m	Benefit:Cost ratio (Reduction in AAD:Total capital and revenue costs discounted at 3.5% over 15 years):	14 : 1
Overall benefits:	• This option increased overall discharge volumes into the Suriname River and to the north into the Atlantic by continuing to allow discharge during periods of high tide when normal gravity discharge through sluice gates would cease. • The areas benefiting most in reduction in the occurrence, depth and extent of flooding is within the northern and southern, more rural parts of the city, however the benefit is significant. The two additional pumps applied at the northern Suriname River front are less beneficial as the drainage network leading to these pumps is already discharging close to the optimum. It is likely that to be more effective here, would require improvements to the canal network draining the area. • Additional pumping at these locations will also have the effect of				

	reducing the duration of flooding, where it does occur, particularly when associated with short duration high intensity storms, due to the ability to maintain discharge rates during high tides. • Although potentially quite costly, the benefit-cost ratio is reasonably good, and the installation could be relatively straightforward, as much of the land at the sluice gates is already owned by the GoS, and some of the pumping equipment has already been procured. • The overall economic benefit through reduction in risk from this option is estimated to be US$10.9m AAD.
Overall disadvantages:	• If pumping to the north is included within the proposal, the improvement in drainage is likely to result in an overall flood risk (or long-term commitment to potentially unsustainable flood defences) by encouraging accelerated urban development in areas prone to coastal flood hazard, placing greater numbers of people at peril. • The drainage canals will pass through important areas of potential mangrove forest towards the north coast, and will significantly change the drainage patterns of fresh water within the area resulting in damage to the fragile ecosystems • The pumping stations and sluice gates required to ensure drainage of the area is maintained during high tides will be located within an unstable muddy coastal zone, vulnerable to erosion and coastal flooding, and are unlikely to be sustainable in the long term. The associated coastal study discussed in Part 2 of this report has highlighted the unsustainability of establishing hard infrastructure for drainage in this area. • Although in part, the drainage will be funded by the new development, the increase in drainage capacity required to provide additional benefit will be significant with high economic costs as well as potentially very high social and environmental impacts from a sustainability standpoint. Increase in maintenance and running costs. • Some additional land take may be required. • Not equally beneficial across the whole area.
Summary of opportunity:	The opportunity is to improve drainage from flood prone districts within the parts of the drainage network that suffer from tide locking, to be achieved using existing discharge locations and equipment that has in part, already been purchased (5 pumps and associated equipment). With a relatively small expenditure, this opportunity can provide a quick win in terms of reduced flood risk from pluvial flooding, a benefit that can be increased further by improving the capability of the drainage network that feeds the discharge points.
Refined proposal and cost revision (if applicable):	The proposed mitigation option has changed slightly from the assessment scenario in that it does not include additional pumping along the northern coastal area. It does include installation of 4 pumps at locations along the Suriname River with some further investigation carried out to prioritise the locations, and determine if there are any limitations within the canal network that would be feeding the pumping stations. It is possible that the remaining pump could be used to increase pumping capacity at a location with existing pumps installed.
Recommendations and actions. The benefits of this option have been clearly demonstrated by the study, however, selective implementation would maximise the overall reduction in flood risk, and avoid negative impacts.	

The following actions area proposed:

- Carry out a more detailed technical feasibility study, and if appropriate, prepare more detailed scheme designs to allow formal costing and project assessment.
- Carry out an Environmental and Social Impact Assessment for the selected locations and surrounding areas.
- Building on this investment plan, prepare an economic business case and costed proposal for further consideration and prioritisation.

This is considered a **high** priority**.**

<table>
<tr><td colspan="6">Mitigation Option 6.</td></tr>
<tr><td>Mitigation option assessed:</td><td colspan="5">Increase the pumping capacity at existing land drainage pumping sites. This has been assessed as an option by doubling pumping capacity where pumps currently exist (currently baseline model assumes 11 pumping stations along Suriname River, 8 internal pumping stations, and 2 pumping station on the Saramacca River, and 1 on the Atlantic coast).</td></tr>
<tr><td colspan="6">
</td></tr>
<tr><td>Estimated capital investment:</td><td>$34m</td><td>Economic benefit (Reduction in AAD):</td><td>$1.3m</td><td>Benefit:Cost ratio (Reduction in AAD:Total capital and revenue costs discounted at 3.5% over 15 years):</td><td>0.6 : 1</td></tr>
<tr><td>Overall benefits:</td><td colspan="5">• The benefit from this option is clearly improving the drainage rate across the many parts of the city by allowing greater continuous discharge during high tide.
• The reduction in AAD shown in the above map indicates the areas where the current pumping capacity is insufficient. The overall benefit is however smaller than might be expected because many of the existing pumps are already well matched with the capacity of the canal system, and its ability to drain parts of the city to these pumped discharge points.
• The overall economic benefit through reduction in risk from this option is estimated to be US$1.3m AAD.</td></tr>
<tr><td>Overall disadvantages:</td><td colspan="5">• Although the sites and infrastructure are already in place at existing pumping stations, significantly increasing pumping capacity at many</td></tr>
</table>

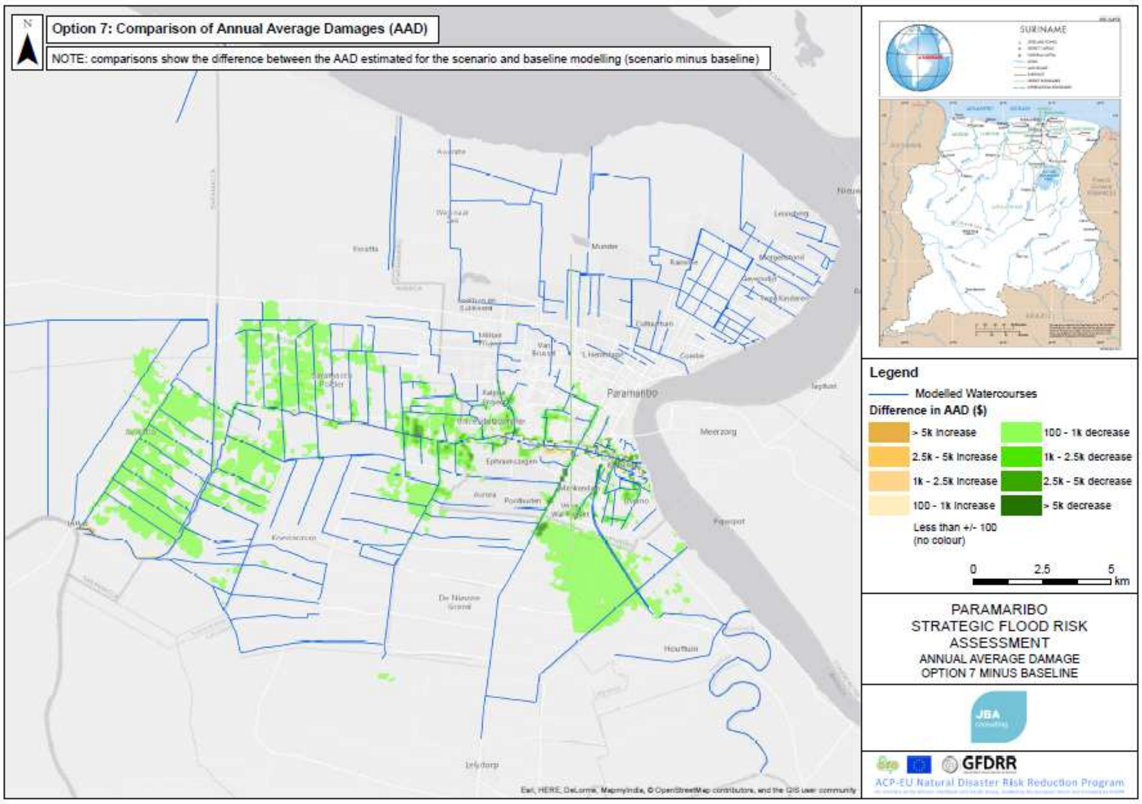
	locations will require substantial civil engineering works, and in some cases additional land. Costs of increasing pumping capacity therefore, can be higher than might be anticipated. • The benefits are not as great as might have been expected, due to the other limitations of the system, such as canal capacity, rate of drainage of surface water into the canals. Also in parts of the north eastern area, land prone to flooding is at a slightly lower level than the pumps. Some flooding will already have happened before the flood flows reach the pumps and can be effectively discharged. This reduces the effectiveness of the pumping station, and negates any benefit from increasing the pumping capacity.
Summary of opportunity:	This option is designed to improve the overall discharge capacity of the drainage network across large parts of Paramaribo by increasing the amount of surface water that can be pumped into the Suriname River, the Saramacca Canal, or the Atlantic Ocean. However, benefits are only achieved where the existing pumps are frequently overwhelmed by the amount of water reaching the pumping station. Where the pumps are already capable of discharging the water at a sufficient rate to cope with the rate of water reaching them, little additional benefit is achieved by over-sizing the pumps.
Refined proposal and cost revision (if applicable):	The modelling work has shown that 3 pumps along the Suriname River, and one of the internal pumps within the city currently appear to be under sized, and would benefit from increased capacity. A detailed feasibility study is required to confirm the findings, and define the optimum additional pumping, given the potential benefit, and likely costs. The cost for the implementation of this option is likely to be considerably reduced.

Recommendations and actions.

This option has been shown to be of limited benefit, and the approach has been shown to cause potential problems. This option is not recommended for widespread implementation, however selective implementation would maximise the potential reduction in flood risk, and minimise increased costs. It may be possible to utilise the equipment already purchased (currently in storage) and originally intended for a location along the north coast (see option 5 – hard infrastructure to be avoided along the north coast). The following actions area suggested:

- Carry out a more detailed technical and economic feasibility study, and if appropriate, prepare more detailed scheme designs to allow formal costing and project assessment.
- Carry out an Environmental and Social Impact Assessment for the selected locations and surrounding areas.
- Building on this investment plan, prepare an economic business case and costed proposal for further consideration and prioritisation.

This is considered a **medium** priority**.**

<table>
<tr><td colspan="6">Mitigation Option 7.</td></tr>
<tr><td>Mitigation option assessed:</td><td colspan="5">Saramacca Canal improvements – increase conveyance along the entire length of the canal through dredging, removal of vegetation, and re-profiling. Re-alignment will be carried out within the existing boundary of the canal, but may be in the order of several metres where practical, removing any pinch points if possible.</td></tr>
<tr><td colspan="6">
</td></tr>
<tr><td>Estimated capital investment:</td><td>$25m</td><td>Economic benefit (Reduction in AAD):</td><td>$8.9</td><td>Benefit:Cost ratio (Reduction in AAD:Total capital and revenue costs discounted at 3.5% over 15 years):</td><td>3.3 : 1</td></tr>
<tr><td>Overall benefits:</td><td colspan="5">By increasing the effectiveness of the Saramacca Canal in terms of storage capacity and conveyance, there is a notable reduction in flooding in the areas draining directly to the canal – more prominently towards the eastern and central part of the study area.
Water quality within the canal will be improved, although there may be some detrimental impact on aquatic habitats in some areas due to the reduction in vegetation.
The overall economic benefit through reduction in risk from this option is estimated to be US$8.9m AAD.</td></tr>
<tr><td>Overall disadvantages:</td><td colspan="5">Initial capital cost, with significant ongoing maintenance requiring specialist equipment and machinery to keep the canal free flowing.
The benefits available from improvements to the Saramacca Canal are also dependant on the effectiveness of the feeder canals in draining the</td></tr>
</table>

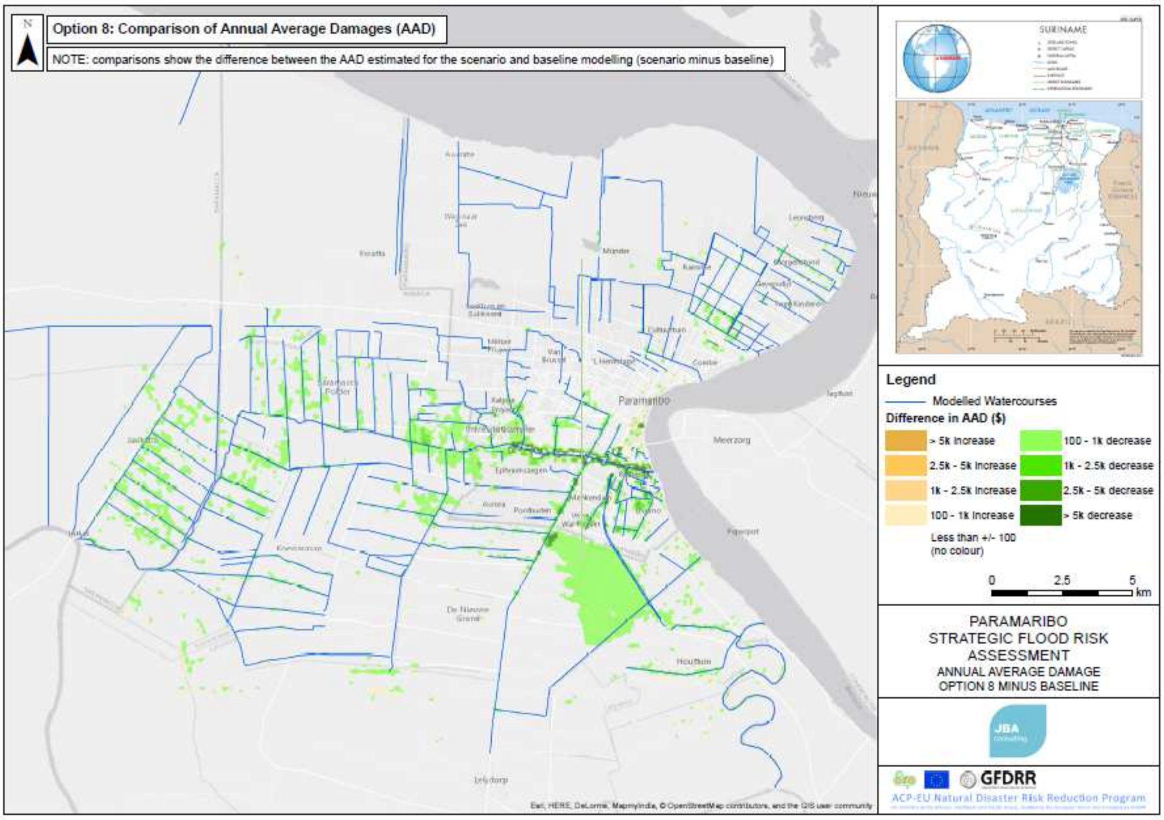
	surface water from the city, and the ability of the Saramacca Canal to discharge into the Suriname River. • There may be some detrimental impact on aquatic habitats in some areas due to the disturbance and reduction in vegetation.
Summary of opportunity:	The Saramacca Canal is a key part of the drainage system for the central and western areas of Paramaribo and surrounding areas (an area of approximately 190km^2). Improving the effectiveness of this feature is clearly shown to benefit a wide area by reducing the depth and extent of flooding for all return periods. The scale of improvements is constrained to some extent by land ownership, and the improvements should be constrained to within existing boundaries, and the benefits are also somewhat dependent on the capability of the feeder canals that drain the surrounding land, and the volume and rate of discharge to the Suriname River.
Refined proposal and cost revision (if applicable):	The proposed mitigation option remains largely unchanged from the option tested as part of this study. A major dredging and re-profiling project would clean out the canal and significantly improve its capacity and conveyance capability. The project would procure specialist machinery for the initial improvement project and on-going maintenance and routine clearance work.

Recommendations and actions.

The benefits of this option have been clearly demonstrated by the study, and the approach has been shown to significantly reduce flood risk. This option is recommended and the following actions area suggested:

- Carry out a more detailed technical and economic feasibility study, and if appropriate, prepare more detailed schedules of work, investigate equipment requirement and calculate quantities of materials etc, to allow formal costing and project assessment.
- Carry out an Environmental and Social Impact Assessment to support the technical feasibility assessment.
- Building on this investment plan, prepare an economic business case and costed proposal for further consideration and prioritisation.

This is considered a **high** priority**.**

Mitigation Option 8.					
Mitigation option assessed:	Increase discharge capacity at eastern end of Saramacca Canal through widening or improvements to the efficiency of the sluice gates, which are currently only partially operational. Tidal locking will still occur, but greater volume of discharge would be achieved at low tide.				
					
Estimated capital investment:	$10m	Economic benefit (Reduction in AAD):	$4.9m	Benefit:Cost ratio (Reduction in AAD:Total capital and revenue costs discounted at 3.5% over 15 years):	10 : 1
Overall benefits:	• By increasing the rate and volume of discharge into the Suriname River, drainage from the areas that discharge into the canal will be improved, particularly areas close to the canal and the flood prone area to the south (Latour, Pontbuiten, and Livorno resorts). • By improving the sluice gates, operational management and control of water levels within the canal system will be improved. • By increasing the discharge capacity of the Saramacca Canal, drainage improvements in other parts of the system are more likely to achieve their full potential. • The overall economic benefit through reduction in risk from this option is estimated to be US$4.9m AAD.				
Overall disadvantages:	• Initial capital cost, will be relatively high, and the full benefit realisation will depend on other improvements within the system allowing flood water to reach the sluice gates more efficiently.				

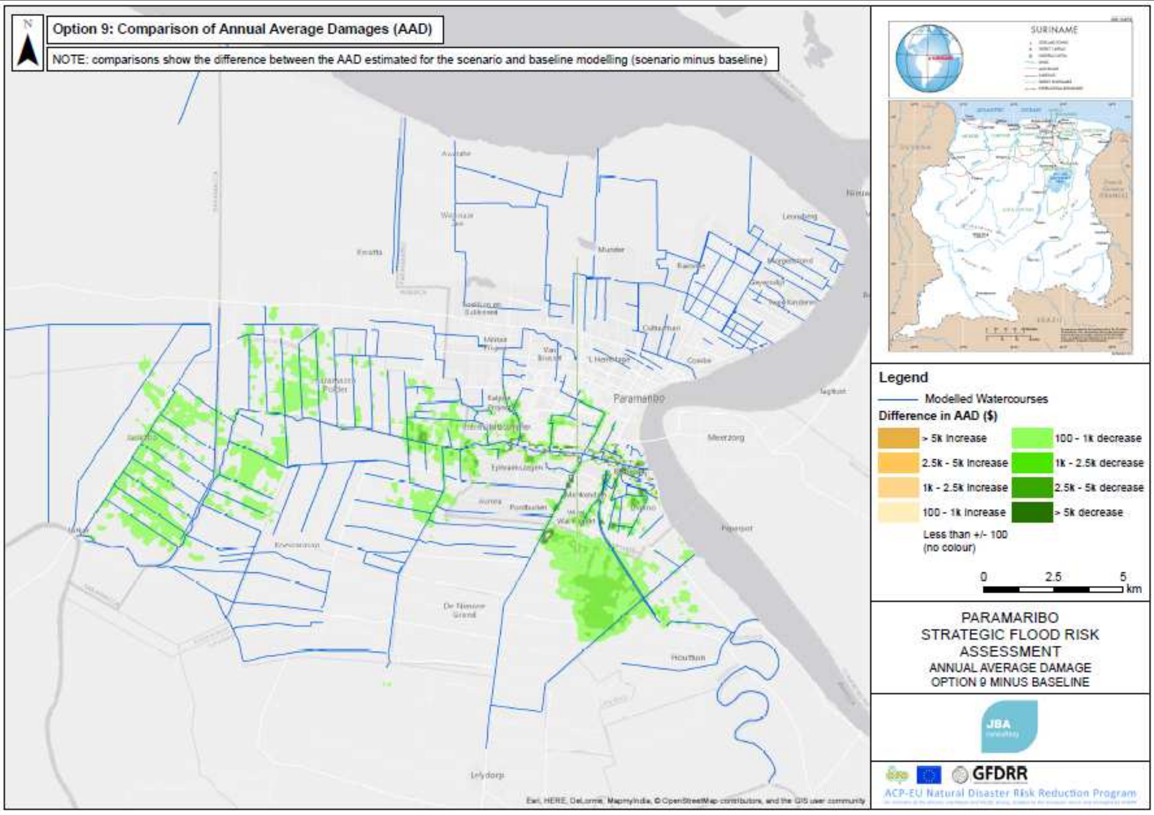
	• Tide locking will still occur with periods when the sluice gates need to be closed to prevent inflows due to high tide water levels in the Suriname River.
Summary of opportunity:	This option will replace the existing poorly functioning sluice gates with reliable and efficient gates that will allow significantly more discharge during periods when the water levels within the Suriname River allow. Carrying out this work, will result in an immediate benefit through improved drainage capacity, but will also enable the full benefits of other related improvements within the system.
Refined proposal and cost revision (if applicable):	The proposed mitigation option remains largely unchanged from the option tested as part of this study. This will consist of a major engineering project to refurbish/replace the flow control structures currently in place with modern equipment with the latest mechanical and electrical technology. The work will be carried out within the confines of the current land ownership, and will utilise existing infrastructure where feasible.

Recommendations and actions.

The benefits of this option have been clearly demonstrated by the study, and the approach has been shown to significantly reduce flood risk, as well as supporting other potential flood risk reduction measures. The following actions area proposed:

- Carry out a detailed technical and economic feasibility study, and if viable, prepare detailed scheme designs to allow formal costing and project analysis.
- Carry out an Environmental and Social Impact Assessment to support the technical feasibility assessment.
- Building on this investment plan, prepare an economic business case and costed proposal for further consideration and prioritisation.

This is considered a **high** priority**.**

<table>
<tr><td colspan="6">Mitigation Option 9.</td></tr>
<tr><td>Mitigation option assessed:</td><td colspan="5">Increase discharge capacity at eastern end of Saramacca Canal through the installation of large pumps to allow longer period of discharge into the Suriname River (assumed pumping capacity of 20 cumecs for the purpose of the assessment).</td></tr>
<tr><td colspan="6">
</td></tr>
<tr><td>Estimated capital investment:</td><td>US$25m</td><td>Economic benefit (Reduction in AAD):</td><td>US$11.6m</td><td>Benefit:Cost ratio (Reduction in AAD:Total capital and revenue costs discounted at 3.5% over 15 years):</td><td>8 : 1</td></tr>
<tr><td>Overall benefits:</td><td colspan="5">

This option provides a means of continuing to discharge from the Saramacca Canal to the Suriname River throughout the tidal cycle, and will reduce the impact of tide locking.
Flood risk will be reduced as a result of this option throughout the area that drains to the Saramacca Canal, although the impact will be limited to periods when high tides would otherwise prevent discharge, and so the benefit will be greatest nearest towards the east and centre of the city.
The overall economic benefit through reduction in risk from this option is estimated to be US$11.6m AAD.
</td></tr>
<tr><td>Overall disadvantages:</td><td colspan="5">

The option is assessed using a 20 cumecs pumping capacity, which is a large but realistic and practical option for an additional pumping station given the likely limitations of space and finance. This is however significantly less than the gravity discharge rate through the sluice gates
</td></tr>
</table>

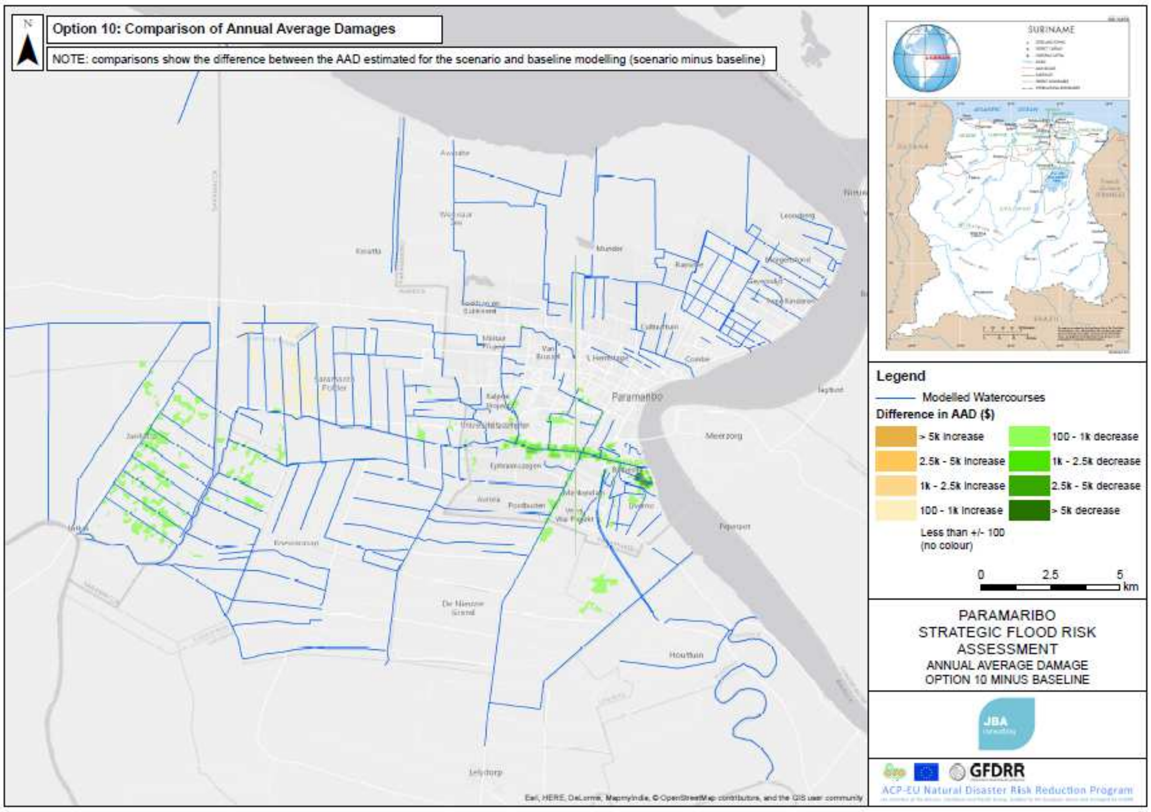
	during low tide, and so the benefit is less than could be achieved with less constraints. • Capital costs of installation is relatively high, but with a significant on-going operational and maintenance costs.
Summary of opportunity:	This option provides an effective long-term means of maintaining discharge during high tides, which with future sea level rise will become more important. There is a significant capital cost as well as ongoing maintenance and operational costs, but the benefit-cost ratio is considerable, and this option will enable and support other potential improvements within the drainage network, and it is very likely that a combination of this option and the improvements to the sluice gates (option No 8) would provide the greatest overall benefit opportunity.
Refined proposal and cost revision (if applicable):	The proposed mitigation option remains largely unchanged from the option tested as part of this study. This will consist of a major engineering project to install a large pumping station at the eastern end of the Saramacca Canal. The work will be carried out within the confines of the current land ownership, and will utilise existing infrastructure where feasible

Recommendations and actions.

