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LIST OF ABBREVIATION

ADPC	Asian Disaster Preparedness Center
ADB	Asian Development Bank
ADS	Agriculture Development Strategy
AR	Agriculture Flood Risk
BESS	Basin Exploratory Scoping Study
CAPEX	Capital Expenditures
CCS/CCC	Material and Construction Cost
DALMS	Department of Agriculture Land Management and Statistics
DMH	Department of Meteorology and Hydrology
DOA	Department of Agriculture
DR	Discount Rate
DRD	Department of Rural Development
DRR	Disaster Risk Reduction
DS	New Dike Slope
DUHD	Department of Urban Housing Development
DWIR	Directorate of Water Resources and Improvement of River System
EGM08	Earth Gravitational Model 2008
FAO	Food and Agriculture Organization
EAD (or AED)	Expected Annual Damage
ESIA	Environmental and Social Impact Assessment
GDP	Gross Domestic Product
GEV	Generalized Extreme Value
GIS	Geographic Information System
GOM	Government of Myanmar
GRP	Glass Fiber Reinforced Plastic
GYR	Greater Yangon Region
HDPE	High Density Polyethylene
HIC	Hydro Informatics Centre

HSC	Hydraulic Structure Cost
IADS	Integrated Ayeyarwady Delta Strategy
IADS-B	Integrated Ayeyarwady Delta Strategy-Phase B
ICIMOD	International Centre for Integrated Mountain Development
IFC	International Finance Corporation
IWMI	International Water Management Institute
IWRM	Integrated Water Resources Management
IWUMD	Irrigation and Water Utilization Management Department
JICA	Japan International Cooperation Agency
LIFT	Livelihood and Food Security Trust Fund
MAPDRR	Myanmar Action Plan on Disaster Risk Reduction
MCCSAP	Myanmar Climate Change Strategy and Action Plan
MIMU	Myanmar Information Management Unit
MMU	Myanmar Maritime University
MOALI	Ministry of Agriculture, Livestock and Irrigation
MOC	Ministry of Construction
MONREC	Ministry of Natural Resources and Environmental Conservation
MOTC	Ministry of Transport and Communications
MOU	Memorandum of Understanding
MSDP	Myanmar Sustainable Development Plan
MSL	Mean Sea Level
NAPA	National Adaptation Programs of Action
NASA	National Aeronautics and Space Administration
NDVI	Normalized Difference Vegetable Index
NGO	Non-governmental Organization
NOAA	National Oceanic and Atmospheric Administration
NWP	National Water Policy
NWRC	National Water Resources Committee
NYC	New Yangon City

NYDC	New Yangon City Development
OPEX	Operating Expenditures
POT	Peak Over Threshold
PSU	Practical Salinity Unit
PWL	Pumping Water Level
RHS	Required Hydraulic Structure
RP	Return Period
RSLR	Relative Sea Level Rise
RWSS	Regional Water Security Study
SOBA	Ayeyarwady State of the Basin Assessment
SWL	Static Water Level
UNEP	United Nations Environment Program
UNFCCC	United Nations Framework Convention on Climate Change
UNICEF	United Nations Children's Fund
USAID	United States Agency for International Development
WASH	Water, Sanitation and Hygiene
WWTP	Wastewater Treatment Plant
YCDC	Yangon City Development Committee
YRDC	Yangon Region Development Committee
YTU	Yangon Technological University

GLOSSARY

English term	English explanation	Myanmar explanation
Assessment Framework	A methodology with indicators to analyze the impact of planned measures and future scenarios	အနာဂတ်တွင်ဖြစ်လာနိုင်ချေရှိသော ဖြစ်စဉ်များနှင့် သတ်မှတ်ထားသော ကုစားချက်များ၏ အကျိုးသက်ရောက်မှုများကို လေ့လာဆန်းစစ်ရန် အညွှန်းကိန်းများနှင့် ဖွဲ့စည်းထားသည့် နည်းလမ်း။
Bankability	Sufficient collateral, future cashflow, and high probability of success, to be acceptable to institutional lenders for financing	အဖွဲ့အစည်းဆိုင်ရာ ငွေကြေးထောက်ပံ့သူ (ချေးငွေထုတ်ပေးသူများ) အတွက် လက်ခံနိုင်ဖွယ်ရှိသော လုံလောက်သည့် အာမခံနိုင်မှု၊ အနာဂတ်ငွေကြေးလည်ပတ်မှု နှင့် အောင်မြင်နိုင်ချေမြင့်မားမှု။
CAPEX	Capital expense which is the fund spent on maintaining, or improving the fixed assets	သတ်မှတ်ထားသော ပိုင်ဆိုင်မှုများအား တိုးတက်စေရန် (သို့မဟုတ်) ထိန်းသိမ်းထားရန်အတွက် အသုံးပြုရသော ရန်ပုံငွေ။
Channel	The natural bed where a natural stream of water runs	ရေစီးကြောင်းများစီးဆင်းလျက်ရှိသော သဘာဝအလျောက်တည်ရှိနေသည့် ကြမ်းပြင်။
Creek	A natural stream of water that is smaller than a river and often tributary to a river	မြစ်၏အရွယ်အစားထပ်သေးငယ်ပြီး တစ်ခါတစ်ရံ မြစ်အတွင်းသို့ စီးဆင်းလေ့ရှိသည့် သဘာဝအလျောက်ရှိသောရေစီးကြောင်း။
Cost Recovery	Rate of return of certain investments	ရင်းနှီးမြှုပ်နှံမှုများမှ ပြန်လည်ရရှိသော ငွေကြေးနှုန်းထားပမာဏ။
Dike / embankment	An earth structure (or a wall) which is built along the riverbank to protect the hinterland from flooding	ရေကြီးမှုမှ ကာကွယ်ရန် မြစ်ကမ်းပါးတစ်လျှောက် ဆောက်လုပ်ထားသော မြေသားတာ သို့မဟုတ် မြေသား နရံ။
Discharge	The volume of water flowing through a river channel at a given point of time (m³/s)	မြစ်ချောင်းအတွင်း သတ်မှတ်ထားသော အမှတ်တစ်ခု၌ စီးဆင်းသွားသော ရေထုထည် ပမာဏ။
Drainage	The flow of water away from a certain area	သတ်မှတ်ထားသော ဧရိယာမှ အဝေးသို့ ရေစီးဆင်းမှု။
Feasibility study	An assessment of the feasibility of a proposed plan or method	အဆိုပြုထားသော အစီအစဉ် (သို့မဟုတ်) နည်းလမ်း၏ ဖြစ်နိုင်ချေရှိမှုကို လေ့လာဆန်းစစ်ခြင်း။
Flooding - Coastal	Flooding which occurs due to storm surges from the Gulf of Mottama	မုတ္တမပင်လယ်ကွေ့မှ မုန်တိုင်းဒီရေလှိုင်းကြောင့် ဖြစ်သော ရေကြီးမှု။
Flooding - Fluvial	Flooding which occurs when the water levels in the river are higher than the local embankments	အနီးအနားရှိ ကမ်းတာများထက် မြစ်ရေမြင့်တက်မှုကြောင့် ဖြစ်သော ရေကြီးမှု။
Flooding - Pluvial	Flooding which is caused by extreme rainfall events	ထူးကဲ မိုးရေချိန်ကြောင့်ဖြစ်သော ရေကြီးမှု။