The benefits of this option have been clearly demonstrated by the study, and the approach has been shown to significantly reduce flood risk, as well as supporting other potential flood risk reduction measures. The following actions area proposed:

- Carry out a detailed technical and economic feasibility study, including the analysis of the combined benefit of carrying out the sluice gates improvement works, and (assuming a viable outcome), prepare detailed scheme designs to allow formal costing and project analysis.
- Carry out an Environmental and Social Impact Assessment to support the technical feasibility assessment.
- Building on this investment plan, prepare an economic business case and costed proposal for further consideration and prioritisation.

This is considered a **high** priority**.**

<table>
<tr><td colspan="6">Mitigation Option 10.</td></tr>
<tr><td>Mitigation option assessed:</td><td colspan="5">Install a navigation lock in the middle of the canal (located at the highest elevation point along the canal), allowing higher water levels towards west, and lower levels towards the east prior to flooding events, and greater draw-down possible within the higher priority (for flood discharge) eastern end of the canal.</td></tr>
<tr><td colspan="6">
</td></tr>
<tr><td>Estimated capital investment:</td><td>$7m</td><td>Economic benefit (Reduction in AAD):</td><td>$0.5m</td><td>Benefit:Cost ratio (Reduction in AAD:Total capital and revenue costs discounted at 3.5% over 15 years):</td><td>1.4 : 1</td></tr>
<tr><td>Overall benefits:</td><td colspan="5">• Through improved water level management within the canal, it will be possible to maintain lower water levels towards the eastern end of the canal, and therefore improve drainage from the city into the canal.
• There is also an indication that there is some benefit in the less urban areas to the west, which is a result of the independence of the western parts of the canal drainage system.
• There would be additional benefits for improved navigation, better water level management for irrigation during periods of low rainfall or drought.
• The overall economic benefit through reduction in flood risk from this option is estimated to be US$0.5m AAD.</td></tr>
<tr><td>Overall disadvantages:</td><td colspan="5">• Small increase in flooding in certain parts of the area – mainly less-urban areas in Wanica District, but still significant.</td></tr>
</table>

	• Major engineering project, with low benefit-cost ratio for flood mitigation.
Summary of opportunity:	This option provides some small benefit in terms of flood risk management, however there are other potential benefits that have not been investigated within this study.
Refined proposal and cost revision (if applicable):	No change to the overall proposal; however, in terms of a flood risk management alone, this would be a relatively low priority project. Elements of the benefits provided by this option could perhaps be delivered through more effective water management within the Saramacca Canal brought about through better control of discharges at the eastern end of the canal to the Suriname River (i.e. through improvements to the existing sluice gates or addition of pumping).

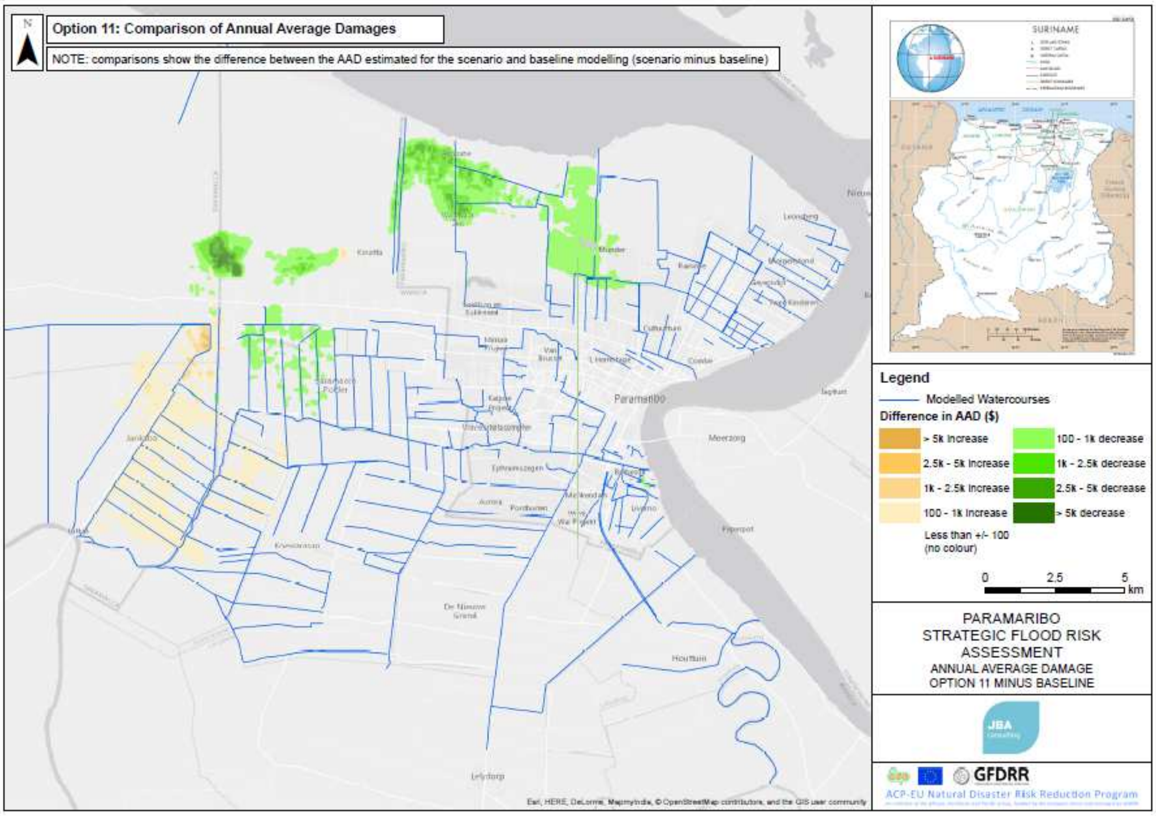
Recommendations and actions.

The benefits of this option in terms of flood risk management are relatively small, however wider benefits have been identified by the study. The following actions area suggested:

- Carryout a wider benefit-cost analysis to confirm and quantify the overall economic, social, and environmental benefits and impacts of this option.
- Develop water level management plans for the canal, with consideration of the more effective flood risk reduction measures being proposed, such as canal dredging and widening, and improved water level control using pumping and re-furbished sluice gates.

This is considered a **medium** priority**.**

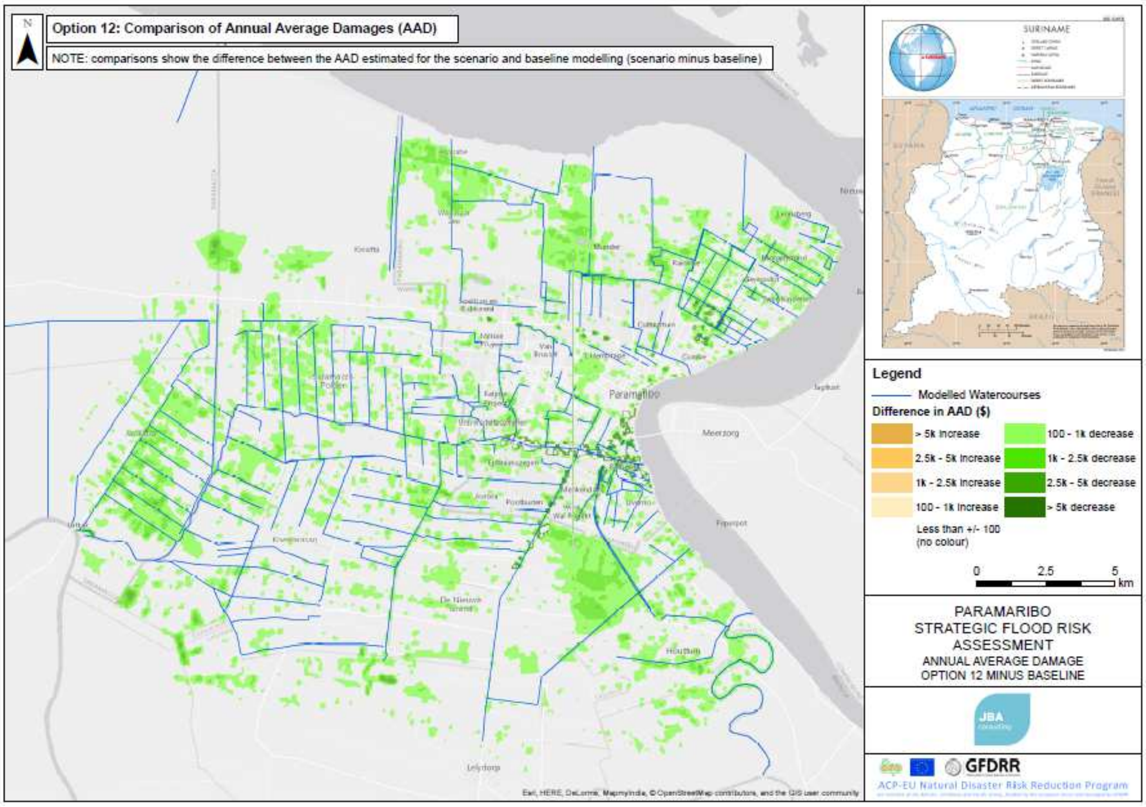
Mitigation Option 11.	
Mitigation option assessed:	Major drainage improvements to the north west of Paramaribo through Kwatta area, reflecting the work that has already been partly done through increased canal coverage, realignment of existing watercourses, and apply pumps and sluice gates at two locations along the Atlantic coast to allow longer discharge period (assume pumping capacity of 10 Cumecs).



Estimated capital investment:	$9m	Economic benefit (Reduction in AAD):	$1.2m	Benefit:Cost ratio (Reduction in AAD:Total capital and revenue costs discounted at 3.5% over 15 years):	2.1 : 1

Overall benefits:	• There is a clear significant reduction in flooding and flood risk within the area where the drainage improvements would take place (i.e, Weg Naar See, but also to the east, and this option improves drainage within Munder Resort due to the linked canal system. • The overall economic benefit through reduction in risk from this option is estimated to be US$1.2m AAD.
Overall disadvantages:	• Small increase in flooding in certain parts of the area – mainly less-urban areas, but still significant. • Low benefit-cost ratio • If pumping to the north is included within the proposal, the improvement in drainage is likely to result in an overall flood risk (or long-term commitment to potentially unsustainable flood defences) by encouraging accelerated urban development in areas prone to coastal

	flood hazard, placing greater numbers of people at peril. • The drainage canals will pass through important areas of potential mangrove forest towards the north coast, and will significantly change the drainage patterns of fresh water within the area resulting in damage to the fragile ecosystems • The pumping stations and sluice gates required to ensure drainage of the area is maintained during high tides will be located within an unstable muddy coastal zone, vulnerable to erosion and coastal flooding, and are unlikely to be sustainable in the long term. The associated coastal study which forms Part 2 of this report has highlighted the unsustainability of establishing hard infrastructure for drainage in this area.
Summary of opportunity:	This opportunity makes use of ongoing initiatives which have not yet been fully implemented, with additional pumping and slice gates. It will allow completion of works to increase drainage from the western areas of the city, and will directly benefit the less urban southern parts of Weg Naar See, but will also improve drainage across a wider area by reducing the pressure on the overall drainage network in the area.
Refined proposal and cost revision (if applicable):	This option is not recommended, due to the overall negative impact that drainage to the north would have on the long-term sustainability of the vulnerable coastal zone. If further urban development occurs in this area, it is recommended that attenuation and storage of surface water through creation of fresh, or brackish water wetlands should be investigated as a more sustainable option.
Recommendations and actions. Although the short-term benefits in terms of reduction in pluvial flood risk has been demonstrated, the negative social and environmental impacts of this approach, and the long-term unsustainability are considered to outweigh the short-term benefits. No actions are recommended. This option is **not recommended.**	

<table>
<tr><td colspan="6">Mitigation Option 12.</td></tr>
<tr><td>Mitigation option assessed:</td><td colspan="5">Flood forecasting and early warning system development and implementation – covering pluvial and tidal flood hazard. This has been assessed through the estimation of the reduction in AAD through increased resilience to flooding brought about by the provision of meaningful and accurate early warnings of flooding, with sufficient lead time to react, and with an effective response capacity.</td></tr>
<tr><td colspan="6">
</td></tr>
<tr><td>Estimated capital investment:</td><td>$0.5m</td><td>Economic benefit (Reduction in AAD):</td><td>$13.9m</td><td>Benefit:Cost ratio (Reduction in AAD:Total capital and revenue costs discounted at 3.5% over 15 years):</td><td>97 : 1</td></tr>
<tr><td>Overall benefits:</td><td colspan="5">The benefit from this option will be in terms of damage prevented through prior knowledge of an impending flood event.
Developing and operating a flood forecasting system has the additional benefit of providing a catalyst for emergency response planning, public education and raising risk awareness within the population.
The potential benefit-cost ratio is very high for this option, as the cost of implementation is low. Although the individual reduction in damage for each property or asset at risk is low, the cumulative reductions in damages for both fluvial and coastal flooding across the entire area is potentially large.
The overall economic benefit through reduction in risk from this option is estimated to be US$13.9m AAD.</td></tr>
</table>

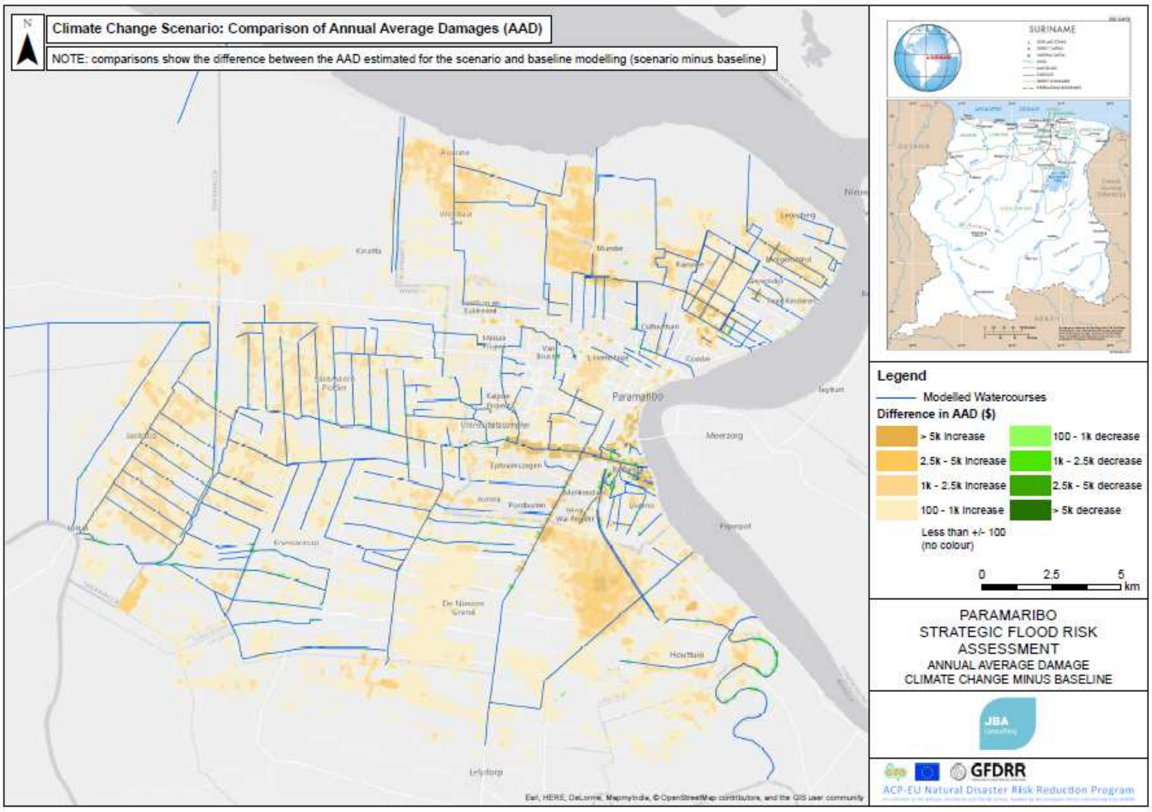
Overall disadvantages:	• None
Summary of opportunity:	Using the modelling and analysis work carried out for this study as a foundation, there is an opportunity to reduce the vulnerability of the population of Paramaribo and surrounding areas to flood hazard through development of an automated flood forecasting and early warning system for both pluvial and tidal flooding.
Refined proposal and cost revision (if applicable):	The existing modelling work would provide a starting point to develop a flood forecasting system for Paramaribo, and surrounding areas. The system would be driven by the existing weather radar, coupled with the existing automated raingauge network, and existing tide and water level gauges (with the addition of an off-shore tidal gauge).

Recommendations and actions.

The benefits of this option are clearly demonstrated by the study, and the approach is a low impact, but with significant benefits. This option is highly recommended for implementation, and the following actions area proposed:

- Develop the detailed scope for a flood forecasting and early warning system, investigating the technology available, and best solutions.
- Carry out a hydro-met review to ensure local gauges are suitable, with appropriate level of data quality and data retrieval capability
- Investigate the potential to install an off-shore tide gauge.
- Begin to build capacity through training and planning, ensuring the institutional arrangements as well as technical capacity is in place.

This is considered a **high** priority**.**

<table>
<tr><td colspan="6">Mitigation Option 13.</td></tr>
<tr><td>Mitigation option assessed:</td><td colspan="5">Land use planning and building codes – this option will help manage flood risk by reducing the impact of flooding. This assumes that flooding still occurs, and indeed is likely to increase with sea level rise and climate change, but flood resilience can be increased through better zoning, ensuring vulnerable development does not take place in flood prone areas, and appropriate design of all development to reduce flood risk. This will apply particularly to new developments, which, in order to receive planning permission would be expected to have an overall beneficial impact on flood risk, i.e. they would be placed in areas with least risk, and designed in a way that mitigates against any potential additional flood risk (including impact on others). The default planning policy should be that any new development must not increase flood risk, but should provide a positive net benefit through a zero impact for risk associated with the development itself, and a positive impact on the surrounding flood risk if possible and practical. The onus will be on the developer to provide justification for not delivering a net benefit from the proposed development.</td></tr>
<tr><td colspan="6">
</td></tr>
<tr><td>Estimated capital investment:</td><td>$0.5m</td><td>Economic benefit (Reduction in AAD):</td><td>$2.3m</td><td>Benefit:Cost ratio (Reduction in AAD:Total capital and revenue costs discounted at 3.5% over 15 years):</td><td>11 : 1</td></tr>
<tr><td>Overall benefits:</td><td colspan="5">Although not directly comparable with the structural approaches to flood risk mitigation, the overall benefit from this approach will be a long-term prevention of increase in flood impact across the entire city and surrounding area.</td></tr>
</table>

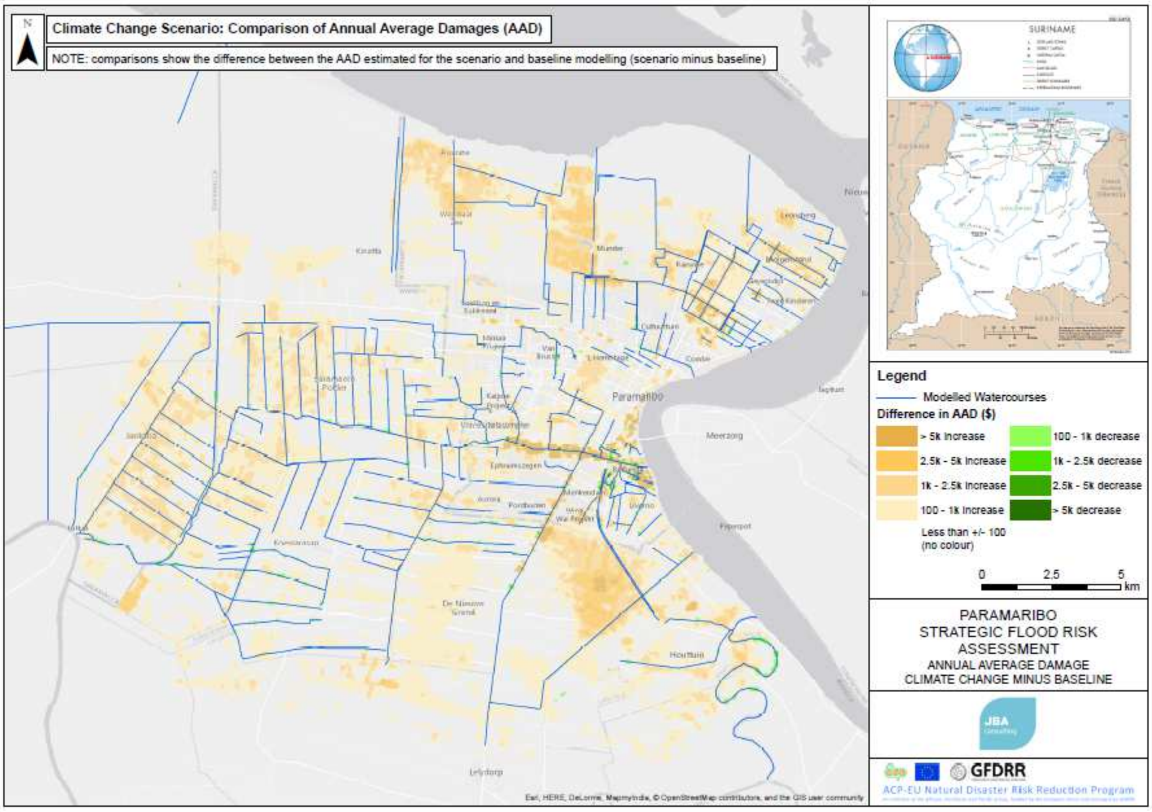
	• The reduction in flood risk will be greatest in less urban areas where urban growth is likely to be greatest, but will also apply in more central areas where the planning and building regulations will also apply to infill development, replacement, or any changes or extensions to the existing built environment. • Introduction of more stringent planning rules will have the added benefit of being able to control types of buildings and uses in different parts of the city and improve zone management. • Relatively low financial cost to set up, and will ideally be implemented as part of a wider initiative to manage run-off from the built environment, such as formalisation of drainage consenting. • The overall economic benefit through reduction in risk from this option is estimated to be US$2.3m AAD. (Note: the map above presents the increase in AAD across the study area that would occur as a result of future climate change – the damage avoided resulting from this option relates to this increase).
Overall disadvantages:	• Implementation of this option will require institutional as well as constitutional changes, which will take time, effort and commitment to implement. • This option will not bring significant immediate benefits, and should be considered as part of a long-term strategy for disaster risk reduction. • Small addition cost to developers for carrying out a flood risk and drainage study for each development.
Summary of opportunity:	This option is for the strengthening land use planning and building control to prevent further increases in flood risk, and where possible, the reduction in flood damage over current levels. This is a long-term objective, and should form part of a wider institutional approach towards improved flood risk management.
Refined proposal and cost revision (if applicable):	The proposed mitigation option remains unchanged from the option described and tested as part of this study. The benefits are clear, but it is recognised that the implementation will take time to be effected.

Recommendations and actions.

The benefits of this option are clearly demonstrated by the study, and the approach will deliver long-term improvements in flood risk management capability. This option is recommended as part of a strategic move towards more sustainable urban growth. The following actions area proposed:

- Further consideration is required to define how this option could be implemented in practice. A separate study should be carried out to review existing practices, identify improvements and options for implementation, and investigate best practice globally to help re-define the most appropriate institutional and operational arrangements.
- The process of developing policies, standards and guidance documents should be started, (recognising the time and complexity of achieving agreement across the wide range of stakeholders involved), pooling existing good practice and utilising local experts and knowledge to ensure the standards are relevant and practical.

This is considered a **medium** priority**.**

Mitigation Option 14.					
Mitigation option assessed:	Storage, on site usage where applicable, and attenuation of surface water run-off from the built environment (sustainable drainage systems), prior to any controlled release to the drainage infrastructure. This approach deals with flood risk at source, by dealing with surface water run-off at a property or development level. Successful implementation of this option requires institutional and statutory processes and procedures for specifying, administrating, and enforcing the necessary technical components of the requirements, and will be closely linked to the 'Planning and Building Regulations' strengthening initiatives. This option is reflected in the study through a reduced increase in flood damage that would occur in the future due to climate change and urban growth.				
					
Estimated capital investment:	$0.55m	Economic benefit (Reduction in AAD):	$1.2m	Benefit:Cost ratio (Reduction in AAD:Total capital and revenue costs discounted at 3.5% over 15 years):	3 : 1
Overall benefits:	• Although not directly comparable with the structural approaches to flood risk mitigation, the overall benefit from this approach will be a long-term prevention of increase in flood impact across the entire city and surrounding area. • The reduction in flood risk will be greatest in less urban areas where urban growth and development activity is likely to be greatest, but will also apply in more central areas where the adoption of sustainable drainage systems will also apply to infill development, replacement, or				

	any changes or extensions to the existing built environment. • Relatively low financial cost to set up, and will ideally be implemented as part of a wider initiative to manage run-off through strengthening the planning and building regulations. • The overall economic benefit through reduction in risk from this option is estimated to be US$1.2m AAD. (Note: the map above presents the increase in AAD across the study area that would occur as a result of future climate change – the damage avoided resulting from this option relates to this increase).
Overall disadvantages:	• Implementation of this option will require institutional as well as changes to the statutory regulations regarding land owner responsibility for surface water. This will take time, effort and commitment to implement. • The costs of this option include likely additional small costs for developers to implement appropriate storage measures. • This option will not bring significant immediate benefits, and should be considered as part of a long-term strategy for disaster risk reduction.
Summary of opportunity:	• This option is for the development of sustainable drainage design and control measures that will be implemented as part of strengthening of the land use planning and building control to prevent further increases in flood risk, and where possible, the reduction in flood damage over current levels. This is a long-term objective, and should form part of a wider institutional approach towards improved flood risk management.
Refined proposal and cost revision (if applicable):	The proposed mitigation option remains unchanged from the option described and tested as part of this study. The benefits are clear, but it is recognised that the implementation will take time to be effected.
Recommendations and actions. The benefits of this option are clearly demonstrated by the study, and the approach will deliver long-term improvements in flood risk management capability. This option is recommended as part of a strategic move towards more sustainable urban growth. The following actions area proposed: • Further consideration is required to define how best to integrate the administration and practical application of this option into the planning process. A separate study should be carried out to review any existing practices, or guidelines, identify improvements and options for implementation. • The process of developing policies, standards and guidance documents should be started (recognising the time and complexity of achieving agreement across the wide range of stakeholders involved), pooling existing good practice and utilising local experts and knowledge to ensure the standards are relevant and practical. This is considered a **medium** priority**.**	

5.3 Investment planning.

As this report has demonstrated, flooding in and around the city of Paramaribo is relatively common, it is also sporadic and the risk is widespread across the whole area. This is a feature of the flat and low-lying landscape, the tropical climate with intense rainfall, the urban spread into areas more prone to flooding, and the increasing threat from the sea. There is consequently no single practical action or investment that will solve the flooding problem.

The objective of this analysis has been to better understand the causes and effects of flooding, and to provide a basis for focusing flood risk reduction investment where it will be of greatest value. This assessment has been carried out with the best data and information available, and although not possible to quantify, takes into account the practicality of certain mitigation options as well as their environmental and social impacts. The following is a summary of the study analysis, with recommendations for investment over the next 10 years, identifying clear priorities that maximise overall benefit.

The need for a strategic and integrated programme of improvements to the provision of flood risk management services and infrastructure within and surrounding the city of Paramaribo is clear from the study. The overall approach of 'keeping the water away from people' through drainage network improvements etc., need to be coupled with a 'keeping people away from the water' approach, which includes non-structural measures that help people avoid flooding, or become more resilient when flooding does occur. The following is a summary of the recommendations resulting from the analysis:

1. The greatest single benefit identified by the study in terms of flood risk reduction comes from implementing a flood forecasting and early warning system. As well as the obvious benefit from early warning of impending floods, secondary benefits such as improved public awareness, improved emergency response planning and enhanced readiness, will significantly help reduce flood risk and improve sustainability. This has been identified as a high priority initiative and should to be taken forward and implemented as part of a strategic flood risk management plan.

2. The Saramacca Canal is a key element of the drainage network and is an important part of any flood risk reduction solution. The largest benefit associated with the canal comes from increased discharge to the Suriname River through installation of pumps, and to a slightly lesser (but still significant) extent, through improved efficiency of drainage through the sluice gates. It is likely that a combination of both would deliver even greater benefits, and could be implemented in combination more efficiently, therefore reducing overall costs. This has been identified as a high priority initiative and should to be taken forward and implemented as part of a strategic flood risk management plan.

3. Additional pumping at a relatively small number of key locations has been shown to be very effective at reducing flood risk in parts of the city and surrounding areas. Four locations with existing sluice gates have been identified where pumping could be added with significant flood risk reduction benefit, and should to be taken forward and implemented as part of a strategic flood risk management plan.

4. Improving the volume and conveyance capacity of the Saramacca Canal has been shown to significantly reduce flood risk within the extensive area that directly drains towards the canal.

The benefits of this provide the 4th largest reduction in damages that were calculated, and would be justified on its own merits with a benefit-cost ratio of more than 3:1. This option would however provide significant other benefits, which would include enhancing the effectiveness of the discharge improvements at the eastern end of the canal, and would provide additional social, economic and environmental benefit through improved water level and flow management. This has been identified as a high priority initiative and should to be taken forward and implemented as part of a strategic flood risk management plan.

5. The final part of the overall drainage system improvements is the proposed increase in capacity and conveyance within the main canal network throughout the city and surrounding area. This approach on its own has not demonstrated significant reduction in flood risk, however it is known that some parts of the network are less effective than others, and whilst there is clearly some benefit on its own, the real benefit will stem from the combined effect of increased conveyance from within the city to the Saramacca Canal, the improved storage and conveyance within the Saramacca Canal, and the increased rate and duration of discharge into the Suriname River. This has therefore been identified as a high priority initiative and should to be taken forward for implementation as an integral part of a strategic flood risk management plan.

6. Although less compelling in terms of simple benefit-cost ratio, improved spatial and land use planning that takes full account of flood risk, with associated building and drainage regulations, will have an important part to play in sustainable and effective flood risk management. By careful zoning and regulation of land use to avoid inappropriate development in flood risk areas, and more stringent requirements on developers to reduce run-off from new developments and introduce greater resilience (i.e. individual property level flood protection), long term sustainable flood risk reductions can be achieved. Spatial and land use planning will play an essential role in coastal management and reducing coastal vulnerability, and is discussed in more detail in this regard, in Part 2 of the report. This has therefore been identified as a high priority initiative and should to be taken forward for implementation as an integral part of a strategic flood risk management plan.

7. The increasing risk from the sea to the north of the city due to rising sea level and increased frequency of storms, surge tides and waves, is a significant threat. This study has identified the considerable level of both current and future damages, and the needs to be cognitive of the overall flood risk that threatens Paramaribo and surrounding areas. A detailed study has been carried out to specifically address the issues of coastal management, and has identified mitigation options specifically for coastal flood risk and erosion, which are set out in Part 2 of this report. A key output of that analysis is the need for careful management of the coastal strip and the inevitability of continued dynamic behaviour along this coast. The main consequence of the this for the management of pluvial (surface water flooding) events, is the need to avoid construction of hard engineered structures near or at the coast, particularly where they effect the natural and delicate balance of sediment movement and land drainage within the coastal fringe. A priority recommendation of this report is that no further drainage schemes or projects are initiated that drain towards the north coast using canals and sluice gates or pumping stations. As set out in Part 2, all drainage towards the north should be directly discharged to wetland areas strategically positioned beyond any coastal defences that are implemented to

protect the city, within a broad strip of land designated for coastal protection. Critical to this will be the links to the Coastal Protection Act, and future land use planning regulations.

5.4 Project development

A total of 14 key flood risk mitigation options were identified and analyzed for Greater Paramaribo, described in detail through sections 5.2 and 5.3.

The resulting investment plan makes the argument for six 6 investments to be proposed as high priority actions and are set out below with estimated present costs. as the proposed potential activities for Bank funding.

1. The Saramacca Canal improvements project would consist of (in order of priority if only partial implementation):

- Repair and improved efficiency of the existing sluice gates at the eastern end of the Saramacca Canal to increased volume of discharge to the Suriname River (Option 8 - Capital cost = US$10m),
- Improved volume and conveyance capacity of the Saramacca Canal throughout its length (Option 7 – Capital cost = US$25m), to allow more efficient flow towards the improved discharge capacity to the Suriname River.
- Installation of pumps at the eastern end of the Saramacca Canal to increased duration (and therefore volume) of discharge to the Suriname River (Option 9 - Capital cost = US$25m)

2. Additional project required to maximize the benefits from the improvements to the Saramacca Canal (should be considered in combination with all or parts of the above, but should be considered in preference over the 3rd item, i.e. installation of pumps):

- Improvements within the main city canal network that drains to the Saramacca Canal (Option 2 – Capital cost = US$11m).

3. Further high benefit drainage project (not related to the Saramacca Canal):

- Additional pumping capacity at four locations with existing sluice gates to increase direct discharge to the Suriname River (Option 5 – Capital cost = US$12m).

4. Supporting initiative with low cost but large benefit:

- Flood forecasting and early warning system (Option 12 – Capital cost = US$0.5m) should be implemented as part of any overall flood risk reduction project, and is supported by a strong cost benefit ratio.

The detail of the projects will require further clarification and refinement, however, this technical report provides the necessary information to develop a series of projects as a “flood risk management program” to address the recurrent flood issue.

Of the 14 flood mitigation options considered within the study, there are a further 6 that are considered lower priority and should be implemented but at a later stage, and 2 have been discounted.

6 Future technical work.

6.1.1.1 Current study.

As a strategic flood risk assessment, this study has been carried out predominantly with the data that has been readily available, either locally, or internationally as generic data that has been applied to the local Suriname situation. The main exception to this is the purchase of the AIRBUS WorldDEM 12m resolution DTM, which was essential to achieve a flood model with an acceptable level of accuracy. It is always possible to spend more time and money to improve the accuracy, resolution and confidence in the modelling and analysis, however the level of detail and resolution of this study has been commensurate with the required outcomes, and the overall outcomes are defendable, and sufficiently well-defined to establish a prioritised programme of work

6.1.1.2 Future work.

In order to progress the proposed programme of work, the specific actions and studies are set out within each options-analysis carried out in Section 5.2, however, the main areas for further work are as follows:

- Detailed topographic data will be required (LiDAR, supported by ground survey – particularly where dense vegetation obscures the aerial measurement).
- Flood modelling – more detailed and higher resolution sub-models, or set of sub-models may be required to refine the proposed work packages, and for more detailed design work.
- Improved vulnerability and cost data are needed to better understand local detail and variability of flood risk – a more comprehensive economic, social and environmental study is required to flesh out the impact and feasibility of individual work packages.
- Formulation and refinement of the individual work packages, with more detailed costings, schedule of works, and priorities, within the overall framework set out within this document which identifies dependencies and linkages between many of the options considered.

APPENDIX A: Modelling Technical Report.

1 Data and implementation within the model

1.1 Purpose of the Study

The aim of this project was to better understand the flood risk in the Greater Paramaribo City area, Suriname, by developing a hydraulic model to inform a Strategic Flood Risk Assessment (SFRA).

The model has been developed to strategically capture the rainfall-run-off response and tidal flooding. It extends from the coastal strip to the north, the river frontage to the east and the drainage systems west and south of Greater Paramaribo City draining to the Saramacca Canal and the Suriname River.

Design rainfall and tidal water levels are required for annual exceedance probabilities (AEP) of 10%, 2%, 1% and 0.5%. Climate change scenarios have also been considered for and estimates of potential change in total rainfall and mean sea level rise were predicted at the year 2050.

The model has been used to prepare an assessment of the baseline conditions and then to simulate a range of scenarios and mitigation options, the future scenario looking at the year 2050 and a number of mitigation scenarios.

A key purpose of the study was to provide a modelling and software platform that could be used in the future to investigate more detailed options, using higher resolution data and more precise representations of influential hydraulic features and structures. To facilitate this approach a handover workshop was held in Suriname in April 2017 and more detailed model information is contained in digital files assembled for the purpose of handing over the model. This digital handover data also contains more details on the cost benefit analyses and estimates prepared.

1.2 Available data

A GIS data platform has been prepared to include all data used in the modelling. This platform provides a summary of data from previous studies and data collected specifically for this current study. The data has been gathered in the following categories:

- Canal network
- Location of surveyed channel sections
- Spot level checks of main road
- Location of main structures (pumping stations and sluice gates)
- Location of gauging stations
- Photography records taken during site visits
- Classification of land uses

Due to 'gaps' and/or 'ambiguities' in the data it has been necessary to include assumptions in the model which are recorded in the following sections. Figure 1-1 illustrates the GIS data platform.

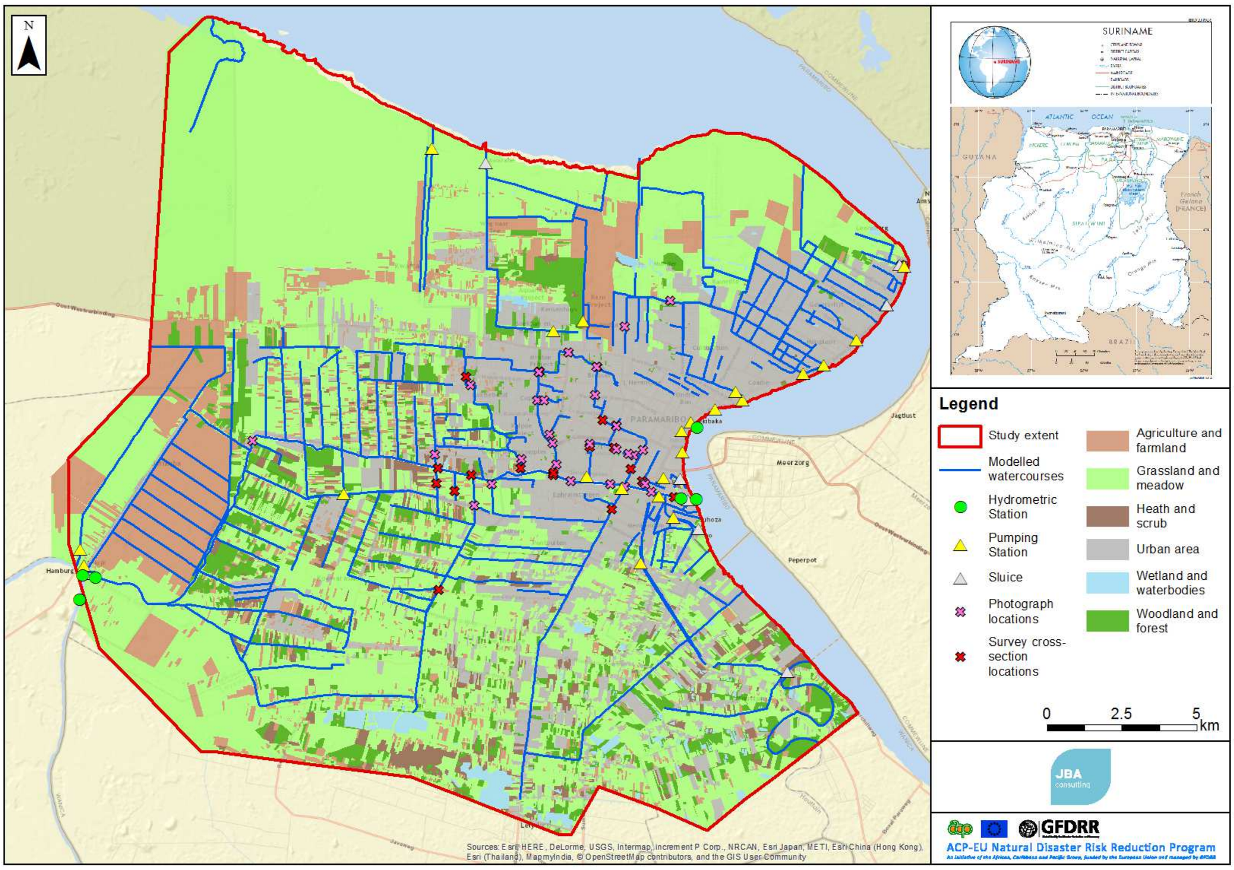


Figure Appendix A1-1 GIS data platform

1.2.1 Canal Network

The canal network was identified using the existing SOBEK model and aerial imaginary. This data was in addition to the existing topographic survey of the Sarammacca Canal.

The process of selection the canals to be represented in the model have been recorded in the document "2016s4840- Justification of method.pdf" included in the final project deliverables. Waterways to be used within the modelling have been assigned a rating of “high priority”. These have been chosen based on their size and locational importance. For example, the waterway is:

- a main arterial route within the river/canal network,
- a channel of significant size (e.g. identified by Channel_Banks_UTM21N.shp)
- situated within an area of dense urban fabric,
- flows through/converges with a channel that flows through a structure e.g. pumping station or sluice.

Where a feature has been assigned a rating of “medium priority”, the waterway is thought to have relative importance – for example, it converges with a main channel/runs through a highly urbanised area, however it is also a small contributor to the overall flow of water throughout the greater Paramaribo area or is an isolated channel, and therefore is less vital to include within the modelling.

1.2.2 Survey datasets

Available survey data relevant to the construction of the hydraulic model is recorded within Table Appendix A1-1.

Survey reference	Survey type	Date collected	Survey company	Survey extent
S1	Cross-sections	04 March 2009	Unknown	Saramacca canal
S2	Cross-sections	12 Dec 2008	Unknown	Sluis Kreek
S3	Cross-sections	01 Feb 2016	Unknown	Various XS across Paramaribo
S4	Cross-sections	01 Sep 2009	Unknown	Sommelsdijkse Kreek
S5	Cross-sections		Unknown	
S6	Cross-sections	09 Feb 2016	Unknown	Saramacca canal
S7	Topographic survey	24 Aug 2016	Unknown	Road spot heights across Paramaribo
S8	Cross-sections	31 Aug 2016	Unknown	Paramaribo canals/along river bank
S9	Cross-sections and topographic survey	28 Dec 2016	CM Engineering	Spot level survey collected across the main roads
S10	Topographic survey		Unknown	North embankment area; Weg Naar Zee
J00521	Graylingwell GS survey		Unknown	Graylingwell GS

Table Appendix A1-1: Available survey data

Note: survey references are unknown except for J00521. Reference S1 to S10 were given in this study to make them easy to identify

1.2.3 Structures

Available information on the significant features, such as pumps and sluices are recorded in Table Appendix A1-2

Area	No.	Sluice / pump	Pump capacity	Discharge area	Status	Discharge direction
Paramaribo Resort						
Paramaribo - Noord	1	Pumping station Leonsberg	No data	No data	In function	Directly Suriname river
	2	Sluice Clevia	No data	No data	In function	Directly Suriname river
	3	Sluice Geyersvlijt - Noord	No data	No data	In function	Directly Suriname river
	4	Pumping station Geyersvlijt	No data	No data	In function	Directly Suriname river
	5	Pumping station Morgenstond	No data	No data	In function	Directly Suriname river
	6	Pumping station	No data	No data	In function	Directly Suriname

Area	No.	Sluice / pump	Pump capacity	Discharge area	Status	Discharge direction
		Sluiskreek				river
	7	Pumping station Boomskreek	1.25 m³/s	No data	In function	Directly Suriname river
Sommelsdijcksekreek	8	Pumping station Sommeldijcksekreek	No data	No data	In function	Directly Suriname river
	9	Pumping station Benjaminstraat	No data	No data	In function	through Pumpingstation Drambrandersgracht to Suriname river
	10	Pumping station Peu et Content	No data	No data	In function	Directly the Sea (north)
	11	Pumping station Kuldipsingh	No data	No data	In function	Directly the Sea (north)
Paramaribo - Midden	12	Pumping station Knuffelsgracht	No data	No data	Inoperative	Directly Suriname river
	13	Pumping station Jodenbreestraat	1.25 m³/s	No data	In function	Directly Suriname river
	14	Pumping station Drambrandersgracht	No data	No data	In function	Directly Suriname river
	15	Pumping station Limesgracht	0.5 m³/s	No data	In function	Directly Suriname river
	16	Sluice Centrale markt	No data	No data	In function	Directly Suriname river
	17	Pumping station Nw. Haven	No data	No data	In function	Directly Suriname river
Paramaribo - Zuid	18	Pumping station Walabastraat	No data	No data	In function	Directly Suriname river
	19	Pumping station Kemperweg	1.1 m^3/s	80 ha	In function	Directly Saramacca canal to Suriname river
	20	Pumping station Koffiedam	2.2 m^3/s	150 ha	In function	Directly Saramacca canal to Suriname river

Area	No.	Sluice / pump	Pump capacity	Discharge area	Status	Discharge direction
	21	Pumping station Winti Wai	No data	No data	In function	Through Pumping station koffie dam Directly and Saramacca canal to Suriname river
	22	Pumping station Ramgoelam	No data	No data	In function	Through Spoorsloot (open drainage) and Saramacca canal to Suriname river
	23	Pumping station Tamanoea	No data	No data	In function	Through Spoorsloot (open drainage) and Saramacca canal to Suriname river
Saramacca Doorsteek	24	Sluice Sarmacca doorsteek (Slash lock)	No data	No data	In function	Directly Suriname river
	25	Suhoza sluice	No data	No data	In function	Directly Suriname river
	26	Sluice Houttuin	No data	No data	In function	Directly Para river
Weg naar zee	27	Pumping station weg naar zee	1.5 m³/s	No data	In function	Directly the Sea (north)
	28	Sluice Henry Fernandes	No data	No data	In function	Directly the Sea (north)
Saramacca Resort						
Uitkijk	29	Sluice Uitkijk (Slash lock)	No Data	No data	In function	Connects Saramacca canal with Saramacca river
	30	Havelaar sluice	No Data	No data	Inoperative	Connects Saramacca canal with Saramacca river
	31	Pumping station Uitkijkpolder	2 m³/s	No data	In function	Directly Saramacca river

Area	No.	Sluice / pump	Pump capacity	Discharge area	Status	Discharge direction
	32	Pumping station Erfpachtspolder	No Data	No data	In function	Directly Saramacca river
	33	Koendala sluice, calcutta West	No Data	No data	In function	Connects Saramacca canal with Saramacca river
Wanica Resort						
Santo Polder	34	Irrigation pumping station	No Data	No data	In function	Directly Saramacca canal

Table Appendix A1-2: Existing structures data

1.2.4 Existing hydraulic model (SOBEK model)

The existing hydraulic model developed by Delft Hydraulics (Deltares) for the De-Watering Master Plan study (2001)[20] was used to identify the main drainage system, extracting dimension such as channel depths and top width. It was also used to check roughness values and connectivity between different channels.

1.2.5 Digital terrain elevation

Two datasets were made available for this study; the NEXTMap World 10 (based on the 30m IFSAR data) from Intermap Technologies Inc, and AIRBUS World DEM.

Initial investigations suggested that using the former would not provide meaningful results, particularly in heavily vegetated coastal areas and the built-up areas within the city. Therefore, the data that has been selected to build the model was the AIRBUS World DEM, processed to produce the required DTM at a horizontal resolution of 12m. The advantages of this data set are:

- Genuinely measured at 12m resolution (as opposed to being measured at lower resolution but resampled to provide a smaller grid).
- Most recently flown of the readily available global data sets, and uses most up-to-date technology, and captures the most up-to-date land forms.

1.2.6 Spatial reference

Two system were using across the study the "Zanderij_1972_UTM_Zone_21N" and the "World Geodetic System 1984" (WGS84). The former was used to build the hydraulic model while both Master Database has been produced on both system.

1.2.7 Vertical Datum

Elevation recorded on the AIRBUS World DEM is referred to the Earth Gravitational Model 2008 (EGM2008) datum which basically is Mean Sea Level (MSL). This vertical datum in used in the hydraulic model.

20 Consortium formed by DHV Consultants, WL Delft Hydraulics, Adviesbureau Milieu en Infrastructuur and Sunecon Engineering, for the Government of Suriname. De-Watering Master Plan study (2001)

1.2.8 Gauging station rainfall and tidal levels

Observed river levels, tides, and rainfall records were available at different locations within the study area. Observed river levels were used to inform initial water levels in the canal system. Tidal levels and rainfall data were used to determine the boundary conditions in the model. These are provided in separate documents contained in the handover information and are not given in this Model Operation Manual.