English term	English explanation	Myanmar explanation
Groyne	A structure which is built perpendicular (or at an angle) to the riverbank to deflect the river flow	မြစ်ရေအလျင်အား လမ်းလွှဲရန် မြစ်ကမ်းပါးနှင့် ထောင့်မတ်ကျ (သို့) ထောင့်ချိုးတစ်ခုနှင့် တည်ဆောက်ထားသော အဆောက်အအုံ။
Indicator	Parameter that provides insight in the flood and freshwater security situation	အခြေအနေတစ်ခုတွင်ရှိသော အရာများကို သတ်မှတ်ပေးသော အညွှန်းကိန်း။
Intervention	A measure that has a significant impact on the natural behavior of the delta system	မြစ်ဝကျွန်းပေါ်ဒေသ၏ သဘာဝဖြစ်စဉ်များကို အကျိုးသက်ရောက်မှု သိသာစွာဖြစ်စေသော ကုစားချက်။
Measure	An action (a structure or a plan or a measure) which is taken to improve or prevent water security issues from getting worse in problematic situations	ရေဖူလုံလုံခြုံမှုဆိုင်ရာပြဿနာများအား ပိုမိုဆိုးရွားစေရန် တားဆီးပေးသော လုပ်ဆောင်ချက် (အဆောက်အအုံ (သို့) စီမံကိန်း (သို့) ကုစားချက်)။
OPEX	Operating expenses which is an ongoing cost for a running project	လက်ရှိဆောင်ရွက်နေသော စီမံကိန်းတွင် အသုံးပြုလျက်ရှိသော အသုံးစရိတ်များ။
Pond	A small body of still water formed naturally or by artificial means	သဘာဝအားလျော်စွာ (သို့) လူတို့ပြုပြင်ဖန်တီးထားသော ရေသေကန်။
Preliminary design	Initial design of a measure based on available data	ရရှိထားသော အချက်အလက်များပေါ်အခြေခံထားသော ကုစားချက်၏ ကနဦးပုံစံ။
Pre-feasibility	A preliminary study to determine, analyze and select the potential for investments	ရင်းနှီးမြှုပ်နှံမှုများအတွက် ဖြစ်နိုင်ချေများကို ဆုံးဖြတ်ရန်၊ ဆန်းစစ်ရန်နှင့် ရွေးချယ်ရန် ပဏာမအနေနှင့်ပြုလုပ်သော လေ့လာချက်။
Prioritization	The action or process of deciding the relative importance or urgency of a thing or things	အရေးကြီးသော ဖြစ်နိုင်ချေရှိသည့် ကုစားချက်များအား ရွေးချယ်ဆုံးဖြတ်သော လုပ်ငန်းစဉ်။
Probability	A numerical description of how likely an event is to occur	ဖြစ်စဉ်တစ်ခု၏ ဖြစ်နိုင်ချေမည်မျှရှိသည်ကို ကိုယ်စားပြုသော ကိန်းဂဏန်းဖော်ပြချက်။
Rainwater harvesting	The process of collecting rain and storing it for later use, rather than letting it run off	လိုအပ်လျှင်အသုံးပြုနိုင်ရန် မိုးရေအား စုဆောင်းသိုလှောင်သော လုပ်ငန်းစဉ်။
Retention area (basin)	A large area which is designed to provide enough free space for water coming from runoff during heavy rainfall events	ထူးကဲမိုးရေချိန်အတွင်း မြေမျက်နှာပြင်မှ စီးဆင်းလာသော ရေများအတွက် လုံလောက်သော အကျယ်အဝန်းရှိသည့် သတ်မှတ်ထားသော နေရာကျယ်။
Retention pond	A pond (or a pool) which is designed to store water from surface runoff during heavy rainfall events	ထူးကဲမိုးရေချိန်အတွင်း မြေမျက်နှာပြင်မှ စီးဆင်းလာသော ရေများအား သိုလှောင်ရန် သတ်မှတ်ထားသော ရေကန်ငယ် (သို့မဟုတ် ရေအိုင်)။
Return period	The probable time in which a certain event will occur	ဖြစ်စဉ်တစ်ခု ပြန်လည်ဖြစ်ပွားရန် အလားအလာရှိသောအချိန်။