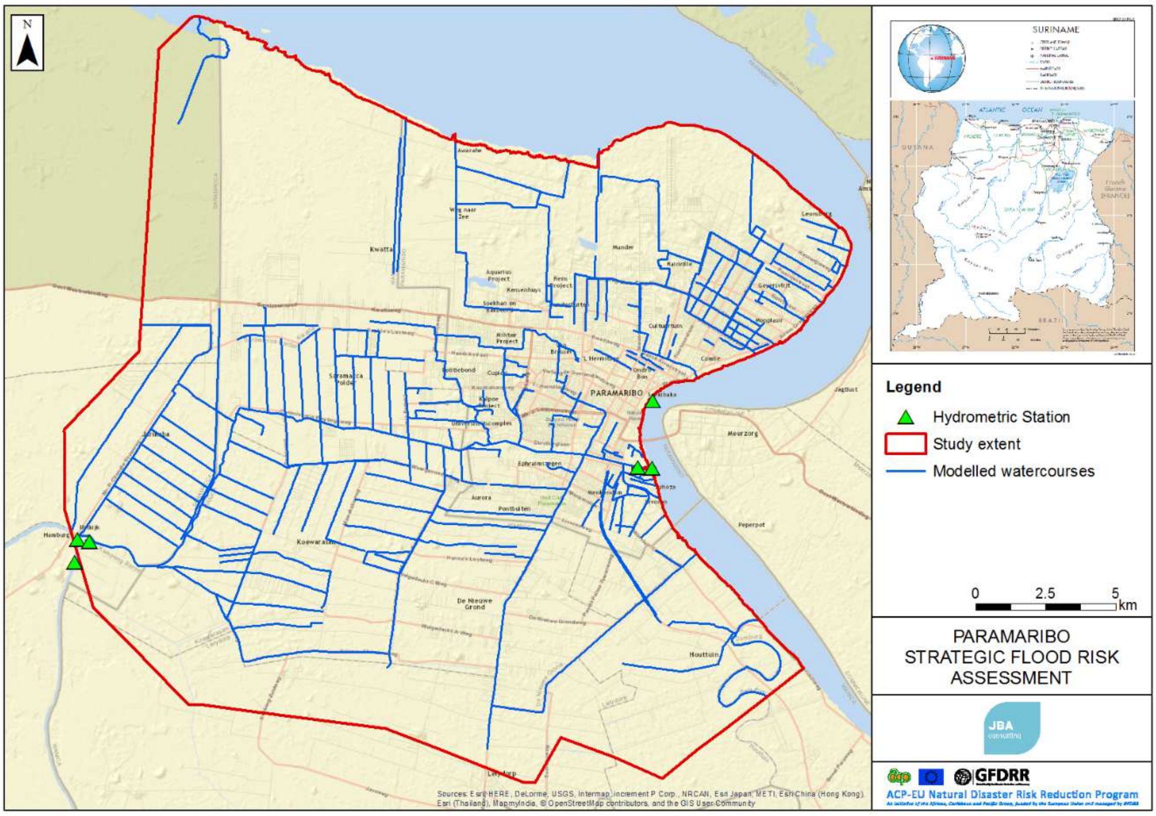


Figure Appendix A1-2 Location of hydrometric river gauge stations

1.2.9 Other data

Summary of other data supplied:

- Existing study
    - De-Watering Master Plan study (2001)
- Various datasets:
    - Costing & vulnerability
    - Exposure area

1.3 Model build

1.3.1 Choice of software

HEC-RAS was chosen as the software to complete the hydraulic model for the following reasons:

- The ability to perform 1D, 2D and combine 1D/2D modelling.
- The software solves Saint-Venant or Diffusion Wave equation in 2D and the user can select the equation to use for any given problem. In general, the Diffusion Wave equations allow to run faster. However, some situations need to be modelled with 2D Diffusion Wave equation to provide results with a higher precision.

- The algorithm used by the software is robust, it is based on an Implicit Finite Volume algorithm which are more stable than traditional finite difference and finite element techniques. Allowing the domain to start completely dry and to handle rapid changes on water levels.
- The use of unstructured computational meshes, the mesh can be a mixture of different cell shapes and sizes.
- The hydraulic properties of each Computational Cell and Cell Faces are calculated based on the underlying terrain model using a technique developed by Casulli[21] "high resolution subgrid model". By adopting this technique, an elevation-volume relationship within each cell is computed, allowing the cells to be partially wet based on the water level.
- In a similar way, Cell Faces are treated as cross-sections and hydraulic properties are computed for each Face, allowing the use of large computational cells without losing detail of the terrain that controls conveyance. An additional benefit of this functionality is the potential to avoid the complexity and instability introduced if there is a necessity to use 1D - 2D linking to transfer water between the 1D and 2D domains.
- The capability to use a large grid size and minimise model run times, without compromising the accuracy of the modelling outputs.
- The ability to produce detailed flood mapping and animations.
- The model software is free and thus there are no immediate or long-term costs linked to using the model for future work.

The purpose of building the hydraulic model was to inform a strategic level study. Based on the mechanisms of flooding limitations on the available data, the extended network of channels and the relative flat nature of the floodplain a 2D approach was used to model the channels and floodplain. This allows the representation of accumulated flooding in the low laying areas of the floodplain, due to high intensity rainfall events, to develop flow paths and convey flow through the floodplain towards the channel network and vice-versa. On tidal events, the mechanism of flooding is also well represented where flooding propagates inland through the channel network and low laying coastal areas.

A number of tests were carried out to determine the optimum grid size which no compromises resolution while keeping manageable simulation times and size of model outputs. Generally, a cell size of 100m was selected for the hydraulic model, although this was reduced at locations where more precision was required to define influential local detail.

The full extent of the Greater Paramaribo City model was schematised in a 2D approach, providing several benefits including:

- Storage of flood water and attenuation that the floodplain provides should be more reliably modelled, as flow paths, storage volumes and conveyance are more explicitly represented in the 2D grid.
- Mapped outputs (depth, velocity, and water level) are exported for the floodplain extent where flooding is predicted, meaning outputs are simpler to extract and differences in flood extents and depths, velocities etc can be more easily derived for scenario tests.

21 Casulli. 2008. A high-resolution wetting and drying algorithm for free-surface hydroginamics. Int. J. Numer. Meth. Fluid. 2008.

A further consideration is that the available survey and topographical data was not generally of a resolution that made it appropriate for use in 1D schematisation.

1.3.2 General schematisation

Channel

The channel system is modelled in the 2D domain. Topographic survey of the Saramacca Canal was used to develop a terrain model of the channel bed. This terrain model was then combined with the general surface (AIRBUS World DEM). As described previously the model software adopts a method that includes representation of the hydraulic properties of the cells in the 2D domain making it possible to represent the conveyance capacity of the channel systems without introducing the complexity of 1D - 2D linking in the model.

In additions, ground levels of the terrain model were also modified to represent the connectivity of the channel system. Based on the information extracted from the Sobek model and inspection on aerial imaginary, a channel with of 12m and minimum depth of 2m were assumed across the whole study area, except for the Saramacca canal as explained above. These channels dimensions were stamped on the terrain model on all channel identified in the study area.

Structures

Pumping stations and sluice gates were the main structures included in the model. Pumping stations placed at the boundary with either the sea or the Suriname River (structures number 1, 4, 5, 6, 7 & 8) were modelled using a 2D boundary conditions, applied to the cell face where the pumping station are located. The type of boundary used to model these pumps was set to a rating curve based on the maximum pumping capacity reported in Table Appendix A1-2 above complemented with information collected during the site visit. The adopted maximum pumping capacities is presented Table Appendix A1-3 below.

The remaining pumps are either pumping within the 2D domain (structures number 9, 20, 21, 22 & 23) or from the 2D domain to the external boundary to the sea or the River Suriname (structures number 13, 14 & 15). These structures were modelled using the “Wormhole Method” for including long culverts in a 2D HEC-RAS model[22].

Structure No.	No. of pumps	Max capacity per pump (m^3/s)	Max capacity modelled (m^3/s)
1	1	1	1
4	1	2.2	2.2
5	3	0.6	1.8
6	3	4.5	13.5
7	2	1.1	2.2
8	3	4.5	13.5
1890	2	1.1	2.2

Table Appendix A1-3: Adopted pumping capacity

Table Appendix A1-4 below indicates the adopted dimensions for other outlet structures such as sluice gates and flat valves represented in the model. These structures are mainly connected to the Suriname River or the Sea at the and at downstream end of a canal. Most structures dimensions, both flow area and invert levels, have been adopted based on photographic records taken during site

22 http://www.surfacewater.biz/long_culvert/

visit (provided by the client) and dimensions of the channels where they are placed. It should be noted that they have not been explicitly represented in the 2D model, the approach adopted for the strategic assessment was to represent each individua outlet in a 1D model and extract the flow-time series through the gates for each event modelled. Then, these series were incorporated in the model as boundaries conditions allowing to discharge from the system.

Outlet structure	No. of units	Dimensions (width * height)	Type / Representation
2	1	1.4m * 2.5m	Gate / flow-time series
3 (*)	1	2.25m * 1.0m	Gate / flow-time series
6	2	3.3m * 1.0m	Gate / flow-time series
7 (*)	1	2.25m * 1.0m	Gate / flow-time series
12 (*)	1	2.25m * 1.0m	Gate / flow-time series
16	2	2.0m * 2.0m	Gate / flow-time series
24	5	4.0m * 3.0m	Gate / flow-time series
25 (*)	2	2.25m * 1.0m	Gate / flow-time series
26 (*)	2	2.25m * 1.0m	Gate / flow-time series
27 (*)	1	2.25m * 1.0m	Gate / flow-time series
28	3	1m (diameter)	Pipe-valve / flow-time series
29	1	8.5m * 5,5m	Gate / flow-time series
30	4	2m (diameter)	Pipe-valve / flow-time series
S5000 (*)	2	2.25m * 1.0m	Gate / flow-time series
S1060 (*)	2	2.25m * 1.0m	Gate / flow-time series
N1650 (*)	3	2.25m * 1.0m	Gate / flow-time series
S1695 (*)	1	2.25m * 1.0m	Gate / flow-time series
S1100 (*)	2	2.25m * 1.0m	Gate / flow-time series
S1890 (*)	2	2.25m * 1.0m	Gate / flow-time series
N5010 (*)	2	2.25m * 1.0m	Gate / flow-time series
Wanica (*)	2	2.25m * 1.0m	Gate / flow-time series

Table Appendix A1-4: Adopted dimension of sluice gates
(*) generic sluice gate dimensions adopted

Waterbodies in the floodplain

Model representation of other waterbodies in the floodplain in addition to the canal network, for instance lakes/ponds linked to Matinusstraat and Aquariusstraat in the North and Celebes Weg to the South, were informed by elevations within the World DEM data,

Buildings

High resolution information on building footprint was limited to a small area of the city and building thresholds were not generally available. Therefore, no adjustment to ground levels were made at building footprints (for instance to account for the presence of building thresholds). Individual buildings were not assigned specific roughness values nor represented in the model, however, at urban locations containing many buildings a general roughness allowance of 0.08 was made in the model to represent the effect of buildings on flood flows in the 2D domain.

Topographic features

Levels for the top of the embankment along the Weg Naar Zee area (north of the study area) were incorporated in the DEM from the existing topographic survey (Table Appendix A1-1, survey reference S10). This was pre-processed using standard features in the TUFLOW software.

Walls along the left bank if the Suriname River were obtained from elevations derived using the World DEM. There was no survey information for these walls and thus it was not possible to include more detailed representation. However, it is considered that these features only offer a low standard of protection, high enough to stop the propagation inland of MHWS levels, used to model as boundary condition for the fluvial flooding events analysed, but too low to prevent flooding during the 1 in 10yr tidal event level at some locations.

Road levels

Spot level checks along the main road across the whole study area were specially collected for this study. This data was used to review the World DEM data and also used to derive a representation of the effect of these features as they are known to be the cause of a key constraint to the performance of the drainage system.

The same approach used to represent the canal system was implemented to 'stamp' the roads in the World DEM and so make a strategic allowance in the model for the elevated nature of the highways adjacent to the drainage systems. Elevations along the surveyed roads were raised by the average difference between the surveyed level and the World DEM value. This analysis was done by partitioning the roads into a series of discrete segments and applying an average difference in ground elevation to a width of 12m which is the pixel resolution of the World DEM. It is accepted that this is not a high resolution approach, but is considered appropriate for the purpose of a strategic assessment.

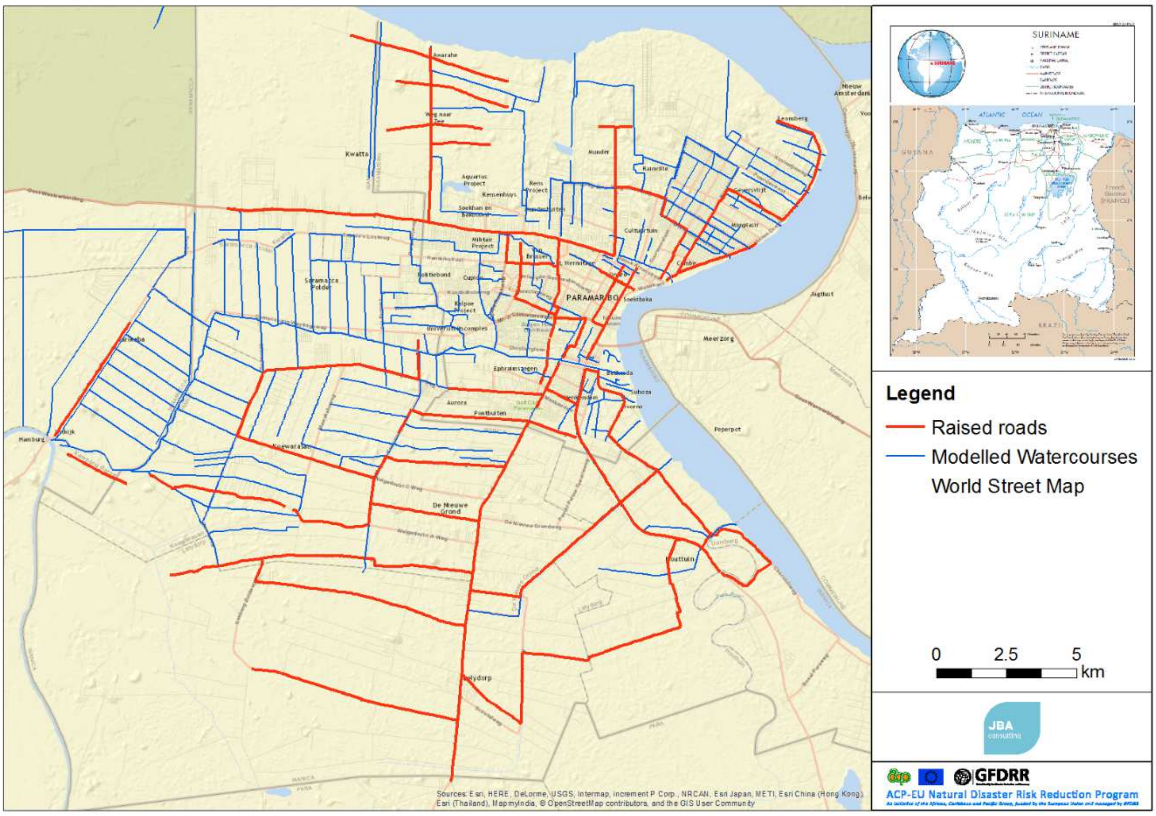


Figure Appendix A1-3 Extent of the road spot level checks

2 Modelling overview

This section provides greater detail on the schematisation of the hydraulic model. Table Appendix A2-1 provides a summary of the model schematisation.

Watercourse	Model chainage	Channel	Floodplain
Saramacca Canal	25.19km Full extent of the Saramacca Canal from Suriname River to Saramacca River.	Channel bed elevation model developed from existing topographic survey and merged to general terrain model	2D continuous grid
Channel network	449.98km Full extent of channel/canal network modelled (excluding Saramacca Canal).	12m wide by 2m deep channel 'stamped' in the general terrain model	2D continuous grid

Table Appendix A2-1: Summary of model schematisation

2.1 2D model overview

2.1.1 Pluvial boundary

Full details of the hydrological assessment are provided in Appendix B of the main report.

The pluvial flood risk was assessed using direct precipitation applied to the whole 2D domain area. The total rainfall estimated for different return periods are presented in Table Appendix A2-2 below. These total rainfall values were then distributed in time, using a generalised profile derived by NOAA for Latin America and the Caribbean for a 24hr storm duration.

Return period (1 in:)	10 year	50 year	100 year	200 year
Total precipitation (mm) - present climate	128	169	187	204
Total precipitation (mm) - future climate	144	191	211	231

Table Appendix A2-2: Total rainfall (mm)

No initial losses to the precipitation were applied on the scenarios modelled, as it was assumed that the soil within the area would likely be saturated. Climate change was taken into account by increasing the total precipitation by 13%. This increase was adopted based on similar studies done in the region using projection to the year 2050.

2.1.2 Tidal boundary

Full details of the tidal level assessment are provided in the main body of the report.

Table Appendix A2-3 indicates the Mean High Water Spring (MHWS) tide was applied as downstream boundary for all pluvial event analysed. This table also indicated the Extreme Sea Levels (ESL) estimated for the different tidal flooding events used in the study.

As indicated in the main report, sea level rise allowance for Paramaribo by 2050 has been developed as a range, based upon IPCC projections for sea level rise (Church et al. 2015) and regional observations of relative sea levels over the last 30 years. The lower limit for sea level rise of +0.09m is based on the IPCC lower estimate of global sea level rise. The upper limit of +0.27m rise by 2050 is based on the IPCC upper estimate of global sea level rise plus a 2.5 mm/yr regional trend.

Return period (1 in:)	MHWS	10 year	50 year	100 year	200 year
Peak tidal level - present climate	1.32	1.95	2.06	2.11	2.16
Peak tidal level - future climate low band	1.41	2.04	2.15	2.20	2.25
Peak tidal level - future climate high band	1.59	2.22	2.33	2.38	2.43

Table Appendix A2-3: Extreme Sea Levels (m, relative to datum WGS84)

The tidal boundary was applied along the whole coastal boundary of the model, both along the Suriname River to the east and along the sea boundary to the north. For coastal events, a sequence of three high tides, with the middle one being the largest was applied, while for pluvial events, a 48hr tidal cycle (MHWS) was used to allow the system to drain off.

At the outlets structures of each canal, the derived flow-time series from the 1D model for each tidal condition were included. This representation mimics the behaviour of the sluice gates, allowing discharges from the canal system when tidal water levels are lower than water levels in the canals and prevents tidal water entering the model when tidal levels are higher than those on the canals water level.

2.2 Model schematic

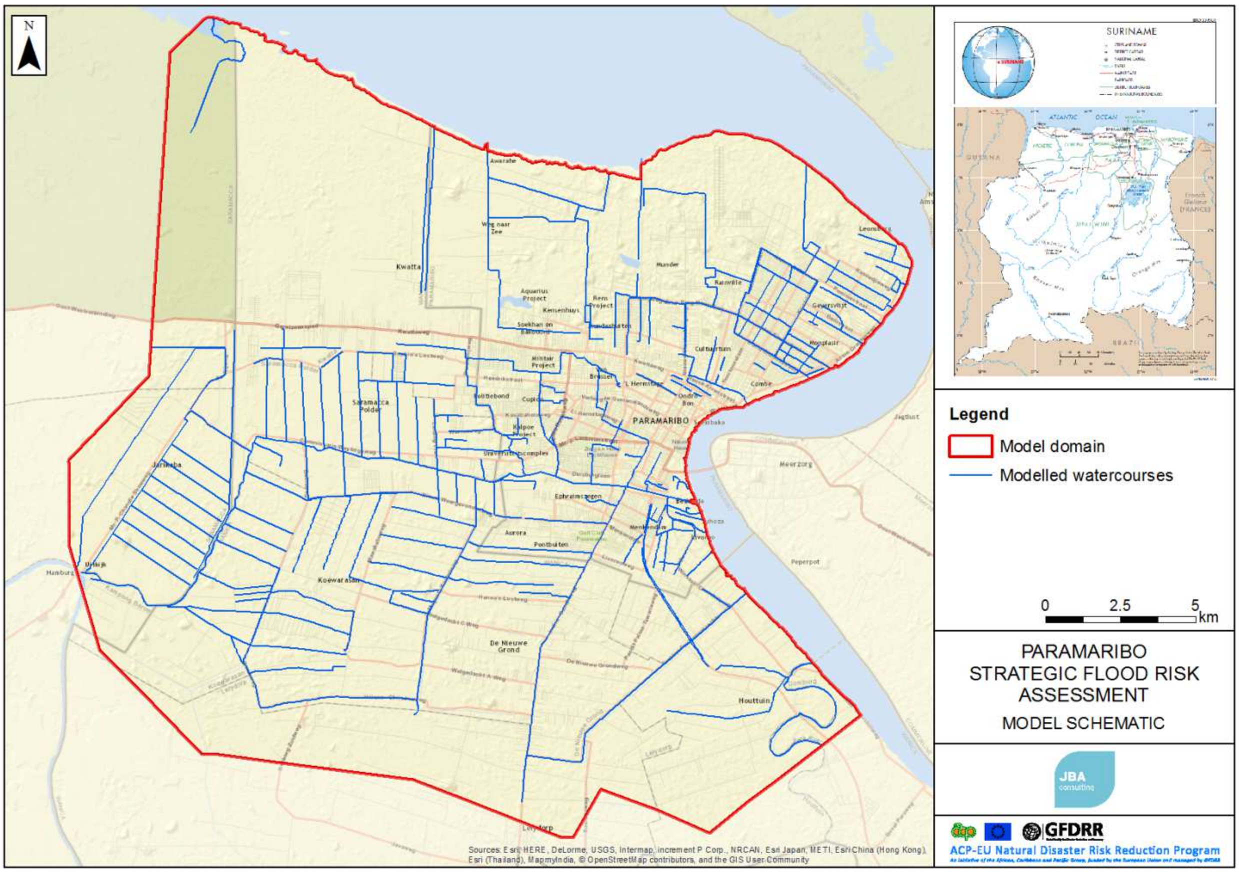


Figure Appendix A2-1: Schematic of the hydraulic model

2.3 2D model overview

Area of 2D domain	503.99km^2	**DTM data source**	World DEM
Resolution of grid	100m	**DTM resolution**	12m
Modifications to topography and reasons	Saramacca Canal	Channel bed elevation model developed from existing topographic survey and merged to general terrain model.	
	All other modelled watercourses	Elevation of watercourses represented using a 12m wide by 2m deep channel stamped in the DTM.	
	Tidal embankment toward north	Elevations of embankment implemented/raised using topographic survey points.	
	Main roads	Elevations of surveyed roads raised using spot check survey data.	

To address the uncertainties in the DTM, ground levels across the main roads were collected. This was carried out using GPS survey equipment mounted on a vehicle; driven along the main roads throughout the city and capturing many thousands of spot heights. These were used to adjust the DTM accordingly, raising the road levels by the average difference between the DTM elevation and the levels collected along different reached of each road. The reason for raising the elevation of these main roads in the model was to capture the constraint to flow from the flood plain to the drainage channels that these features impose.

Further modifications to the DTM included filling up a depression on the northeast area (around Blauwgrond resort) that was considered unrealistic based on feedback from representatives of the Ministry of Public Works. Further discussions are presented in the model verification section below.

2.3.1 2D hydraulic roughness

Manning's n values have been used to represent hydraulic roughness in the 2D domain. The roughness values recorded in Table 2-2 were used in the model (where applicable) and are based on photos taken during site visits/surveys, aerial photography, and various land cover categories defined within the modelled area.

Land Cover	Manning's n
Agricultural	0.06
Canal network	0.06
Grassland	0.07
Saramacca Canal	0.06
Scrubs	0.08
Urban	0.08
Wetland	0.06
Woodland	0.11
Default value for unclassified areas	0.06

Table Appendix A2-4: 2D hydraulic roughness

2.4 Model runs included in this commission

2.4.1 Baseline Design events

Pluvial case

Existing situation was run for the following pluvial AEP events: 10%, 2%, 1% and 0.5%. In addition, one climate change scenarios was simulated for each event. The change factor for this event was 13% in total precipitation and MHWS were increased by 0.27m (upper limit)

This totals 8 design model runs.

Tidal case

Undefended scenarios were run for the following AEP events: 10%, 3.3%, 1% and 0.1%. In addition, two climate change scenarios were simulated for each event. The change factors for these events were +0.09m (lower limit) and +0.27m (upper limit) respectively.

This totals 12 design model runs.

2.4.2 Sensitivity testing

Sensitivity analysis on the pluvial case on the rainfall distribution were carried out and compared against the generalised profile derived by NOAA for Latin America and the Caribbean for a 24hr storm duration.

Sensitivity analysis on the pluvial case 1% AEP event was carried out for:

- Constant Rainfall intensity profile – 1 run
- Linear Change Rainfall Intensity – 1 run

Total of 2 sensitivity runs.

2.4.3 Scenario runs - mitigation options

This section documents the scenario model simulations prepared e.g. adjustments to channel capacity and pumping rates etc. The schedule of simulations is recorded in s per scenario).

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Option	Scenario	Comments
Structural options		
1	Improve road drainage along the roadside instead of the open drains	Thought of as installing large (600mm) pipes, with the intention of improving drainage rates and reducing the likelihood of blockages (through siltation and vegetation growth), this reducing maintenance of the drainage networks. This was represented in the model by reducing roughness across land cover from 0.08 to 0.025
2	Increase the main canal network throughout the city and surrounding area by approx. 20% volume	The main canal network was widened by 20% (including using modifications to the DTM). This would in reality be achieved by dredging the channel and removal of vegetation
3	Increase conveyance through culverts under roadways at key locations	12m cut through the raised roads were placed at 500m spacing on all raised road implemented by modifying the DTM.

4	Install new canal network	For this option, development of a canal network was proposed to the north of the city (within the Blauwgrond resort), with a large drainage capacity towards the Atlantic coast. This was represented in the model by incorporating 10 new canals (2m width by 2m depth) with sluice gates and pumps at the coast. A pumping capacity of 10 m^3/s was assumed which were modelled using a rating curve as downstream boundary condition.
5	Pumps on all the main river wall sluices	This aimed to improve drainage during high tides. A pumping capacity of 5 m^3/s was assumed. This was represented by adding a rating curve at the downstream end of all canal where a pumping station is not included in the baseline scenario.
6	Double pumping capacity where pumps currently exist.	Discharges for the existing pumping stations were increased by twice its baseline capacity. This was represented by modifying the rating curves used in the downstream boundary condition.
7	Saramacca Canal improvements	This involved widening and increasing conveyance along the entire reach of the canal. This would be done by dredging and removal of vegetation. This was represented by increasing the width the Saramacca Cannal to an average of 70m and reducing its roughness value from 0.06 to 0.030.
8	Increase discharge capacity at eastern end of Saramacca Canal	Increased discharge achieved by widening (or incorporating a larger number) of sluice gates. In this scenario, tidal locking still occurs.
9	Increase discharge capacity at eastern end of Saramacca Canal	This option was tested using a pump to allow water to discharge for a longer period; assuming a pumping capacity of $20m^3/s$.
10	Navigation lock in the middle of the canal (located approximately at the watershed).	Adding a navigation lock along the central reaches of the canal aimed to allow higher water levels towards the west, and lower levels towards the east prior to flooding events. This option assumes the canal is 2m lower at the start of the event.
11	Major drainage improvements to the north west of Paramaribo through Kwatta area	This option tested the application of pumps to allow a longer discharge period (assuming a pumping capacity of $10m^3/s$).
12	Combined	This option investigates the combine benefit of implementing the mitigation measures line out in Option 2 + Option 5 + Option 7.
Non-structural options where additional modelling was not required		
13	Flood forecasting and early warning – assume flooding still occurs, but vulnerability can be reduced i.e. reflected through contents depth damage curves	This option assumes that flooding still occurs, but that vulnerability may be reduced; represented using contents depth damage curves. No further modelling was required to access this option as the assessment was carried out by modifying the damage curves.
14	Land use planning and building codes	Again, this option assumes that flooding will still occur, however vulnerability will be reduced i.e. reflected through the expected increase in building density having a much-reduced impact. Modelling was not required.

Table Appendix A2-5: Schedule of scenario simulations

Total of 48 scenario runs (12 scenarios and (four events per scenario).

3 Calibration and verification

Calibration of the hydraulic model was not carried out, in part due to the lack of recorded information on events covering the extended area of the study, and also as it did not form part of the scope of this strategic study. Instead, model verification was carried out to provide confidence in the model outputs.

The model verification consisted in running a number of tidal simulation ranging from MHWS level to the 10% AEP tidal event. These initial model outputs did not include allowance for the operation of tidal gates or pumping stations. However, two set of runs were presented assuming that all structures were closed or open during the tidal events.

Figure Appendix A3-1 below illustrates the model output for the Highest Astronomical Tide (HAT). These outputs were discussed with the representatives of the engineering team of the Ministry of Public Works of Suriname on the work shop carried out in December 2016. At this workshop it is understood the engineering team representatives confirmed that prediction of the model in regards the flood extents and locations shown to this high AEP tidal events were as they would have anticipated.

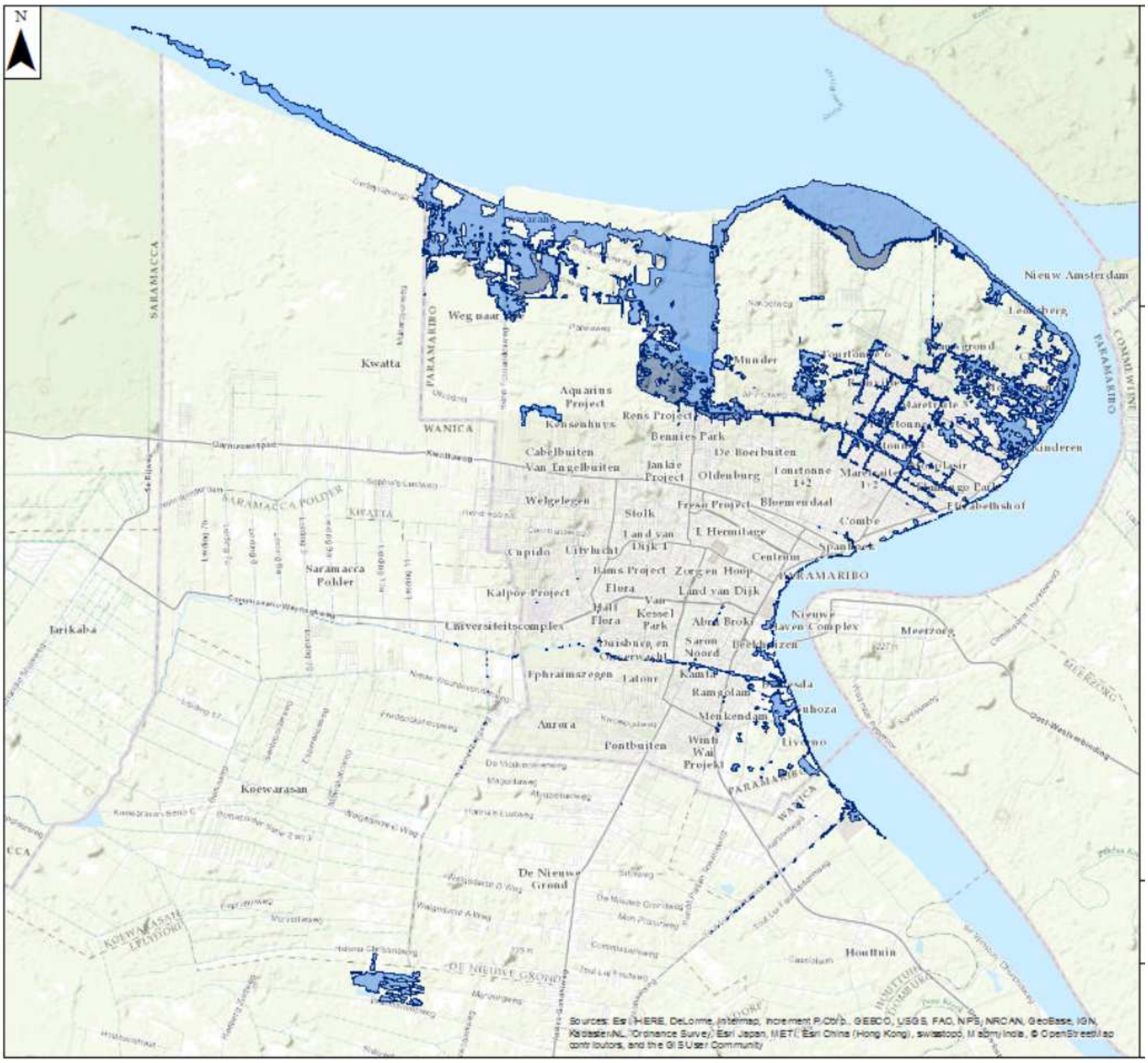


Figure Appendix A3-1: Flood extent - Highest Astronomical Tide (HAT) - Initial model outputs

Note: Highest astronomical tide (1.57m) - gate opened (dark blue) - gates closed (light blue).

A similar exercise was performed for the pluvial events only with no tidal boundary. Figure Appendix A3-2 illustrates maximum water depth for the 1% AEP event. These model outputs were prepared to allow observations to be made on the characteristics of the DTM data and representation of the canal system based on the data (before editing the DTM). As can be seen in the figure, there are two areas (1 & 2 respectively) showing concentric water depth that were considered unrealistic. Following further consultation with MoPW, the DTM was modified and these depressions were digitally 'filled' for the purpose of preparing the model results.

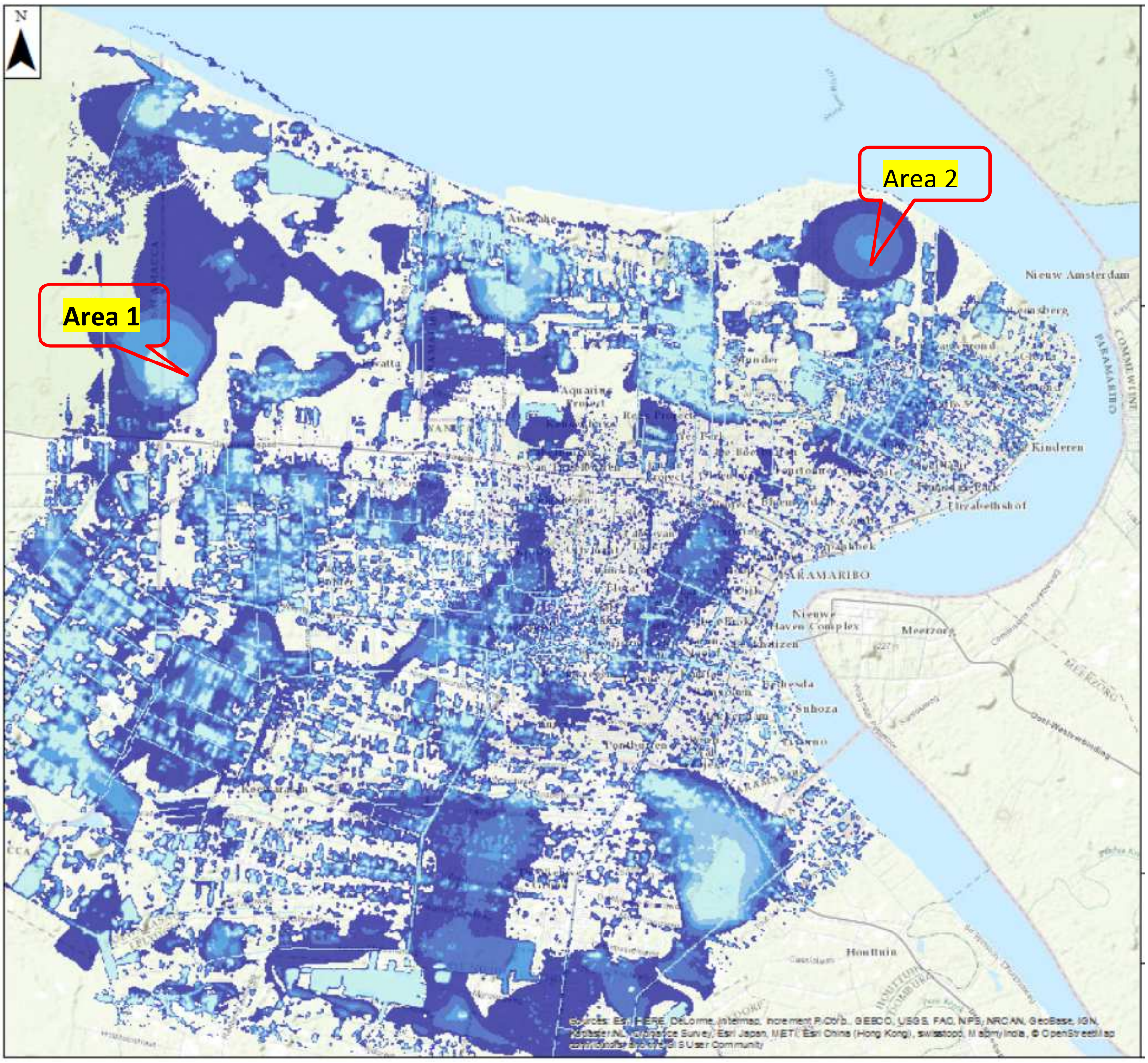


Figure Appendix A3-2: Maximum water depth - 1% AEP event - Initial model outputs
Note: Pumping stations not operational for the initial model verification.

4 Model assumptions, constraints and uncertainty

4.1.1 Assumptions

During any hydraulic modelling study, there will always be limitations, for example with uncertainty, data availability and other issues. The representation of any complex system by a model requires a number of assumptions to be made. In the case of the hydraulic model used in the strategic analysis it has been assumed that:

- AirBus World DEM provides a reasonable reflection of bank heights and particularly that the filtered DEM has appropriately removed the influence of vegetation.
- The assumptions made on the representation of the canal system by using a 'stamp in' technique and the subsequent modification made to the DEM to represent them in the model provide are appropriate for the purpose of a strategic assessment.
- Cross sections used to represent the cross-section profile of the Saramacca Canal in the DEM provide an appropriate representation of the shape and variation of the canal for the purpose of a strategic assessment.
- Model parameters included are appropriate for the purpose of a strategic assessment.
- Design total precipitation and hyetograph provide a reasonable representation of precipitation for a given return period.
- Extreme flood events are most likely during a prolonged wet spell of weather, and soils therefore would be saturated resulting in 100% run-off during the short intense design storm selected.
- Design tidal curves and levels provide a reasonable representation of tidal conditions for a given return period.
- The assumptions made on the hydraulic structures (gates and pumps) and the system used to represent them in the model provide a reasonable representation of the situation (dimensions, capacity, location and operation) for the purpose of a strategic assessment.

4.1.2 Constraints

A 2D only modelling approach was considered most appropriate to represent the flood hazard associated with pluvial and coastal flood risk for this city scale strategic level of the study. Using the features within HEC-RAS that allows the detail within the original high resolution DTM to be captured within the lower resolution model grid, the model can represent the conveyance capacity of the channel systems without the need to introduce the complexity and instability associated with a 1D - 2D model.

This approach represents the complex flow path between the canal system and floodplain, and has the advantage of capturing momentum of the water flow as it passes to and from the channel and floodplain (this is not the case with a combined 1D - 2D model). However, this approach is only as good as the underlying DTM, and although the best DTM data available has been used, there will still be some hydraulically significant features missing, such as bridges, culverts, and narrow flood banks or walls banks, or buildings, which are not explicitly represented in the model.

Discharges from the outlet structures of each canal were simulated externally from the main model using a small 1D only model for each, to more accurately define its hydraulic behaviour under a range of water levels and produce a discharge data set for each. This discharge data was then incorporated into the 2D model as downstream boundary conditions. On pluvial events, this approach does not take into account the dynamic changes in water levels due to the flows being conveyed in the canal system toward the outlet, and the discharges. It takes account of flows generated by the tide coming in/out of the system only. This is a limitation of the software which current version does not allow to link a structure at the domain boundary.

4.1.3 Uncertainties

The DEM used to set the base topography in the 2D model domain is a fundamental source of model uncertainty. The bare earth DTM was filtered to remove the presence of buildings and vegetation. The DEM data used within this study is at a 12m grid resolution. This subsequently impact on the definition of features. While checks using existing topographic survey and spot level check across main roads were carried out, it remains a degree of uncertainties in the DEM.

General modelling assumptions relate to the selection of various parameters within the model, for example, the roughness values used within the model, representation of certain structures and their coefficients. A programme of model proving has been undertaken to understand any uncertainties associated with the choice of parameters and their impact upon model results.

5 Final model files and outputs delivery

This section records the final model outputs delivered as part of this study and provide a description of the data included in each folder delivered in digital format. The data has been organised in three main folders as indicated in Figure Appendix A5-1 and Table Appendix A5-1 below. The intention is that this data will be the basis for the handover information provided.

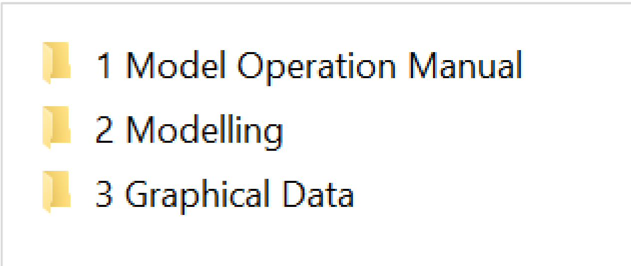


Figure Appendix A5-1: Digital folder structure

Item No.	Summary	Subfolder structure
1 - Model Operation Manual	Model Operation Manual for the study provided in an electronic format. In addition, a summary on the processes for selecting the canals included in the model and estimation of building densities are also included in the PDFs document enclosed	This document: (2016s4840 - Paramaribo_SFRA_Model Operation Manual (V1).pdf 2016s4840- Justification of method.pdf 2016s4840-building density analysis.pdf
2 - Modelling	All modelling files used for final baseline and scenario model runs. A model log spreadsheet is also included. This spreadsheet records all model files used in each scenario to guide on use of the model and help with reproducing any of the simulation if needed.	HECRAS 201624840_Paramaribo_HEC-RAS_Model_logs.xls
3 - Graphical	This contains all graphical deliverables produced for the study, including;	

Data	1 - Master database (shapefiles and ArcGIS/QGIS projects). These master database projects include the main study files, such as modelled watercourse network, available cross-section locations, locations of pump structures within Paramaribo etc. A guidance on using the database is recorded on the document "2016s4840-Model Dataset.pdf".	1 ArcGIS Projects 2 QGIS Projects 3 Shapefiles 2016s4840-Model Dataset.pdf
	2 - PDF maps displaying modelled outputs for each direct rainfall and tidal scenario simulated	1 Flood Outlines 2 Rainfall Distribution profile events 3 Flood depths 4 Flood depth comparisons 5 Annual Average Damages 6 Difference in AAD
	3 - Gridded model outputs (both raw and comparison grids of baseline and scenario models)	1 Direct Rainfall 2 Tidal
	4 - Model animations for direct rainfall and tidal events simulated	CC_DR10_baseline.avi CC_DR50_baseline.avi CC_DR100_baseline.avi CC_DR200_baseline.avi CC_T10.avi CC_T50.avi CC_T100.avi CC_T200.avi PC_DR100_CRainfall_profile.avi PC_DR100_CSR_profile.avi T100_W1&3_v4.avi

Table Appendix A5-1: Project deliverables

6 Key messages and recommendations

6.1 Study objectives

JBA Consulting was commissioned to produce a hydraulic model for the Greater Paramaribo City area, Suriname to inform a Strategic Flood Risk Assessment (SFRA). The study focused on pluvial and coastal flooding for present and future climate (end of 2050 EPOC). Model outputs were prepared for 10%, 2%, 1% and 0.5% AEP events.

The model has also been used to simulate a range of mitigation scenarios.

6.2 Key modelling messages

- GIS platform for preparing and storing data is described as follows:
    - A GIS data platform has been prepared to include all data used in the modelling.
    - The data has been attributed where possible, so the source can be determined.
    - The platform provides a summary of data from previous studies.

- Due to ‘gaps’ or ‘ambiguities’ in the data it has been necessary to include assumptions in the model – so not all data in the model is based on data from previous studies.
    - It would be possible to update the GIS platform as new data becomes available in the future.
- Details of model
    - All assumptions made during the model building process have been recorded in this model operation manual.
    - Representation of channels in 2D domain based on cross–section geometry data from existing survey and SOBEK model.
    - Assumptions made on channel inverts, adopting a minimum channel depth of 2.5m and channel width of 12m.
    - Other modification to the DEM included raising ground levels around main roads and incorporating the embankment on the north area of the study.
    - Representation of sluice structures using boundary conditions. Flow-time series derived from 1D model.
    - Representation of pumping stations on using boundary conditions (rating curve) assuming they operate at maximum pumping capacity.
    - Land cover type were classified into nine classes to represent roughness across the model
    - Direct precipitation was input across the whole area of study using a generic 24hr storm duration profile derived by NOAA for Latin America and the Caribbean. Estimates of total precipitation for each AEP event are presented in a separated document.
    - Tidal boundaries were applied along the sea and river coastal boundary. The same tidal curves were applied to the entire boundary, time displacement from the sea coast (north of the model) to the upstream river coastal area (south east of the model) was not accounted for.
    - Baseline and 12 mitigation options were modelled for the 10%, 5%, 1% & 0.5% AEP, both present and future climate; pluvial and tidal scenarios.
    - Vertical datum and spatial reference used in the hydraulic model are EGM2008 and "Zanderij_1972_UTM_Zone_21N" respectively

6.3 Recommendations

- Improved DEM by collecting and use of LiDAR data
- Collect rainfall, flow and water level (or flood extent) data together with flood records so model can be calibrated
- Assumptions on channel inverts can affect discharges, this should be addressed with improved cross-section data for more detailed future analysis.
- Strategic model hasn’t captured precise local detail of connections and connectivity between channels and land – if these are known to be influential then the model can be adjusted for more detailed future analysis.
- Representation of sluices and pumping stations can be improved when improved version of HECRAS is released (software is programmed for improvement).

APPENDIX B: Hydrological Assessment Report

1 Analysis of 1-day Rainfall

Analysis of 1-day rainfall data for Paramaribo/ Saramacca districts prepared by Dr. Isabella Bovolo, January, 2017. Data provided by Suriname Meteorological Office, 2016.

Table Appendix B1-1. Station Data and Location

Index	Code	Station	Lat	Lon
1	530KJARP	K-JARIKABA-PROEF	5.816667	-55.3333
2	6030LAND	Landsboerderij / St. Boerderij	5.783333	-55.2667
3	6110MARE	Ma-Retraite	5.854167	-55.1372
4	6140MORG	MORGENSTOND	5.85	-55.1333
5	6190HECH	HELENA CHRISTINA	5.733333	-55.25
6	6200PEPE	PEPERPOT	5.8	-55.15
7	6320HOUT	HOUTTUIN	5.75	-55.1833
8	6150NWAM	NW.AMSTERDAM	5.883333	-55.0833
9	5190UITK	UITKIJK	5.766667	-55.35
10	604KZENH	ZORG EN HOOP	5.8	-55.1833

Lat Lon data from http://www.meteosur.sr/stat_loc.htm

Table Appendix B1-2. Summary Data of extreme rainfall

	Station	Code	Data available from:	Data available to:	No of years of data within time period	No of complete years of data	Max 1 day RF in hydro year (mm)	Date	2nd max 1 day RF in hydro year (mm)	Date	3rd max 1 day RF in hydro year (mm)	Date
1	K-Jarikaba Proef	530KJARP	01/1969	12/1995	27	21	230.4 (see Graph B)	23/11/1986	147.5 (see Graph A)	26/05/1983	144.8	12/11/1989
2	Landsboerderij/ St Boerderij	6030LAND	01/1953	12/2016	32	17	151.5 (see Graph C)	14/02/1963	137.7	30/01/1965	127.5	15/04/1967
3	Ma-Retraite	6110MARE	01/1954	12/1998	[a] 39	[a] 13	202.4*	03/07/1996	172.5 (see Graph C)	14/02/1963	170.3*	03/07/1996
4	Morgenstrond	6140MORG	01/1916	12/1999	78	57	182 (see Graph C)	14/02/1963	152	19/05/1927	148.3	22/05/1964
5	Helena Christina	6190HECH	01/1961	12/1991	23	13	170 (see Graph A)	26/05/1983	110	22/04/1977	095.5 095.5 (see Graph B)	26/03/1984 23/05/1986
6	Peperpot	6200PEPE	01/1929	12/2016	[a] 76	[a] 59	280*	05/07/1996	255*	27/06/1991	160*	27/12/2001
		6200PEPE					120.5	21/03/1943				
7	Houttuin	6320HOUT	01/1959	12/1999	35	21	126.9	14/07/1980	118	30/01/1965	113	03/06/1961
8	New Amsterdam	6150NWAM	01/1928	12/2016	[a] 77	[a] 57	243.1*	04/06/1996	205*	21/07/1995	200.07*	11/12/1991
		6150NWAM					182 (see Graph D)	06/01/1967	159*?	05/04/2010	157*	02/07/1990
9	Uitkijk	5190UITK	01/1962	12/2016	48	36	270** (see Graph A)	30/05/1983	198.2	06/06/1984	146.6	15/04/1967
10	Zorg en Hoop	604KZENH	01/1961	12/2016	55	49	144.2 (see Graph E)	16/01/1970	120.2	08/02/2009	118.3	15/09/2002

* Not reliable (seems to be an accumulated value)

**preceded by 148 mm on 26/05/1983. Seems to be anomalous value (see graph).

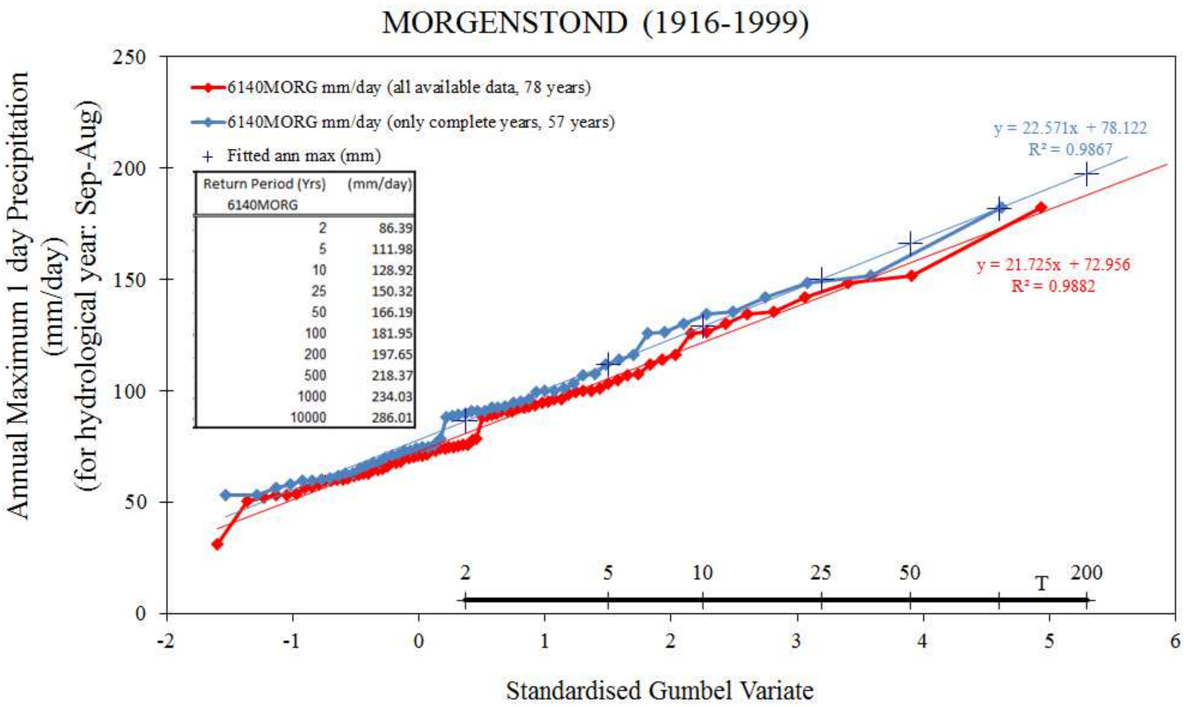
[a] excluding *(not reliable) data points