English term	English explanation	Myanmar explanation
Revetment	A structure which is built along the riverbank slope to protect bank erosion	မြစ်ကမ်းပါးတိုက်စားမှုအား ကာကွယ်ရန် မြစ်ကမ်းပါး၏ဆင်ခြေလျှော့ တစ်လျှောက် တည်ဆောက်ထားသော အဆောက်အအုံ။
River	A large natural stream of water flowing in a channel to the sea, a lake, or another river	ပင်လယ်၊ ရေကန် သို့မဟုတ် အခြားမြစ်ထဲသို့ စီးဆင်းလေ့ရှိသော ကျယ်ပြန့်သည့် သဘာဝရေစီးကြောင်း။
Salinity front	A certain distance measured from the coast which indicates where saline water can intrude from the sea	ကမ်းရိုးတန်းမှစ၍တိုင်းတာသည့် ဆားငန်ရေဝင်ရောက်သော အကွာအဝေး။
Selection	The action or fact of carefully choosing someone or something as being best or most suitable	အကောင်းဆုံး (သို့) အသင့်တော်ဆုံး ဖြစ်သည့် တစ်စုံတစ်ယောက် (သို့) တစ်စုံတစ်ခုအား သေချာစွာရွေးချယ်သည့် လုပ်ငန်းစဉ်။
Sufficient water availability	Sufficient amount and quality of water meeting the demand of a respective area	ရေလိုအပ်သော ဧရိယာများအတွက် လုံလောက်၍ အရည်အသွေးကောင်းမွန်သည့် ရေပမာဏ။
Target	The state or level selected to achieve	ဖြစ်မြောက်အောင်မြင်ရန် ရွေးချယ်ထားသည့် အခြေအနေ။
Tank	A receptacle or storage chamber to store liquids or gas	အရည် (သို့) အငွေ့အား သိုလှောင်သည့်ကန်။
Threshold	The critical limit (or the final acceptable value) of an indicator	အညွှန်းကိန်း၏ အရေးပါသော ကန့်သတ်ချက် ((သို့)နောက်ဆုံးလက်ခံနိုင်သော တန်ဖိုး)
Velocity	The speed at which water moves through its channel (m/s)	တစ်စက္ကန့်အတွင်း စီးဆင်းနိုင်သော ရေ၏အလျင်
Vision	The view or global plan that describes how the country, society or project can develop in the (long term) future	(ရေရှည်) အနာဂတ်တွင် နိုင်ငံ၊ လူ့အဖွဲ့အစည်း (သို့) စီမံကိန်း မည်ကဲ့သို့ တိုးတက်ပြောင်းလဲနိုင်သည်ကို ဖော်ပြသော အမြင် သို့မဟုတ် ကမ္ဘာလုံးဆိုင်ရာ အစီအစဉ်။
Water depth	The difference between the water level and the bottom of the river or inundated area (m)	ရေအနက်နှင့် မြစ်ကြမ်းပြင် (သို့) ရေလွှမ်းမိုးသည့် ဧရိယာကြားရှိ ရေအမြင့်။
Water level	The elevation of the water surface measured in m+EGM2008	EGM2008 အမြင့်မှ တိုင်းတာထားသော ရေမျက်နှာပြင်၏ အမြင့်
Water scarcity	When the demand of water is larger than the available <u>freshwater</u> in the river	ရေလိုအပ်ချက်သည် မြစ်ချောင်းအတွင်း မှရရှိနိုင်သော ရေချို့ပမာဏထက်များခြင်း။
Water security	The reliable availability of an acceptable quantity and quality of water for health, livelihoods, and production, coupled with an acceptable level of water-related risks	လက်ခံနိုင်စွမ်းရှိသော ရေနှင့်သက်ဆိုင်သည့် ဘေးအန္တရာယ်များနှင့်တကွ ကျန်းမာရေး၊ စားဝတ်နေရေးနှင့် ထုတ်လုပ်မှု တို့အတွက် သင့်လျော်သော ရေပမာဏနှင့် အရည်အသွေး စိတ်ချစွာရရှိနိုင်မှု။

1 INTRODUCTION

1.1 Background of the study

The Ayeyarwady Delta consists of a complex network of rivers, in which the flow is dominated by tides and ocean surge from the south and by river flow from the north. Yangon Region is located on the east and south sides of this largely natural delta system.

Yangon Region faces various water related challenges, including coastal and riverine flooding of Yangon City, saltwater intrusion due to over-extraction of river and groundwater supplies, and insufficient water supply for public, commercial, industrial, and agricultural use. Moreover, with Myanmar ranked second out of 187 countries in the 2016 Global Climate Risk Index (Kreft, et al., 2015), Yangon Region is expected to experience climate change like increased chance of more and more extreme precipitation events and increased flooding due to sea level rise. Sea level rise and lower minimum river discharges may form increased risks for the intake of freshwater.

To meet the socio-economic and environmental demands of the quickly developing and urbanizing area around Yangon, which is forecast to become a mega city with a population of 10 million in 2040, Yangon Regional Government, and its associated decision makers, are seeking proposals for measures to strengthen the water security situation.