1 day- return periods (Extreme Value 1 (EV-1/Gumbel) Distribution Plots)

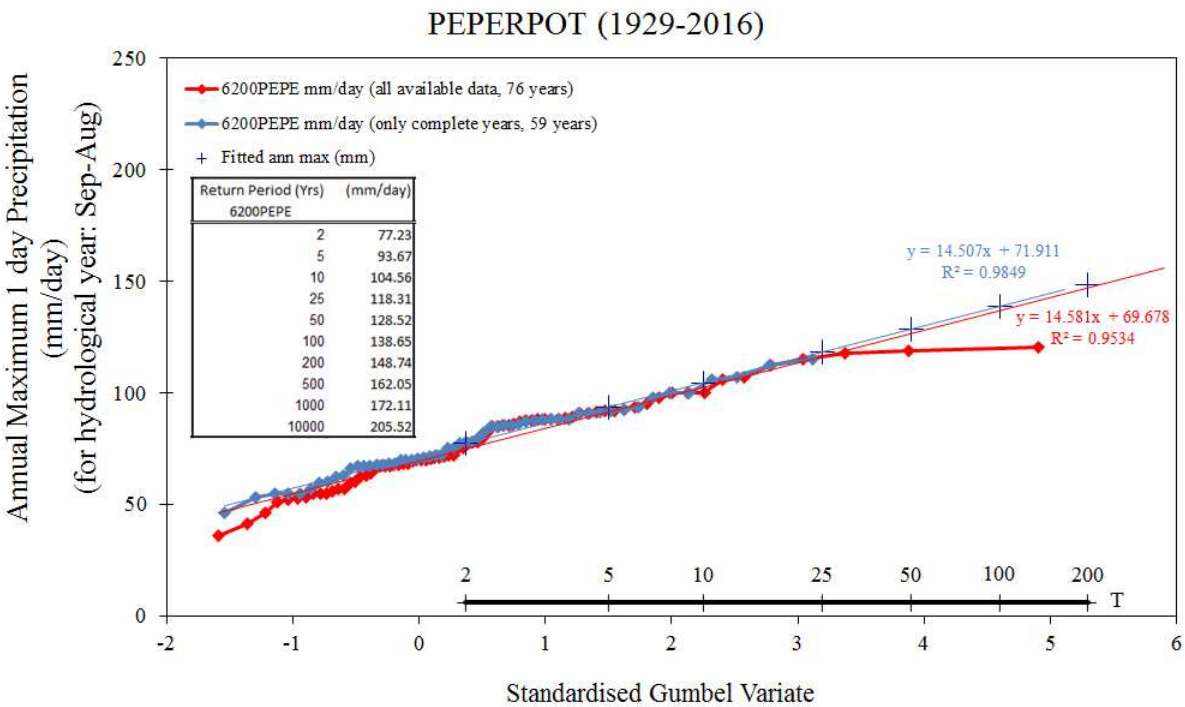
Gumbel Probability Plots shown below are for the annual maximum 1 day rainfall in a hydrological year (Sep-Aug) for each station considering (a) all data (irrespective of completeness) (in red), and (b) only complete data in each hydrological year (in blue). Linear fits are plotted using the Gringorton (WMO) method for (b) complete data in each hydrological year only.

Graphs below are shown in descending order of total number of years of data (ie stations with the most data, which therefore are most reliable, first).

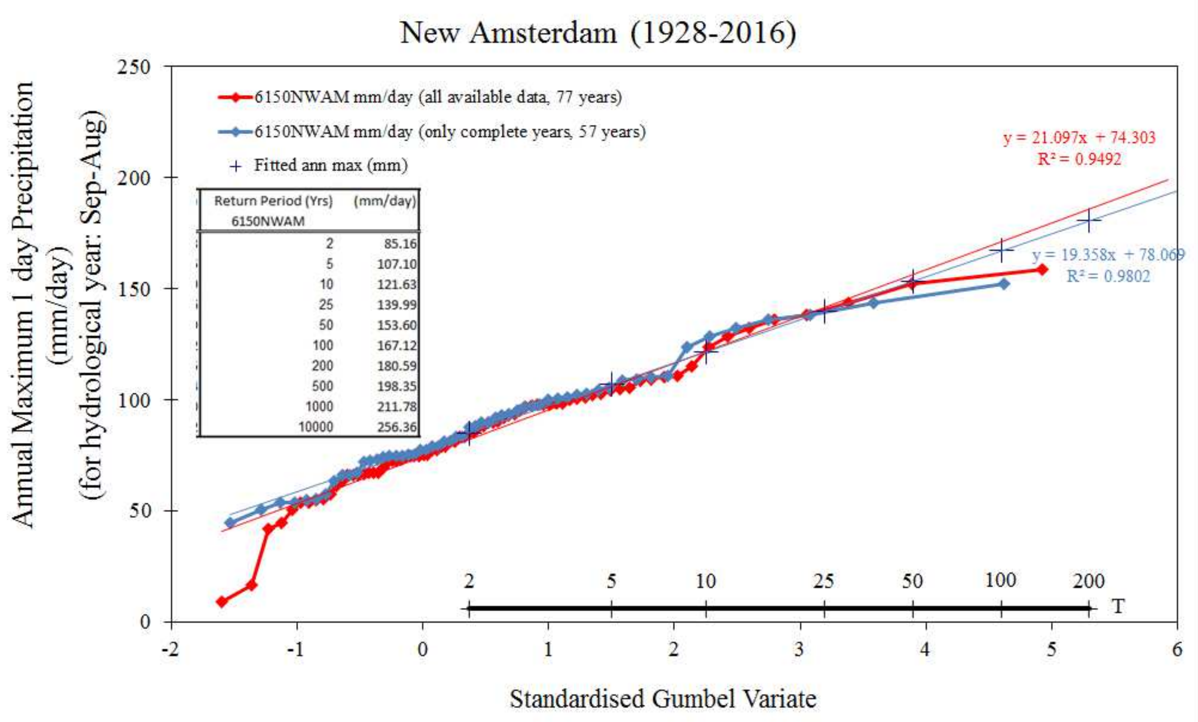
Plot 1: Morgenstrond



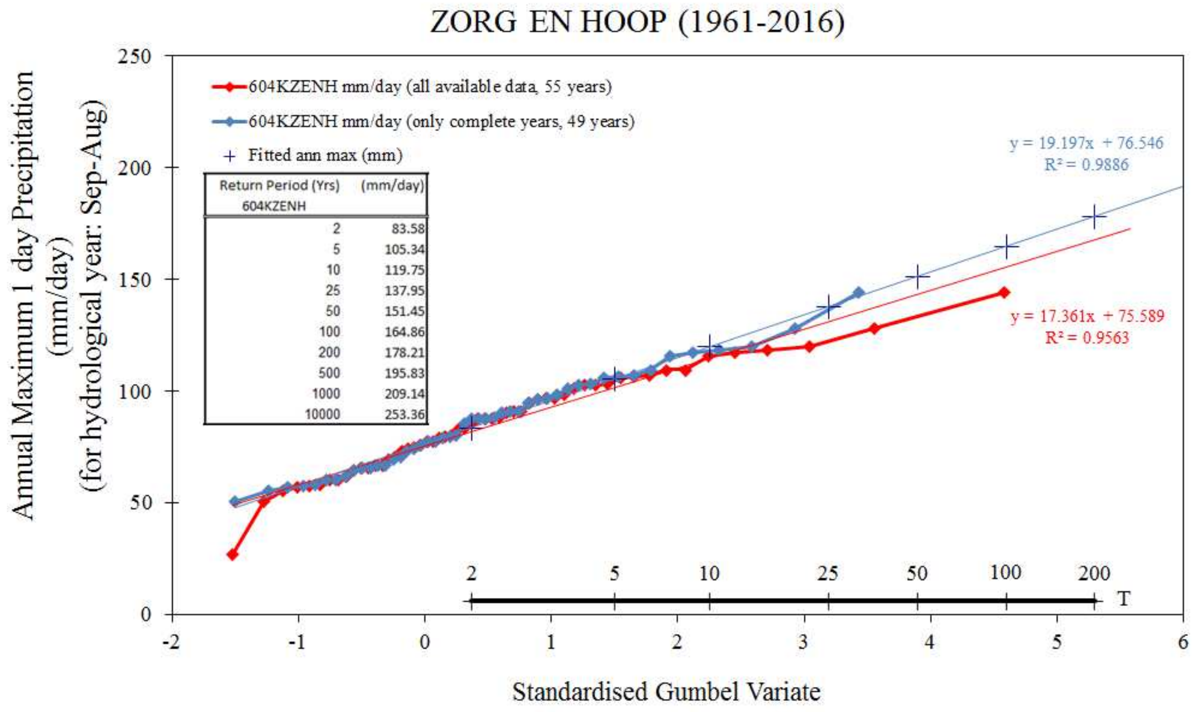
Plot 2: Peperpot



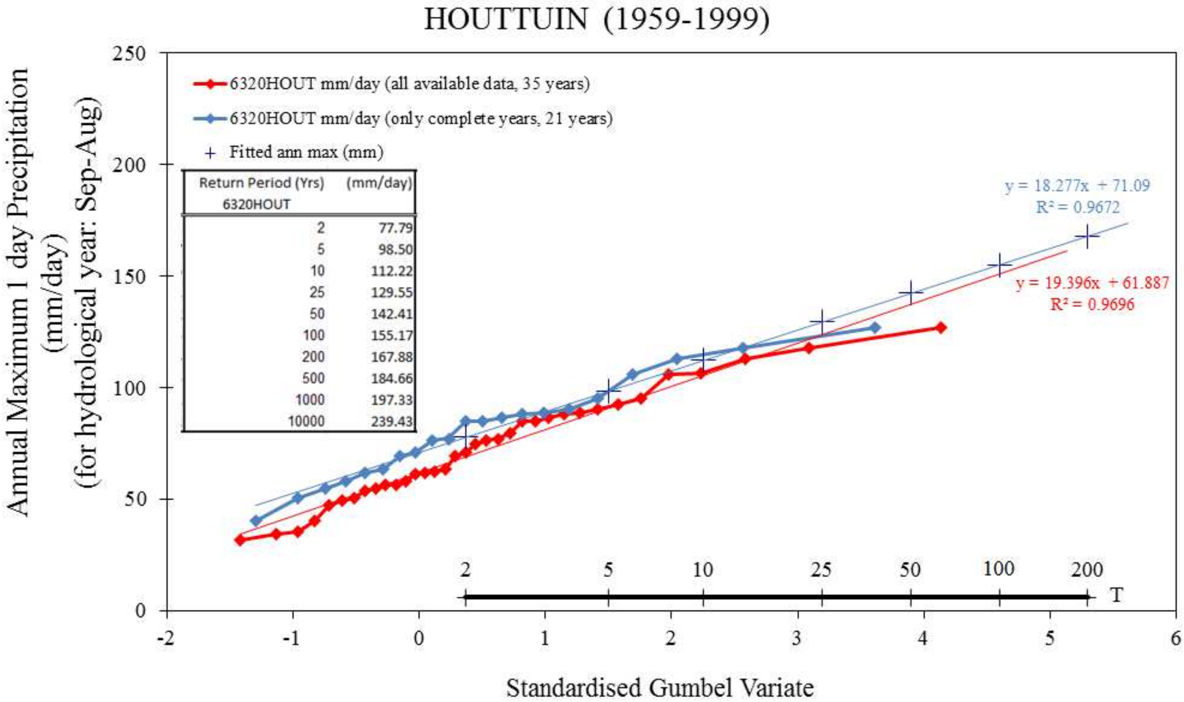
Plot 3: New Amsterdam



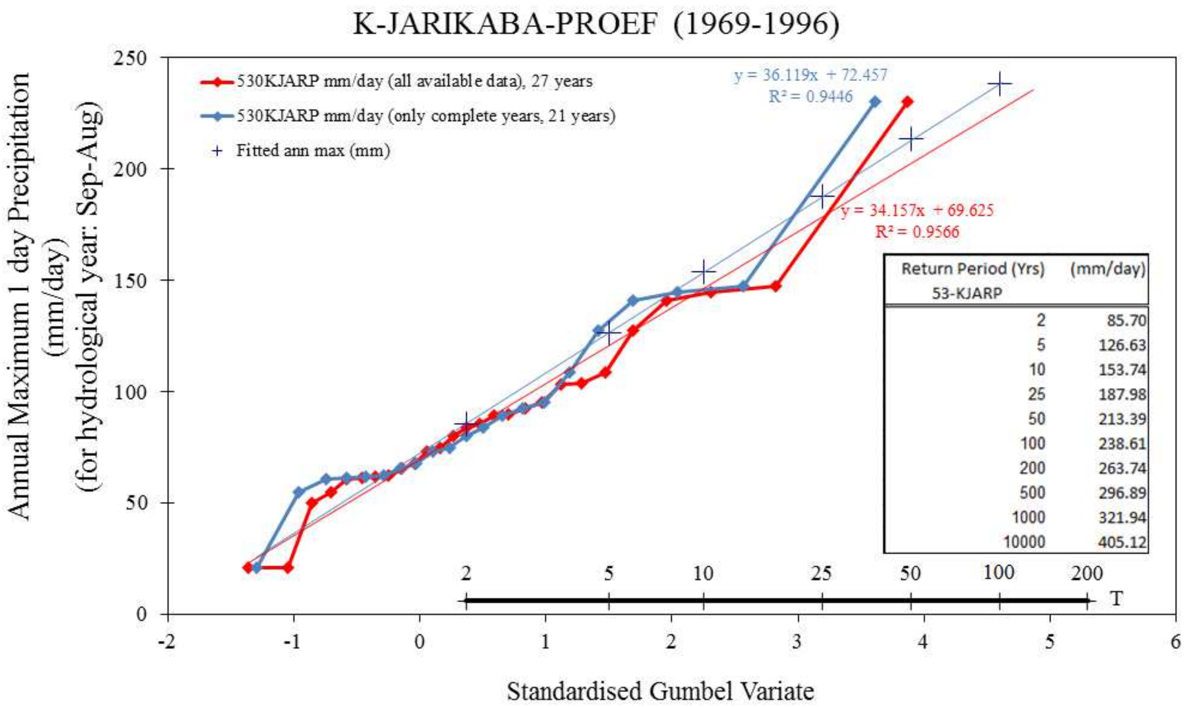
Plot 4: Zorg en Hoop



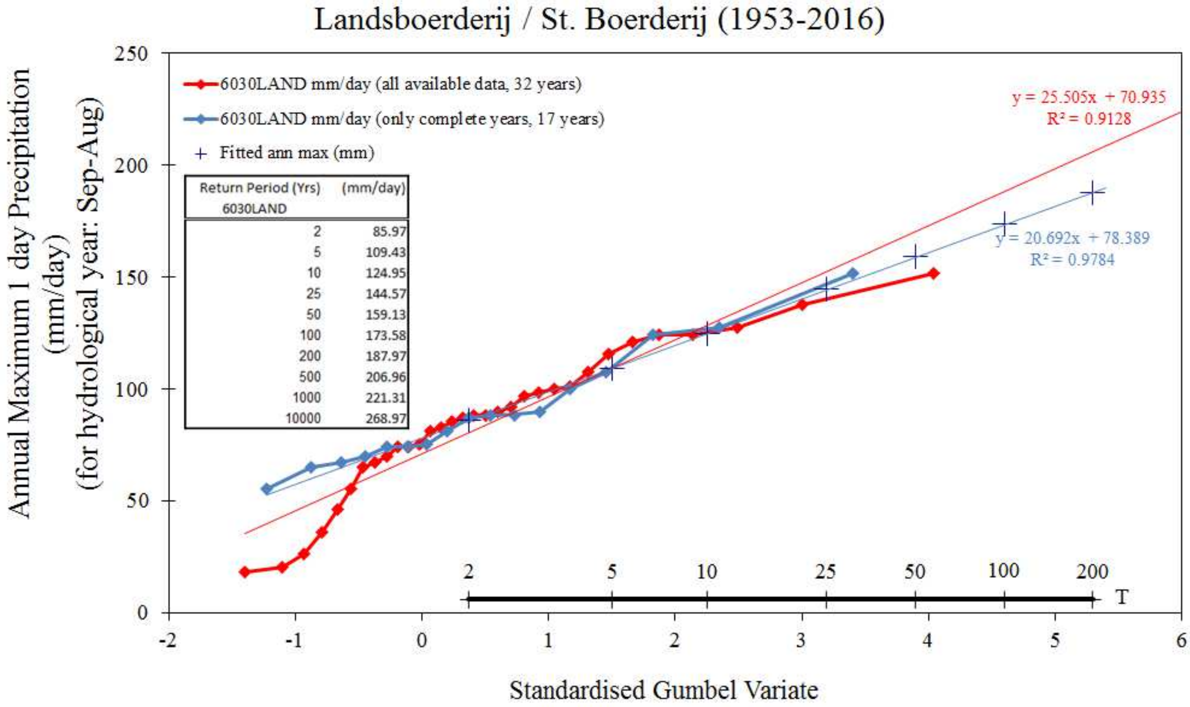
Plot 5: Houituin



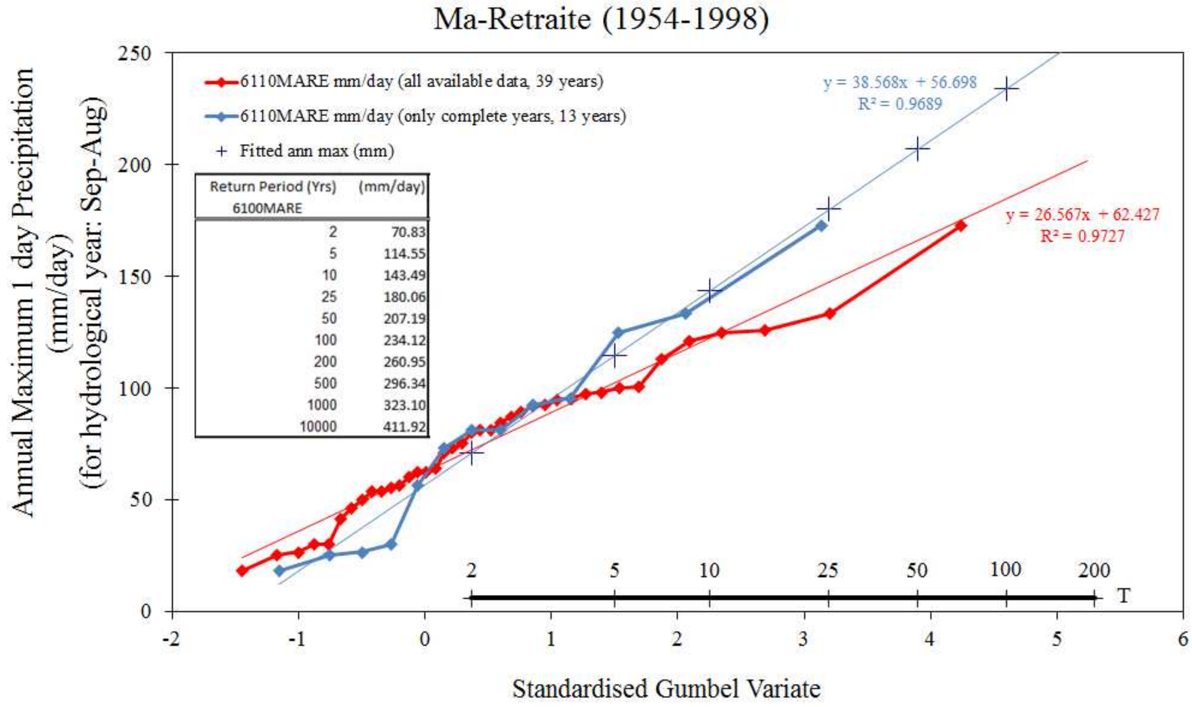
Plot 6: K-Jarikaba - Proef



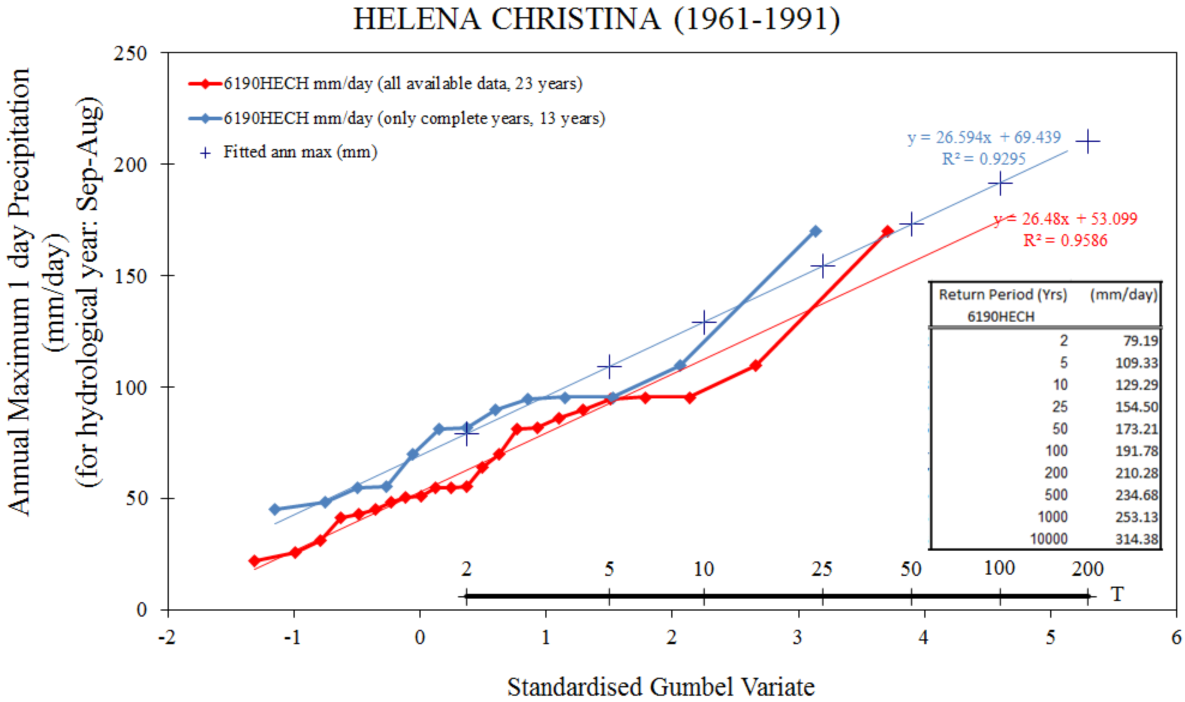
Plot 7: Landsboerderij/St. Boerderij



Plot 8: Ma-Retraite



Plot 9: Helena Christina



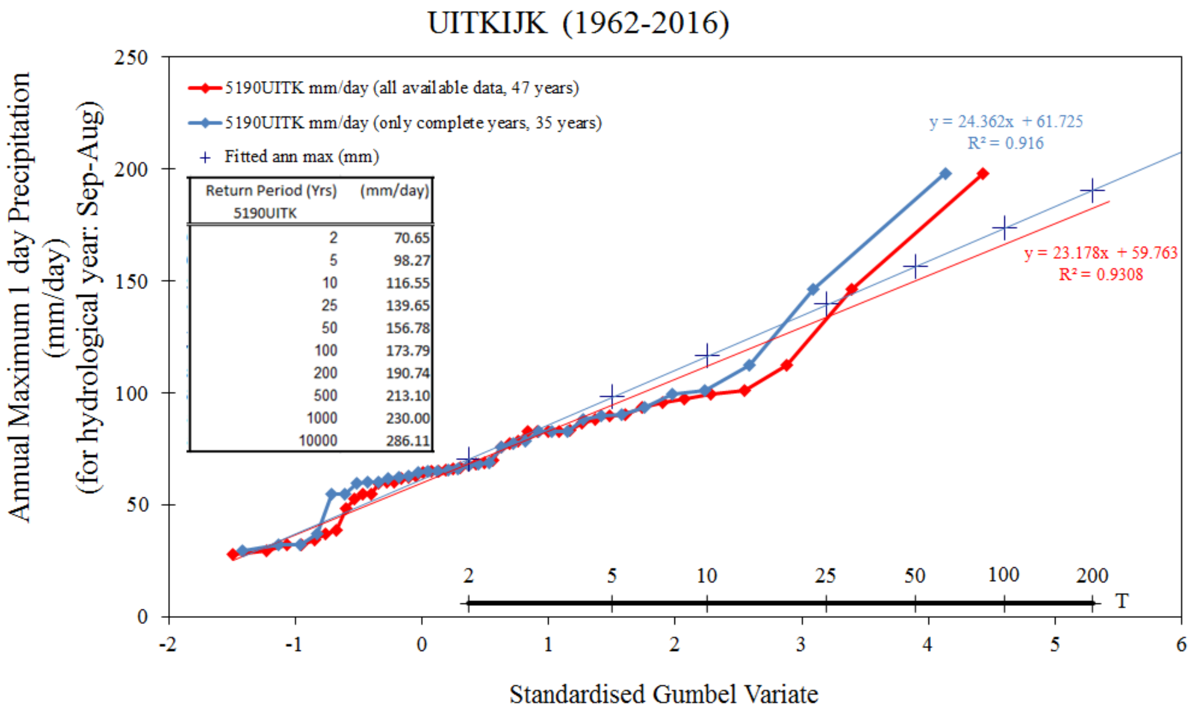
Plot 10: Uitkijk

<u>SPECIAL CASE Uitkijk</u>

3 high data points

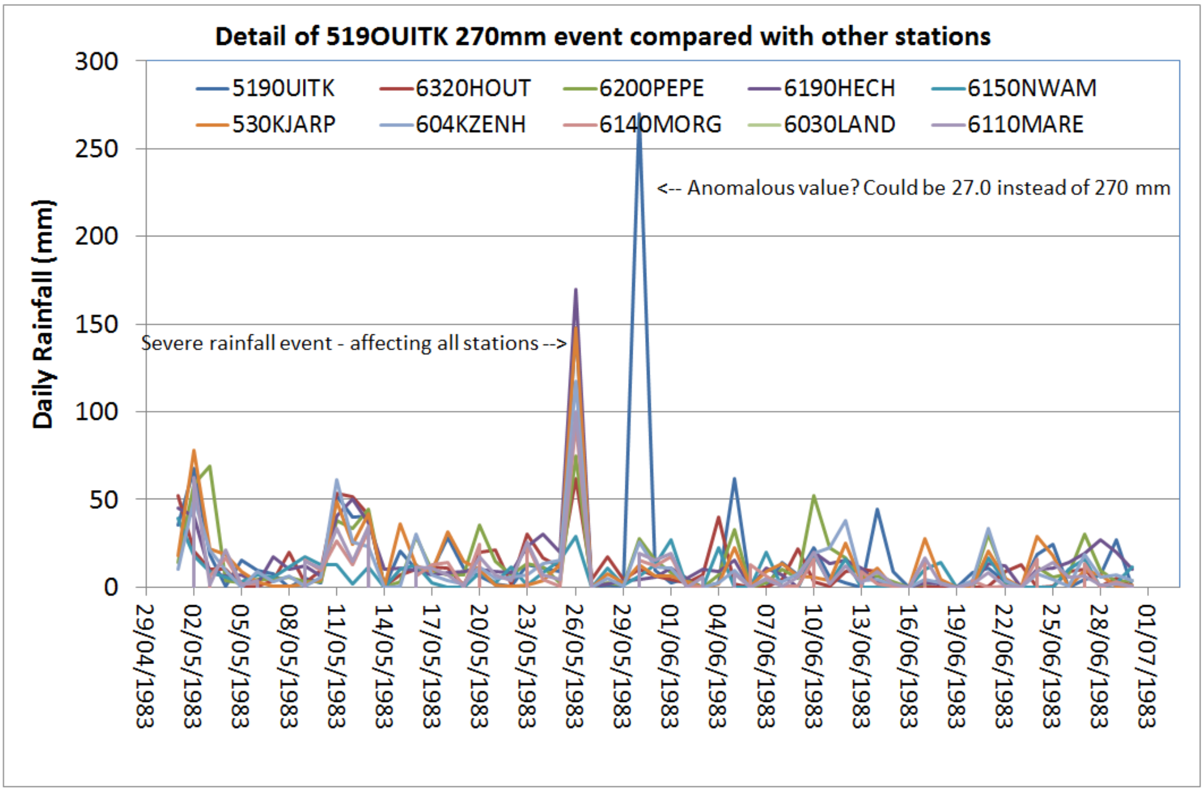
146.6 mm	1966/7	15 Apr, 1967
198.2 mm	1983/84	06 Jun, 1984
270 mm	1982/83	30 May, 1983 (preceded by 148 mm on 26 May, 1983)

Note: The top two data points seem particularly high but these days are preceded by more rainfall, so there is no reason to believe they are erroneous. The 270 value was removed from the plot as this seems to be erroneous based on Graph A below.

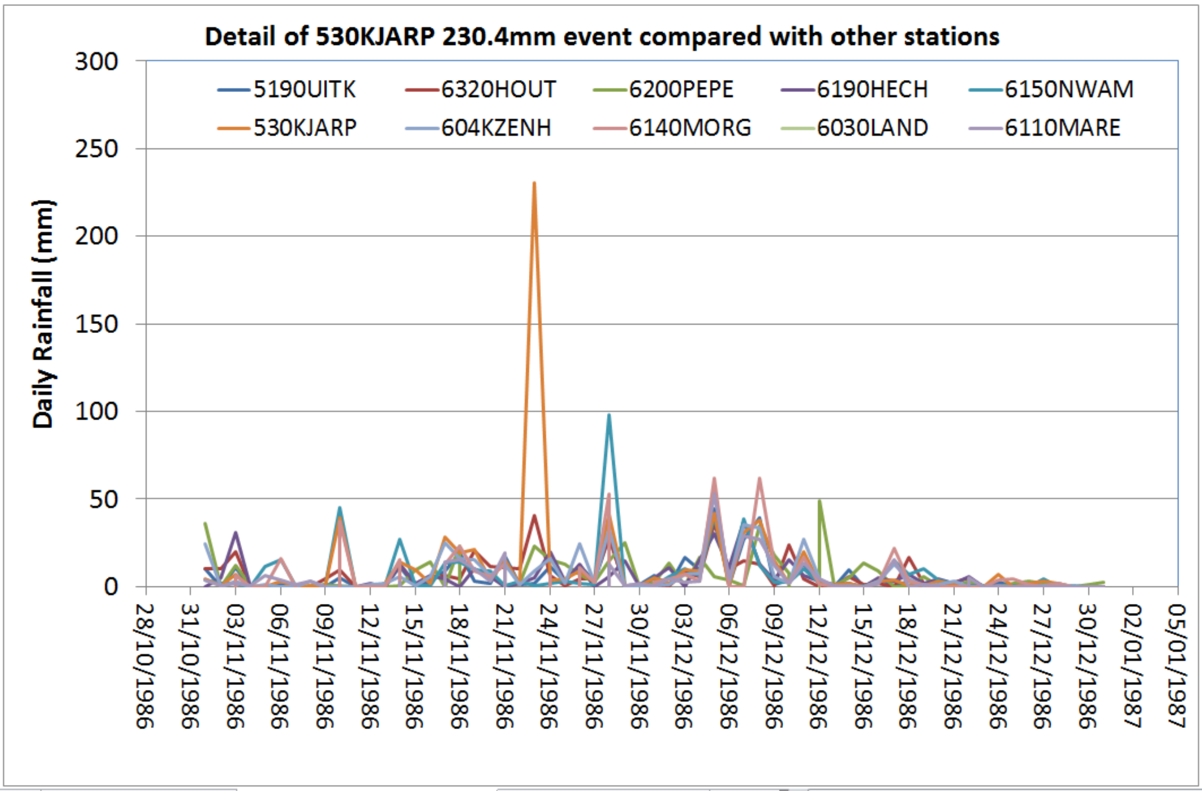


Plots of Selected Extreme Rainfall Event (also see Table 2)

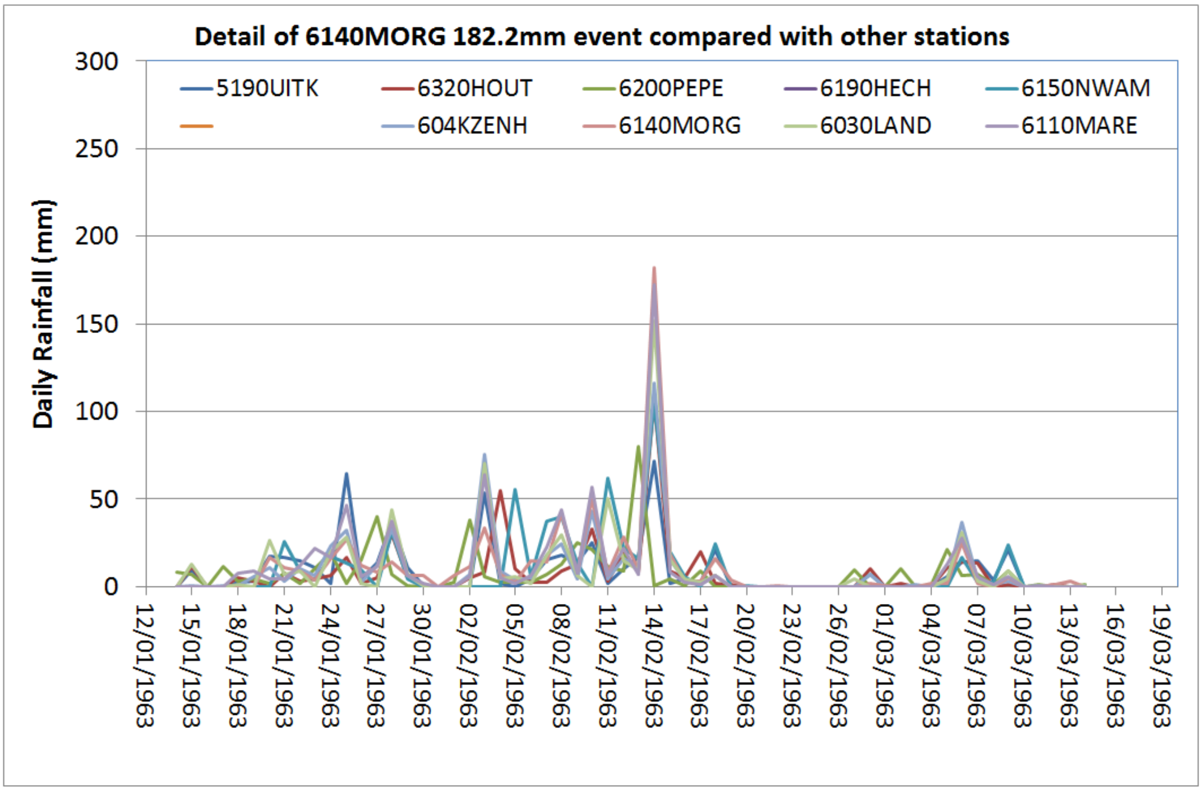
GRAPH A – May 1983



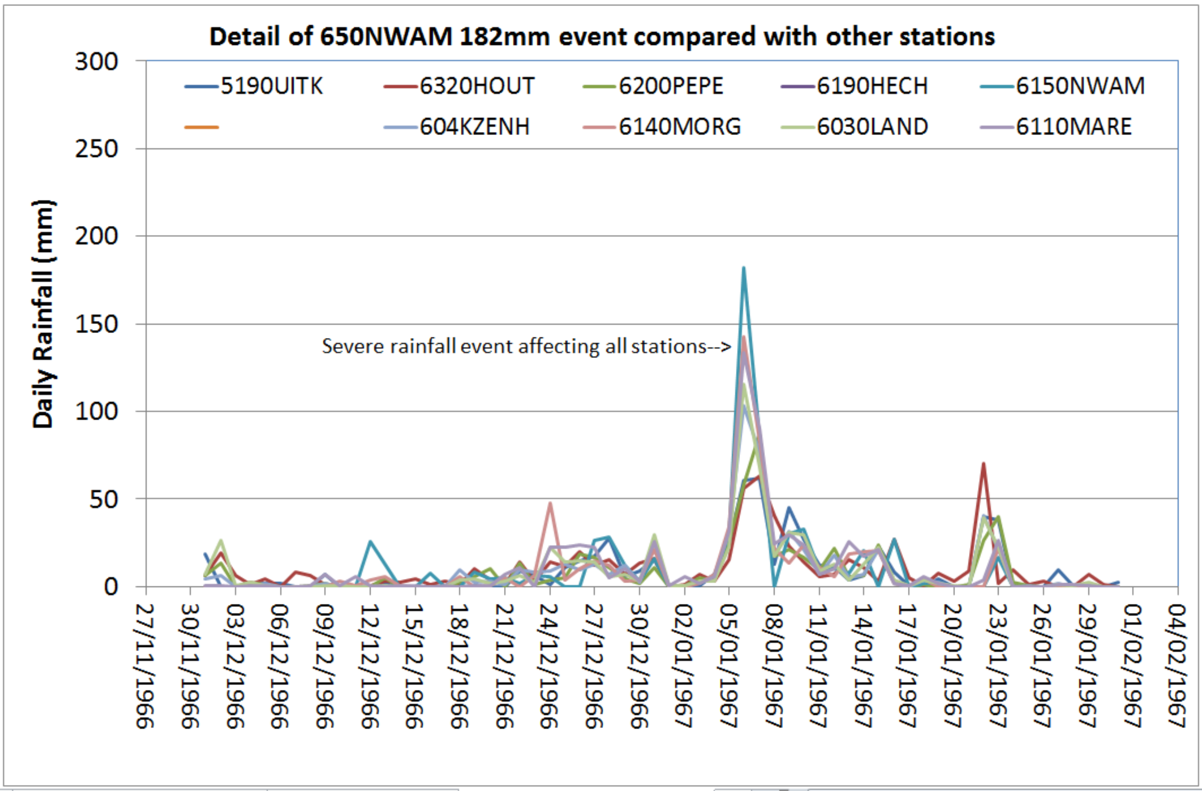
GRAPH B – Nov 1986



GRAPH C – Feb 1963



GRAPH D – Jan 1967



GRAPH E – Jan 1970

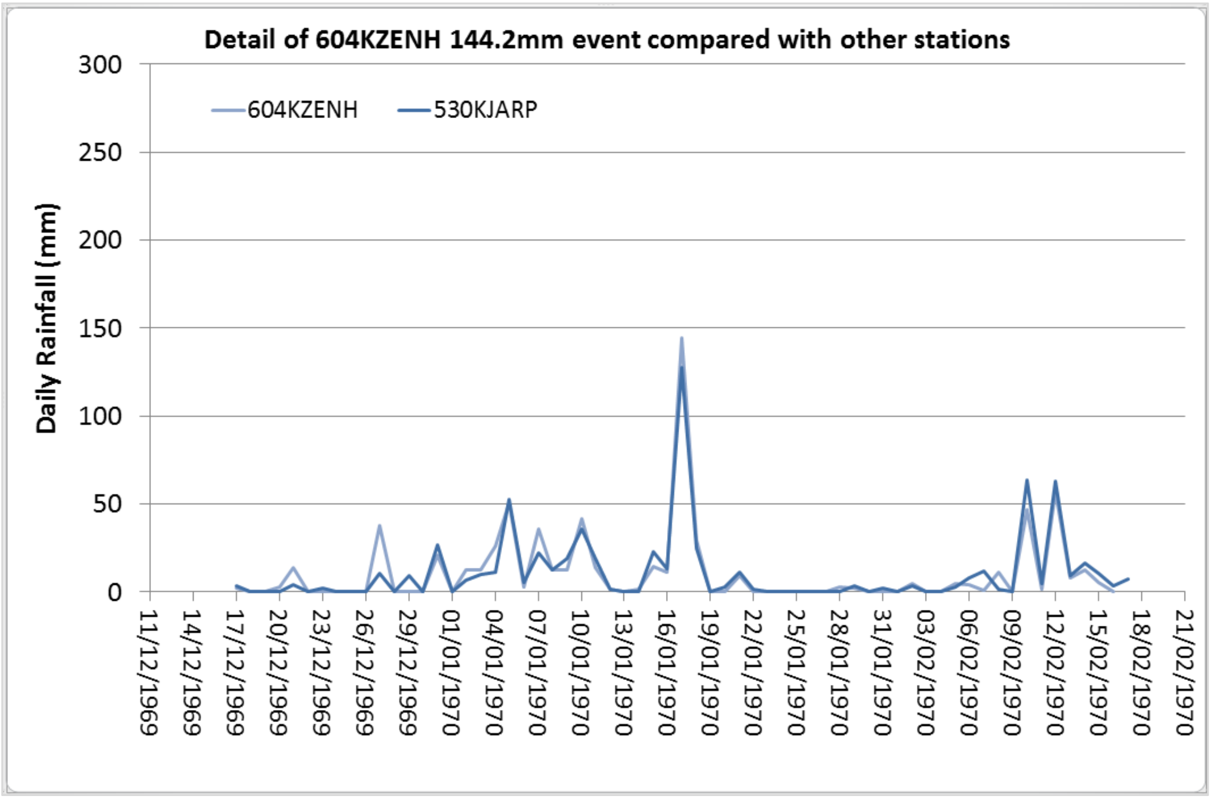


Table Appendix B1-3. Summary of return periods for each station

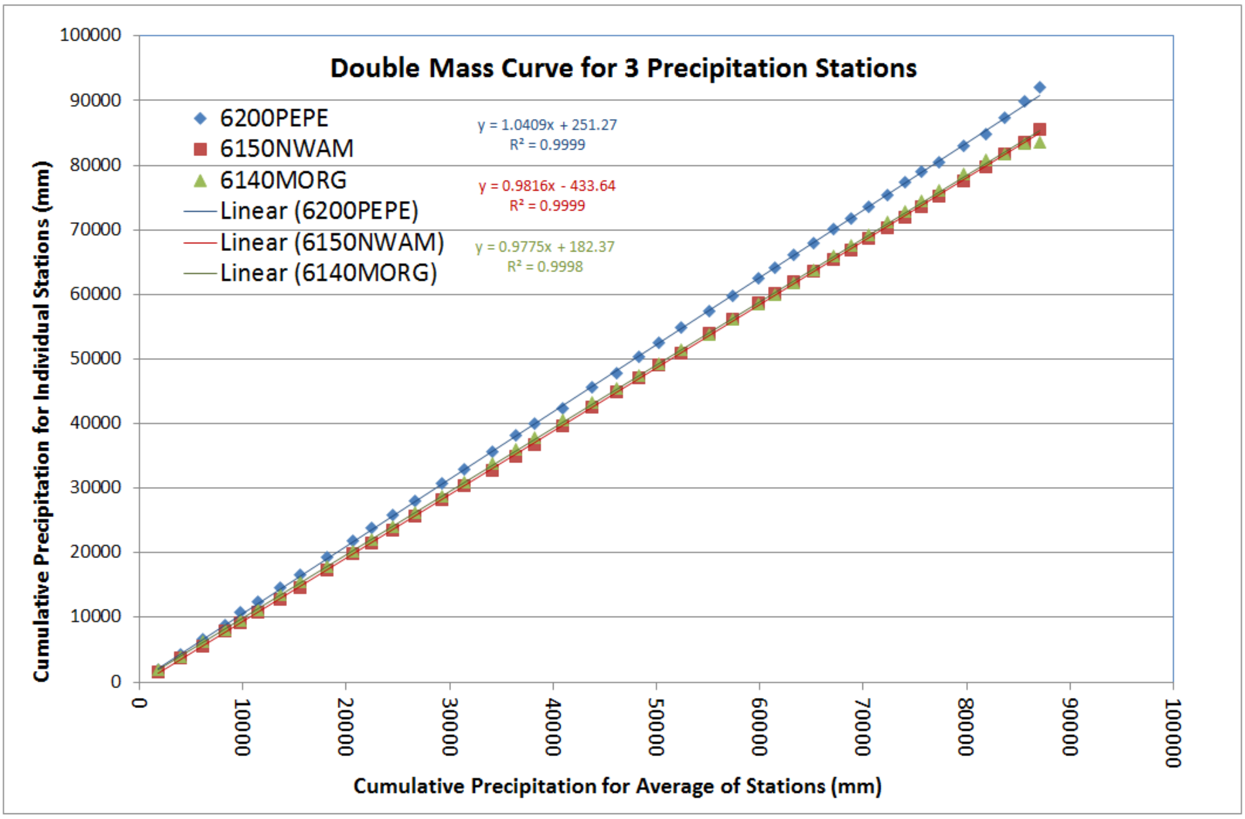
Return Period (Yrs) 53-KJARP	mm/day	Return Period (Yrs) 6030LAND	mm/day	Return Period (Yrs) 6100MARE	mm/day	Return Period (Yrs) 6150NWAM	mm/day	Return Period (Yrs) 6190HECH	mm/day
2	85.70	2	85.97	2	70.83	2	85.16	2	79.19
5	126.63	5	109.43	5	114.55	5	107.10	5	109.33
10	153.74	10	124.95	10	143.49	10	121.63	10	129.29
25	187.98	25	144.57	25	180.06	25	139.99	25	154.50
50	213.39	50	159.13	50	207.19	50	153.60	50	173.21
100	238.61	100	173.58	100	234.12	100	167.12	100	191.78
200	263.74	200	187.97	200	260.95	200	180.59	200	210.28
500	296.89	500	206.96	500	296.34	500	198.35	500	234.68
1000	321.94	1000	221.31	1000	323.10	1000	211.78	1000	253.13
10000	405.12	10000	268.97	10000	411.92	10000	256.36	10000	314.38

Return Period (Yrs) 6200PEPE	(mm/day)	Return Period (Yrs) 6320HOUT	(mm/day)	Return Period (Yrs) 5190UITK	mm/day	Return Period (Yrs) 604KZENH	mm/day	Return Period (Yrs) 6140MORG	mm/day
2	77.23	2	77.79	2	70.65	2	83.58	2	86.39
5	93.67	5	98.50	5	98.27	5	105.34	5	111.98
10	104.56	10	112.22	10	116.55	10	119.75	10	128.92
25	118.31	25	129.55	25	139.65	25	137.95	25	150.32
50	128.52	50	142.41	50	156.78	50	151.45	50	166.19
100	138.65	100	155.17	100	173.79	100	164.86	100	181.95
200	148.74	200	167.88	200	190.74	200	178.21	200	197.65
500	162.05	500	184.66	500	213.10	500	195.83	500	218.37
1000	172.11	1000	197.33	1000	230.00	1000	209.14	1000	234.03
10000	205.52	10000	239.43	10000	286.11	10000	253.36	10000	286.01

Double Mass Curves

Plot 11 was calculated for 3 stations only for complete (calendar) years of data from 1930 to 1968, plus additionally 1978, 1979 and 1982 only (the other years being incomplete). Calculating Double Mass Curves for more recent years is hampered by poor data availability across stations.