Because of the rapid spatial development that is taking place, it is possible that existing development plans and stand-alone measures may jeopardize the current and future water security or have a conflicting impact on each other. If, for example, deepening a navigation channel causes saltwater intrusion to reach the location where a new freshwater intake facility is planned, then this should be known in advance. Plans can then be modified so that the cumulative benefits of all measures can be maximized. Another example of potentially conflicting interests is if one specific area is protected against flooding with higher dikes, that this may worsen the flood risk at other locations.

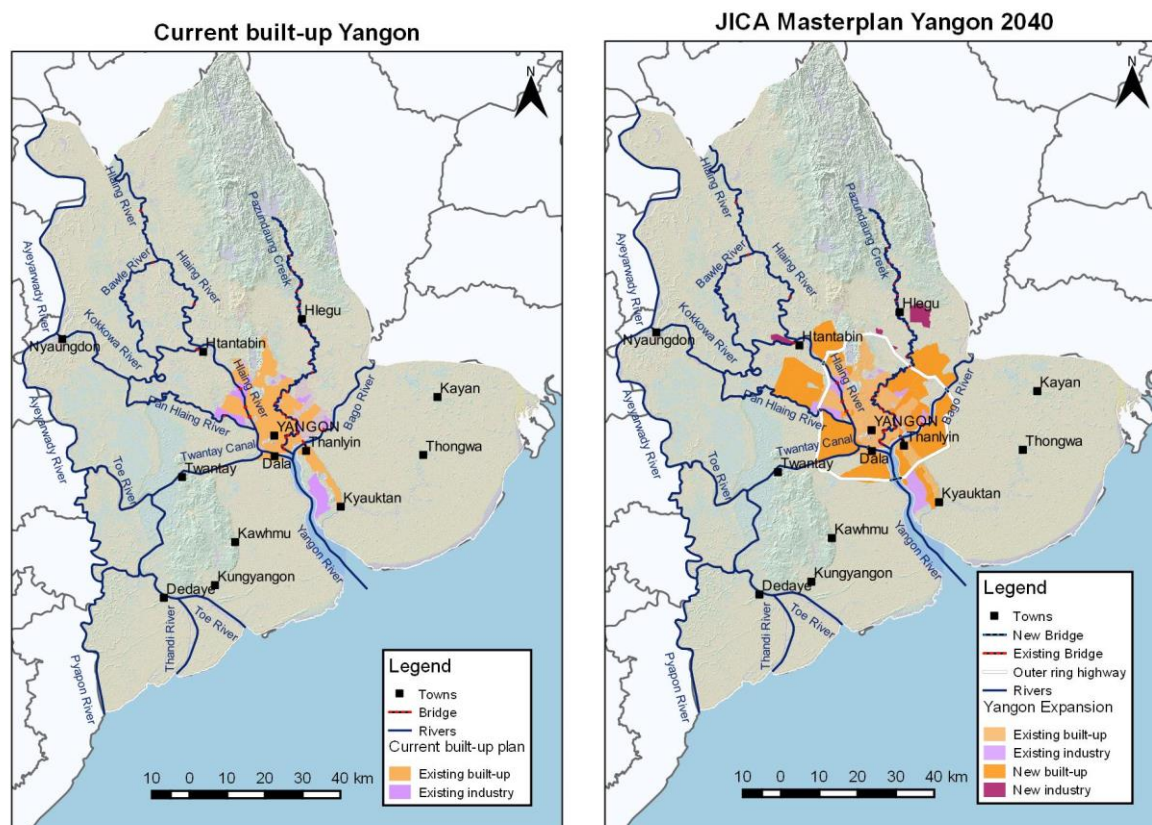


Figure 1: Current built up and JICA Masterplan for Yangon 2040 (JICA, 2018)

The fast development of greater Yangon in a relatively unaffected natural system like the Ayeyarwady Delta, requires an integrated approach and well-informed decision making about the water security measures. The maps in *Figure 1* show the current urbanized and industrial area of Yangon and the outlook as this has been formulated in the JICA Masterplan Yangon for 2040 (JICA, 2018). Many current and former flood plains may be transformed into urban and industrial areas with significantly less space for water than today.

While the natural delta system is complex, the same holds for the institutional and governance system of water resources management. In Myanmar, water supply is often recognized as a task of the government: in rural areas the Department of Rural Development (DRD) under the Ministry of Agriculture, Livestock and Irrigation (MOALI) and in urban Yangon under the water resources and water supply authority of the Yangon City Development Committee (YCDC). Additionally, the department of Urban Housing Development (DUHD) of the Ministry of Construction (MOC) has a role in water supply. For managing flood hazards, the governance settings are even more complicated as no department has the overall authority or responsibility for it. Further, the involvement of different sectoral departments at different governance levels, shows the complexity of reaching integrated consensus about measures that interfere with the natural delta system. The fact that roles and responsibilities for integrated management of water resources and security in the greater Yangon area are not always clear, leads to increasing risks for negative cumulative effects of different developments and measures in the area.

A second complicating aspect is that the current situation of water security may no longer be acceptable. For (international) investors, for example, it is important that flood hazards are being controlled and that water supply is guaranteed. Especially, the lack of reliable freshwater supply seriously hinders the well-being of people and possibly also the economic productivity. An over-exploitation of the water resources and the delta's ecosystem services, can lead to environmental damage as well. New measures that are currently not being considered may help to improve the current water security situation.