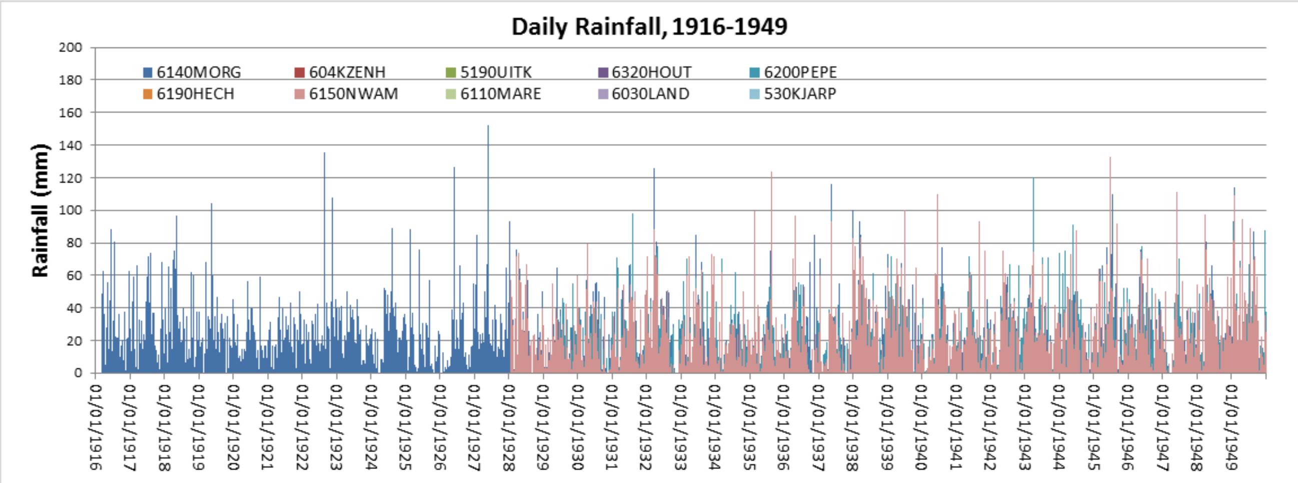
Plot 11: Double Mass Curve for 3 Stations



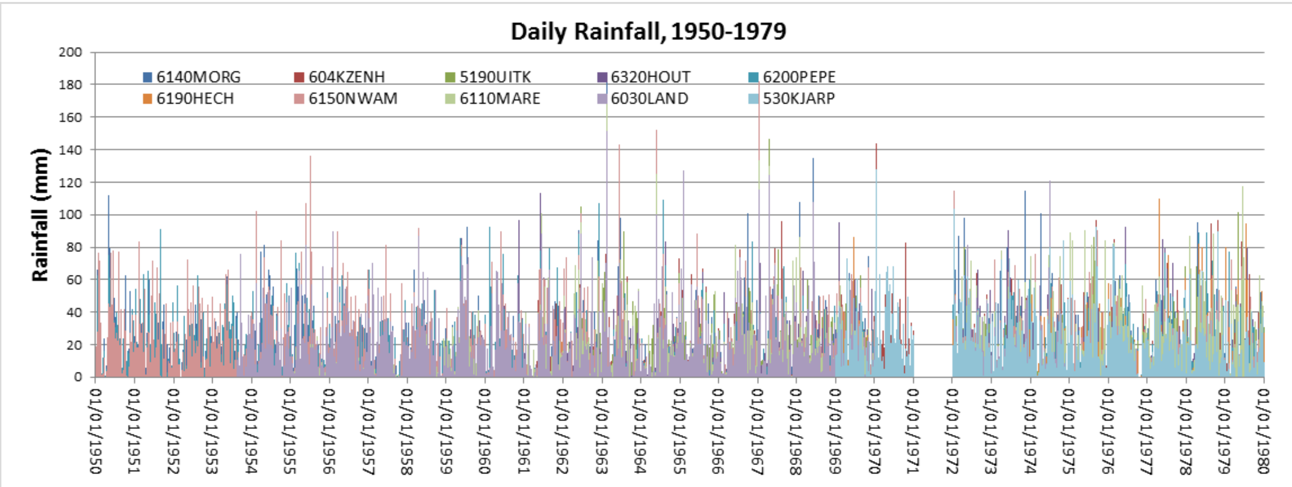
Timeseries plots of all rainfall data

(Note accumulated data points have not been removed)

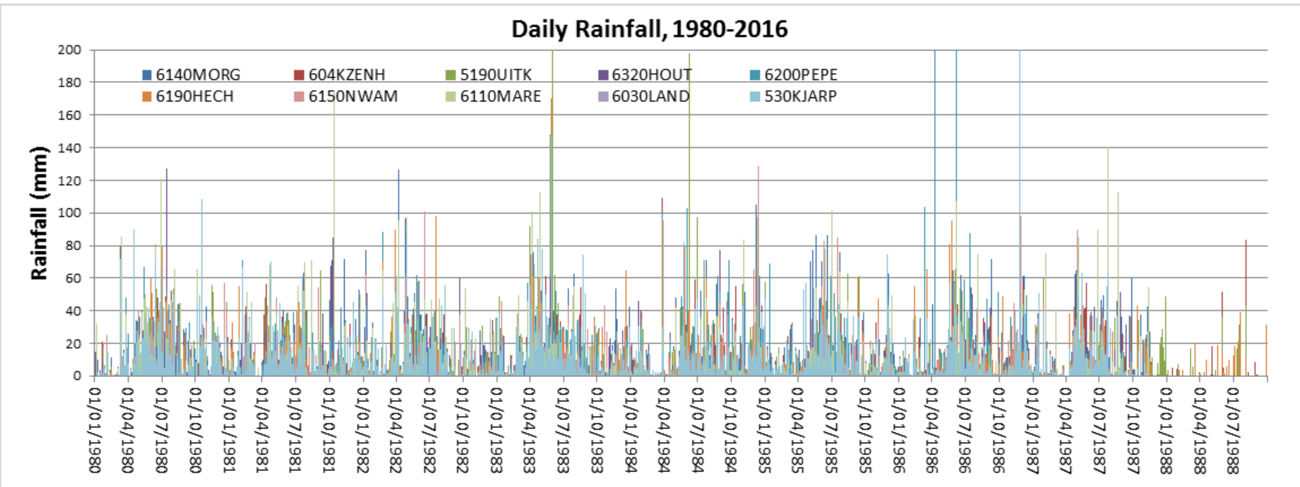
Graph 1: Rainfall 1916-1949



Graph 2: Rainfall 1950-1979



Graph 3: Rainfall 1980-2016



2 Analysis of Hourly Rainfall

Analysis of hourly rainfall data for Paramaribo/ Saramacca districts prepared by Dr. Isabella Bovolo, February, 2017. Data provided by Suriname Meteorological Office, 2016.

Table Appendix B2-1. Station Data and Location

Index	Code	Station	Lat	Lon
1	602KCULT	CULTUURTUIN	5.841389	-55.159722
2	604KZENH	ZORG EN HOOP **	5.8	-55.1833
3	608KDUIS	K-DUISBURG	5.806389	-55.214167
4	607KCELO	K-CELOS	5.81	-55.219444

Lat Lon data from http://www.meteosur.sr/stat_loc.htm
** Station is also a daily gauge

Table Appendix B2-2. Summary Data of extreme rainfall

	Station	Code	Data available from:	Data available to:	No of years of data within time period	No of complete years of data	Max 1 hour RF in hydro year (mm)	Date	Max 2 hour RF in hydro year (mm)	Date	Max 3 hour RF in hydro year (mm)	Date
1	CULTUURTUIN	602KCULT	01/01/1987	31/12/1990	4	3						
			01/05/1999	31/12/2001	4	2						
			01/08/2006	31/01/2009	4	2	89.0	30/07/2007	90.5	30/07/2007	91.3	30/07/2007
2	ZORG EN HOOP **	604KZENH	11/09/1987	31/12/1990	4	2						
			01/05/1999	30/04/2002	5	1	61.5	07/04/2000	81.6	03/08/1988	88.0	19/06/2000
			01/10/2007	31/12/2010	4	1						
			02/07/2013	31/07/2013	1	0						
3	K-DUISBURG	608KDUIS	01/01/1988	31/12/1990	4	2	55.1	30/11/1989	60.5	03/08/1988	63.2	03/08/1988
4	K-CELOS	607KCELO	01/01/1987	31/12/1990	5	3	69.7	21/06/1987	76.4	21/06/1987	76.6	21/06/1987

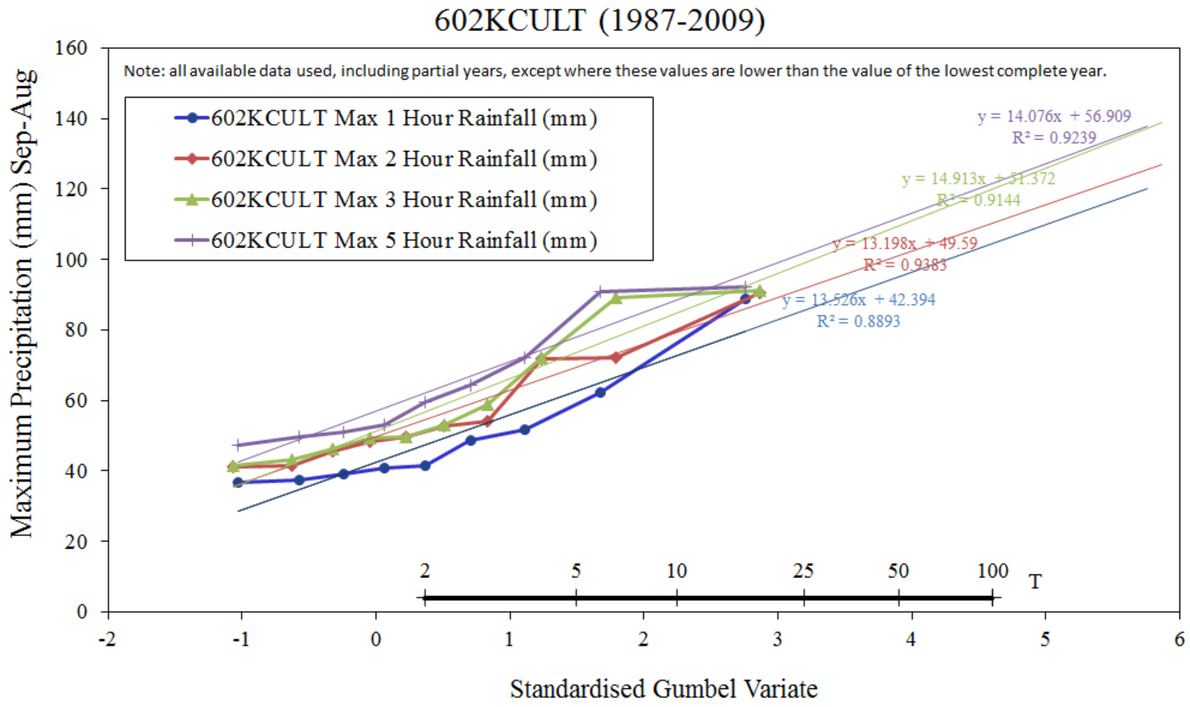
**Station also has daily rainfall gauge.

Hourly return periods (Extreme Value 1 (EV-1/Gumbel) Distribution Plots)

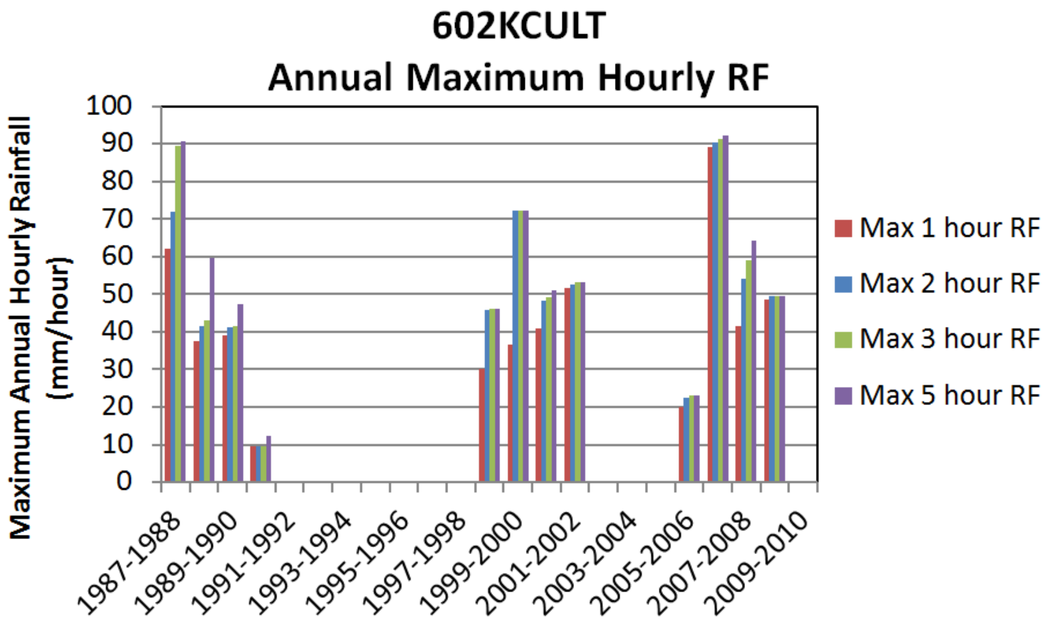
Gumbel Probability Plots shown below are for the 1, 2, 3 and 5 hour maximum rainfall in a hydrological year (Sep-Aug) for each station considering all available data, including partially complete years (Plot 3 and 4) except where these values are lower than the value of the lowest complete year (Plot 1 and 2). Linear fits are plotted using the Gringorton (WMO) method.

Also shown are summary tables for the rainfall Return Periods and graphs of maximum hourly rainfall for each hydrological year.

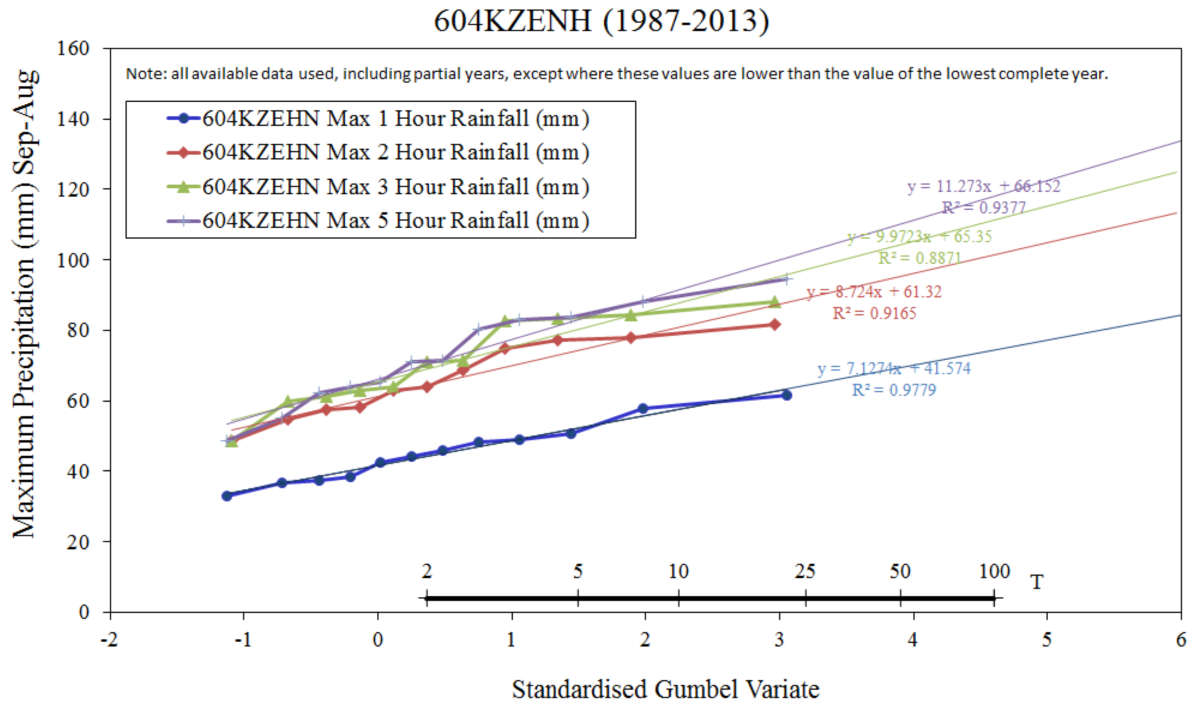
Plot 1: CULTUURTUIN



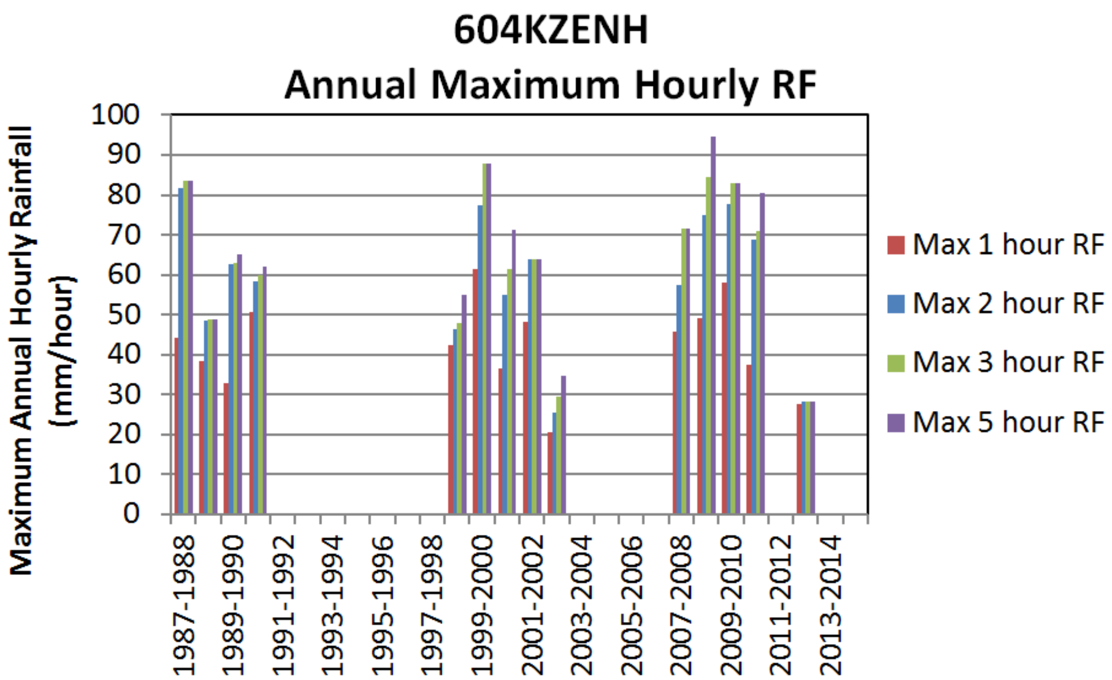
CULTUURTUIN	1 day	2 day	3 day	5 day
Return Period	y = 13.526x + 42.394	y = 13.198x + 49.59	y = 14.913x + 51.372	y = 14.076x + 56.909
2	47.4	54.4	56.8	62.1
5	62.7	69.4	73.7	78.0
10	72.8	79.3	84.9	88.6
25	85.7	91.8	99.1	101.9
50	95.2	101.1	109.6	111.8
100	104.6	110.3	120.0	121.7



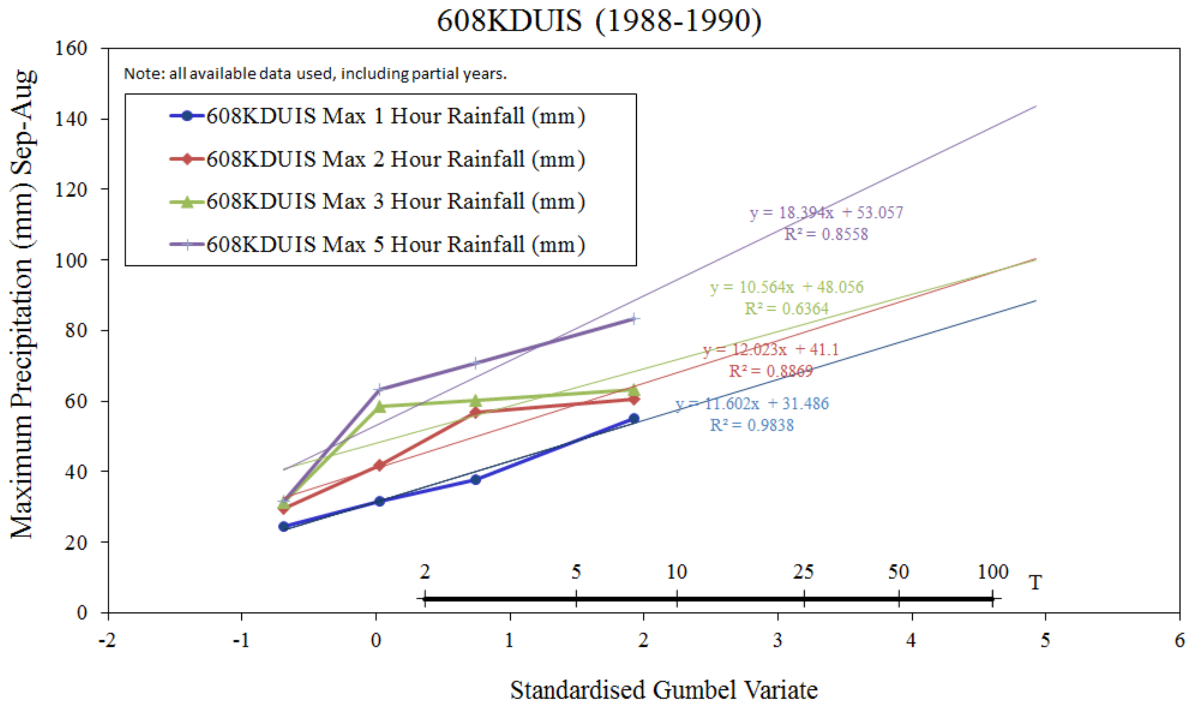
Plot 2: ZORG EN HOOP



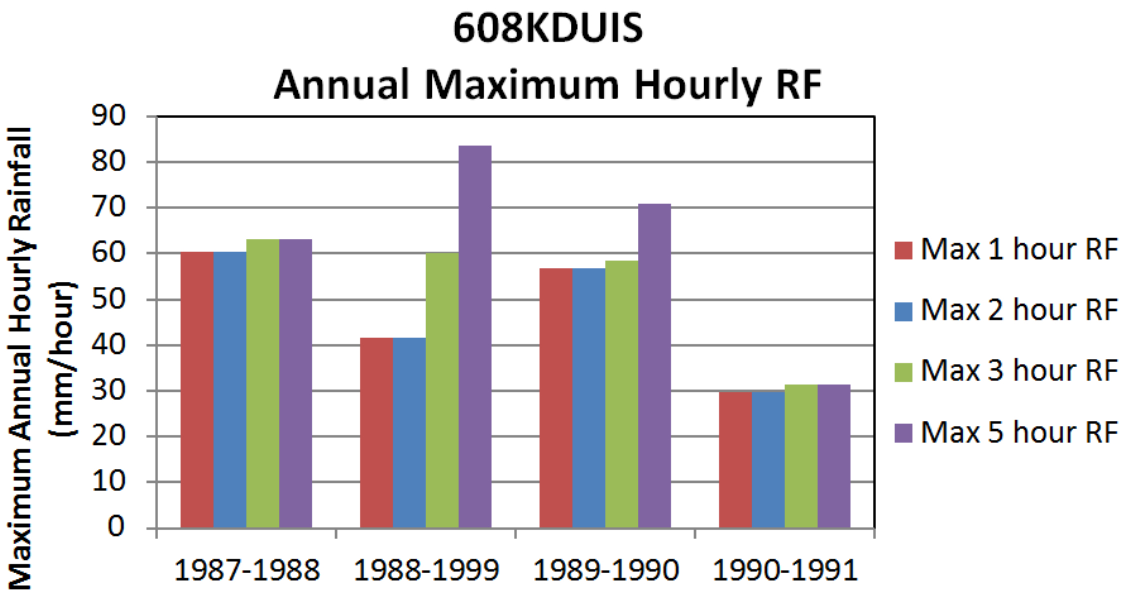
ZORG EN HOOP	1 day	2 day	3 day	5 day
Return Period	y = 7.1274x + 41.574	y = 8.724x + 61.32	y = 9.9723x + 65.35	y = 11.273x + 66.152
2	44.2	64.5	69.0	70.3
5	52.3	74.4	80.3	83.1
10	57.6	81.0	87.8	91.5
25	64.4	89.2	97.2	102.2
50	69.4	95.4	104.3	110.1
100	74.4	101.5	111.2	118.0



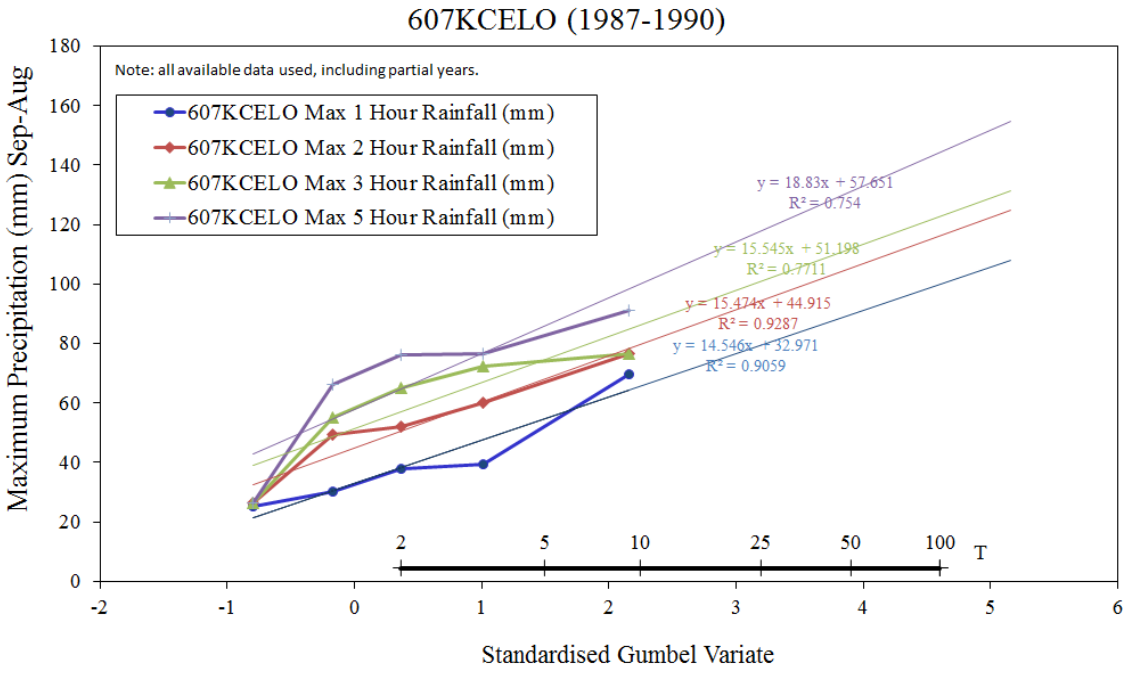
Plot 3: K-DUISBURG



K-DUISBURG	1 day	2 day	3 day	5 day
Return Period	y = 11.602x + 31.486	y = 12.023x + 41.1	y = 10.564x + 48.056	y = 18.394x + 53.057
2	35.7	45.5	51.9	59.8
5	48.9	59.1	63.9	80.6
10	57.6	68.2	71.8	94.5
25	68.6	79.6	81.8	111.9
50	76.8	88.0	89.3	124.8
100	84.9	96.4	96.7	137.7



Plot 4: K-CELOS



K-CELOS	1 day	2 day	3 day	5 day
Return Period	y = 14.546x + 32.971	y = 15.474x + 44.915	y = 15.545x + 51.198	y = 18.83x + 57.651
2	38.3	50.6	56.9	64.6
5	54.8	68.1	74.5	85.9
10	65.7	79.7	86.2	100.0
25	79.5	94.4	100.9	117.9
50	89.7	105.3	111.9	131.1
100	99.9	116.1	122.7	144.3