The governments of Myanmar and the Netherlands decided to work together on the Regional Water Security Study (RWSS) as part of their ongoing MoU on Integrated Water Resources Management. The RWSS covers the area West and South West of Yangon Municipality and is bordered by the Pan Hlaing River and Kokkowa River in the North, the Hlaing River and Yangon River in the East, the Andaman Sea and Gulf of Martaban in the South, and the Toe River in the West. The study area includes the Nyaungdon Area, the Pan Hlaing River Basin, the Twante Canal, and the Southern Yangon District. The project area is shown in Figure 2 (roughly indicated with the red boundary).

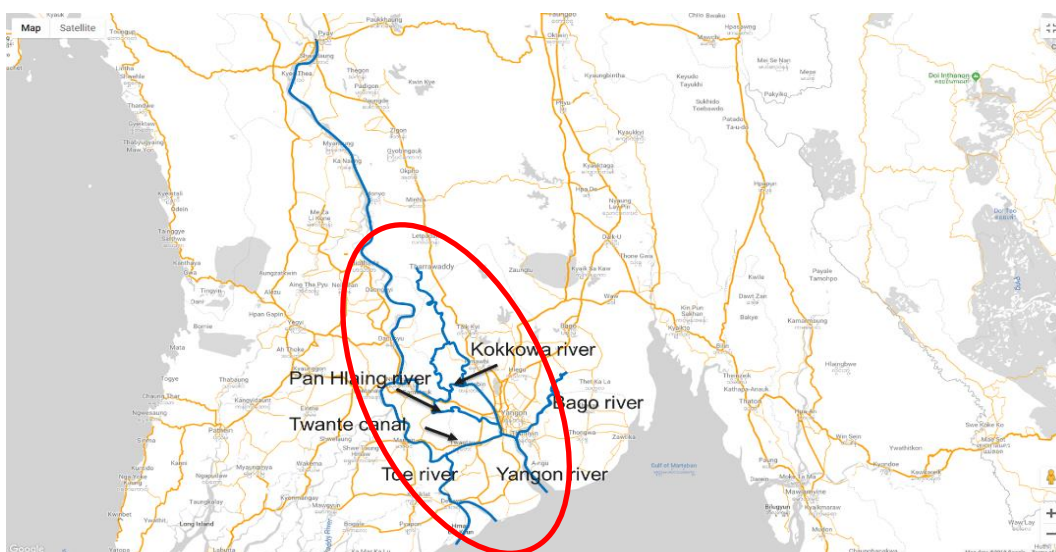


Figure 2: RWSS project area

In the first phase of RWSS, referred to as RWSS (IADS-B), a Framework for Analysis was developed and tested, including a hydrodynamic computer model. In RWSS (IADS-B), a preliminary assessment was made of the current flood and freshwater security baseline. The outcomes of RWSS (IADS-B) were presented and discussed amongst key stakeholders during a workshop on 24 October 2019. A consortium led by Arcadis has been contracted to execute the second phase of the RWSS, the results of which are presented in this report.

1.2 Objective of the study

The objective of the RWSS is:

To define (a) coherent set(s) of priority no-regret measures and investments to sustainably improve water security in the short and medium term (until 2040) in the Yangon Region that are supported by the stakeholders and which can subsequently be designed, financed and implemented under the World Bank financed AIRBM project or picked up by any other development partner.

Water security, as defined by the Global Water Partnership (GWP, 2000), means at any level from the household to the global, that every person has access to enough safe water at affordable cost to lead a clean, healthy and productive life, while ensuring that the natural environment is protected and enhanced. Those using and sharing river basins and aquifers must manage their water sustainably, balancing water use for human development with protection of vital eco-systems and the ecological services they provide. In this project, 'water security' refers to spatial development challenges that comes with "too much water" (pluvial, river, and coastal flood hazards), "too little water" (water scarcity for agriculture, domestic and industrial use) and/or "too 'dirty' water". The latter in this study only includes salinity which is included in the RWSS numerical model.

The flood and freshwater security situations are described with the use of "indicators". A distinction is made between:

- *Hydraulic indicators* – these describe water-related aspects. River discharges and water levels combined with protection levels relate to flood security while salinity levels relate to freshwater security),
- *Socio-economic indicators* – these describe the socio-economic aspects related to changes in the water system, and,
- *Environmental indicators* – these describe environmental aspects related to changes in the water system.

The hydraulic indicators have been quantitatively assessed using hydraulic (numerical) models. The latter two types of indicators are not modelled, but qualitatively assessed. Inputs for this assessment are the computed changes to the hydraulic indicators dealing with flood safety and freshwater security under influence of changes to the water system due to new or planned measures, climate change or upstream river basin changes.

The priority measures must be attractive from an investment point of view. Bankability is important in relation to sufficient collateral, future cashflow and high probability of success, which are required to be acceptable to institutional lenders for financing. The RWSS methodology provides a cost recovery indication (preliminary analysis) by comparing the reduction of damages resulting from the chosen measures against the capital investments (CAPEX) and operational costs (OPEX). Under the RWSS, this is done on a conceptual basis by looking at the quantified improvement of the flood and freshwater security situation per sub-area and per sector.

An important word in the project's objective is "supported", which refers to the importance of a participative and inclusive project approach. This means that all involved stakeholders are included in various ways in the project. Reference is made to Appendix A which lists the various consultations that were held in each project step. Stakeholders have been involved to create understanding on how 'system measures' such as raising the height of dikes, new water intake facilities, land reclamation, the construction of sluices, and so on, contribute to improved flood safety and freshwater availability.

Additionally, understanding the reasoning of prioritization and selection of measures and defining alternative measures to avoid predicted negative impacts are identified. A so-called Consultative Group was formed with representatives from key stakeholders that are consulted. This group of experts connect outcomes of the study in each project step with the ultimate decision-makers.

Capacity building is an important component of the RWSS and aims at improving technical understanding of the functionality of computer models as well as practical use of the models developed under the project, and at sharing information regarding the RWSS methodology with Myanmar experts. A training unit was established with participants from DWIR (MOTC), IWUMD (MOALI), MMU and YTU. The aim is that Myanmar experts themselves can do this type of analysis based on a good understanding of data relevance and quality, applying the model, understanding the relevance of an indicator framework, changing scenarios, and assessing potential measures.

1.3 General approach

This project has a regional scope, which means that the level of detail is restricted to processes and information that is available and typically valid on the spatial scale of the whole project area. The distribution of water over the various river branches, for example, is studied in detail whereas the structural details and integrity of the many sluices and hydraulic structures are not examined individually. The idea at the start of the project was that – if deemed necessary – measures that would improve the water security on regional scale could be developed and proposed. These measures would then interfere with the physics of the whole delta system. During the project, however, it became clear that the types of measures that would make most sense to improve the water security in the project area, would be typically smaller scale measures, such as the provision of a local water pond, or increasing the height of a dike section. Because many of these individual measures are required on the whole regional scale, these measures have been grouped together under specific programs as explained in this report. Given the regional focus of the project, only limited local information is available to be incorporated in the development of the measures. Therefore, engineering is largely done at conceptual level with a few exceptions where detailing has been done up to pre-feasibility level. None of the measures have been worked out at feasibility level, which is expected to be done in follow-up studies.

The project consists of five key steps that are all connected and some take place in parallel, as indicated in Figure 3 below. The first step is to establish a flood safety and freshwater availability baseline in detail (the “baseline assessment”). For this, the available Framework for Analysis (Chapter 2) is updated and geographical subareas (so-called unit areas) are selected. The flood and freshwater security “hydraulic indicators” are specified for each unit area and computed with the available computer models.

The RWSS computer model(s) include:

- The Channel flow model (A) with a domain covering the main river channels within the project area. This model is meant for the simulation of low to medium-high discharge channel-flow where overbank flow is not relevant.
- The Overland flow model (B) with a domain covering the main channels and the ‘dry’ areas in between, within the Yangon area. This model allows for simulation of both overland flow and channel flow, including cyclone modelling and basic rainfall runoff modelling.
- A dedicated Salinity model (3-dimensional version of model A) dedicated to simulating the 3D intrusion of salt.
- A SOBEK Rainfall runoff model of Yangon South allowing detailed rainfall runoff modelling for this sub-area.

The results from this analysis, including an improved understanding of the abiotic behavior of the delta system in the project area, is reported in Chapter 3.

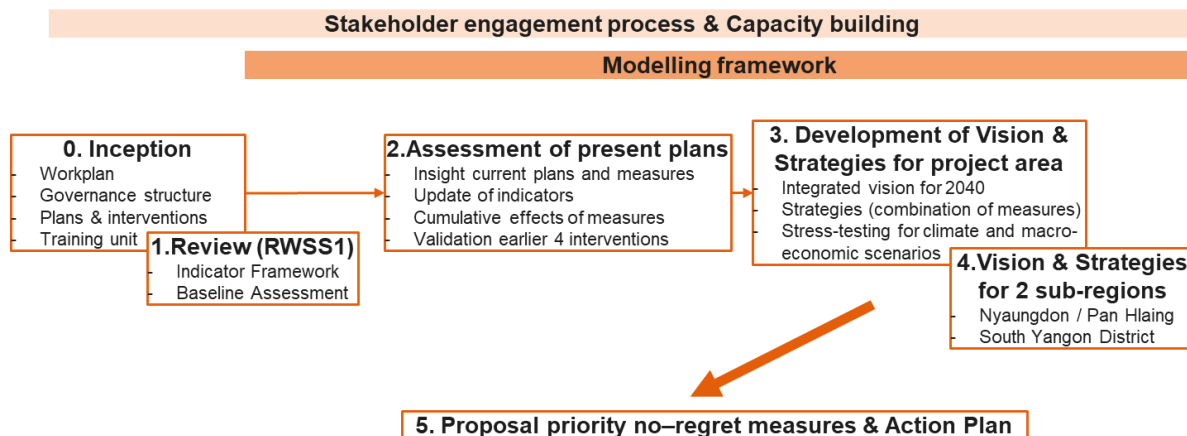


Figure 3: RWSS Project steps

The next step, reported in Chapter 4, is to analyze the possible impact of already planned measures and to determine how that influences the baseline. These measures are collected via stakeholder consultations and literature studies. The computer model is used to compute the changes in the flood and freshwater security indicators. Also, the impact of climate change and upstream (Ayeyarwady) river basin changes on these indicators are considered. Based on the established changes in the hydraulic indicators, a qualitative assessment is made of the socio-economic and environmental indicators. Chapter 4 also presents the outcomes of a quantitative flood risk assessment and an analysis of water supply shortages, which completes the assessment of the current and future water security situation.

The third step is the development of a Vision on the preferred water security situation in 2040. Strategies are developed to achieve this desired future situation, with a focus on the sub-areas, Pan Hlaing and Nyaungdon Island and Yangon South (Chapter 5). These subareas were selected as many of the water security related challenges are concentrated here. The Terms of Reference of the project for that reason, explicitly asks to focus on the named sub-areas.

The strategies are selected, sequenced, and prioritized sets of measures, that aim to achieve the Vision's targets on flood risk management and freshwater availability. These sets of measures are grouped in three Programs and conceptualized in Chapter 6.

Based on the shortlist of measures, a set of no-regret short-term measures is proposed in Chapter 7, followed with recommendations for next steps in Chapter 8.

1.4 Conclusions

In this Section the most important conclusions from the various study activities are listed. For a more elaborated description, the reader is referred to the relevant Section in the Report, where more quantitative information can be found including an analysis of the accuracy and robustness of certain conclusions. The Executive Summary, containing the key messages of the study including the list of proposed short-term no-regret measures and their justification, is available as a separate document.

Water security in the Greater Yangon Region

1. To understand the flow of water through the project area, it is necessary to consider the area as one interconnected deltaic system. The water distribution over the different river branches in the Ayeyarwady Delta is determined by a complex interaction between freshwater discharge from the Ayeyarwady river and saltwater tidal forcing from the sea. In the dry season, tidal influences (water levels, flow velocities and salt intrusion) are observed roughly 50 km further inland, compared to the wet season. Drainage of local rainfall into the different river branches has only little impact on the water distribution. Because of its location between Toe River and Yangon River, Twante Canal plays an important, yet complicated role in the delta system. During high river discharges, the flow direction in the Twante Canal is continuously eastward towards Yangon. During low river discharge

the flow direction alternates between westward with incoming tide, and eastward on the outgoing tide.

2. The current water security challenges in the Greater Yangon Region, acknowledged by consulted stakeholders and authorities, are:
 - a. Relatively high probability of flooding per year in many locations. Along the Ayeyarwady River and its primary river branches (Kokkowa, Hlaing and Toe rivers) extensive areas are very susceptible for fluvial flooding (more frequent than once per 10 year). These areas all have a flood probability of around 1:10 and lower. The most extensive coastal flooding caused by cyclones and storms occurs in the coastal areas in the southwest and upstream along Yangon River. Overall, the probability of river flooding is higher than the probability for coastal flooding upstream of Htantabin (on Hlaing River) and upstream of gauging station 21Mile on the Toe River (entrance of Twante Canal). Upstream of these points, the water levels caused by river floods are generally higher than those caused by coastal storms. In general, coastal storm surges do not reach the northern parts of the study area.
 - b. In some areas regular floods with freshwater provide ecosystem services in the form of flushing and nutrition. However, saltwater flooding associated with coastal floods is damaging agricultural production and freshwater ecosystems as most species need freshwater to survive. Hence, apart from the overall damaging impact of major floods, coastal flooding is generally associated with socio-economic and environmental degradation like mangrove degradation.
 - c. Extreme and long-lasting local rainfall, combined with poor local ground infiltration and surface drainage, may cause large areas to be temporarily flooded. This project considers pluvial flooding a problem when inundation depth exceeds 30 cm for urban areas and 60 cm for rural areas and if this lasts at least one day in large areas. This appears to be the case with return periods of 1 in 10 years in locations that are generally at greater distances from the nearby rivers.
 - d. The relative importance of groundwater has steadily risen throughout the Ayeyarwady Delta due to population growth, agricultural development, and the pollution of surface waters. A significant decrease in groundwater tables between 10 and 35 meters (*Figure 31*) has been observed around Yangon and other cities.
 - e. Many people live in rural communities and towns like Twante Town, Kawhmu Town, and Kungyangon Town rely on local ponds, tube wells or water trucks for their domestic water. The unmet domestic water demand is estimated to be more than 100 liters/day/household for the rural areas and up to several m³/day/household for towns and villages. These show the spatial differences between rural areas and densely populated areas.
 - f. Agricultural land that is not irrigated can produce one crop per year, during the rainy season, which can be doubled when irrigated. Limitations for irrigation are the salinity of the surface water, land elevation (due to pumping requirement) and the absence of (maintained and functioning) irrigation infrastructure.
3. The water security challenges in the future will be different from today due to spatial developments such as urbanization and industrialization (increasing the impacts of floods and shortages), climate change effects leading to sea-level rise and more frequent extreme weather events, and to a lesser extent to changes in the delta system due to the construction of hydropower dams in the upper Ayeyarwady River basin. The expected changes to the water security situation in 2040 are:
 - a. Flood probabilities generally double, particularly for fluvial flooding, as a result of water level increases between 10 and 30 cm due to increased peak discharges and sea level rise.
 - b. Upper basin (hydropower) dam development does not change the flood probabilities significantly because later in the season (when the river discharges increase again) the reservoirs are (partly) filled so that they can't flatten the discharge curve much. Further, many upstream branches do not and are not expected to have dams. The volume of water stored behind dams is too small to significantly impact water supply in prolonged dry periods. The impact of the dams on the sediment transport regimes of the Ayeyarwady river has not been studied in this project. In theory that may have an impact on the longer-term

- flood safety if the average heights of the riverbed changes or if the discharge distribution over the delta branches change.
- c. The economic damage caused by any flood event increases significantly with the expected economic developments in flood prone areas if no appropriate flood defenses are developed. This is because the increase in potential damage can be 10 or 100 times, and so is the risk itself.
 - d. The maximum saltwater intrusion (criterion higher than 0.5 PSU evaluated at surface level) reaches locations 20 km more inland than today.
 - e. The unmet water demand increases due to population growth and it is expected that there will be fewer options to use groundwater.
 - f. To meet the increasing demand for high quality food in the future, single crop production may likely need to move to (high value) irrigated agriculture, further increasing the irrigation water demand.
4. Any physical intervention in the delta system that may change the “flow of water”, has an effect somewhere else in the system. Four such measures are currently being considered by Myanmar developers and authorities:
- a. **The construction of Pan Hlaing Sluice on the eastside of the Pan Hlaing River.** This study concludes that in general, the impact on the flood and water availability challenges, compared to the present situation, is low. Salt intrusion is hardly impacted, and the fluvial and coastal flood return periods only change marginally. The overall score on socioeconomic impacts is expected to be positive, that on environmental aspects neutral or locally slightly negative (Based on Arcadis et al., 2019b).
 - b. **New water intakes Kokkowa River and Toe River.** Simulations show that freshwater extractions in the delta as small as 3 m³/s can have a significant impact on the salt intrusion, increasing the frequency of salt intrusion by approximately 10% at these locations. Nevertheless, constructing both facilities is expected to generate a net positive (+) socioeconomic impact and has a neutral (marginal) impact on environmental aspects.
 - c. **Phase 2 of the “Improvement of Twante Canal Project”, which comprises the construction of multi-purpose barrages on both sides of the canal.** The (fluvial) flood probability along the Toe River increases because of a backwater effect of the (western) barrage raising water levels up to 65 cm. Without raising the levees along Toe River, the flood safety reduces because of this backwater effect. Phase 2 of the Twante Canal project therefore will have to include an extensive dike improvement program. The (coastal) flood probability along the Yangon River up to Yangon City also increases because of a stronger tide funneling effect in the Yangon River caused by the presence of the eastern barrage. The salt wedge moves further inland under extreme conditions, even reaching Kokkowa River up to Mezali. A positive effect of the Twante Canal Phase 2 is that the canal itself can serve as a freshwater reservoir that can supply sufficient quantities of water to nearby areas to increase the total area of irrigated agricultural land. The overall score on socioeconomic impacts is expected to be moderately positive (0/+). The overall score on environmental aspects is expected to be slightly negative, mainly due to the change from alternating fresh/brackish to a freshwater system. However, the closed Twante Canal is partly reestablishing the situation before the canal was dug.
 - d. **New Yangon City Development (NYCD) with a 1 in 200 year event flood safety level.** The impact of the flood protection system (dikes) on the surrounding areas is small because the loss of retention area is small, causing no significant increase in water levels elsewhere. The overall score on socio-economic aspects is considered positive, whereas these are expected neutral on surrounding environmental aspects.

Vision, targets, strategies

5. The following Vision for the Water Security is proposed: “In 2040 the project area is sufficiently protected against damaging floods and can rely on sufficient supply of good quality water for domestic and agricultural use, serving the emerging needs of the urban development. This provides

the social, economic and natural environment where all people can live safely, prosperously and pleasantly, while maintaining a healthy economy and valuable nature.”

Since in the Greater Yangon Region the characteristics and the needs of the urban areas differ considerably from those of the rural areas, two specific sets of targets are developed for the vision in 2040.

For urban areas:

- a. Reduction in flood probability (below 1 in 200 years)
- b. Efficient use of space to enhance development (combination of functions)
- c. Drainage of urban areas (e.g. 70% of Yangon Region towns)
- d. At least 80% of 33 townships to have freshwater supply
- e. Sufficient water for high rise buildings in urban areas - not from groundwater
- f. Wastewater discharge from towns and industries 100% treated to specified standards

For rural areas:

- a. Flood frequency less often than 1 in 50 years
 - b. Inhabitants (80%) of villages of Greater Yangon to have access to freshwater throughout the year
 - c. Optimize benefits (fertilizing) from (fluvial) floods
 - d. Freshwater availability for irrigation, boosting agricultural production by increasing the irrigated area by 50,000 hectares
6. To achieve the above tentative targets, additional measures are required. The study did not indicate the need for one or more large hydraulic infrastructural works that aim to change the water distribution over the different river branches in the delta. Examples of such system measures are river bifurcation control structures, excavating a new channel or constructing river diversion works. These generally expensive and difficult-to-implement measures do not contribute to achieving the set targets. For that, more localized measures are required that have more predictable results towards reaching the targets. Three programs have been developed that form the basis for the development of the strategies:
- a. Weakest Links Program with the objective to upgrade dikes and embankments to the desired flood safety levels (point 7 below) in the whole project area. Measures include increasing the height of an existing dike section and the construction of new dikes with possible closure of natural creek mouths.
 - b. Water Availability (storage and supply) Program aiming at an increase of the suitable freshwater availability in the dry season (point 8 below). Measures include construction of storage ponds and groundwater recharge solutions from household to township level in the focus areas Pan Hlaing Island, Nyaungdon Island and Yangon South. These focus areas have the biggest water availability challenges, which have been acknowledged by the consulted stakeholders.
 - c. Drainage Management and Irrigation Program with the objective to reduce the adverse impact of pluvial flooding by improving or restoring interconnected drainage systems (point 9 below). The focus area is Yangon South, where good opportunities exist to combine measures so that integral solutions that bring most value to the people can be developed.

Details of all measures are provided in the factsheets in Appendix C.

7. To select and prioritize measures under the Weakest Links Program, a quantitative flood risk assessment was made. This includes:
 - a. The calculation of the economic damage and the number of affected people for each potential flood event. Combining this with the probability per year of each of these potential events, results in a 'yearly expected economic damage' and a 'yearly expected number of affected people'. This was done for a situation with current land use (with and without climate change) and for a situation with planned future land use and climate change. Climate change involves both 7% increased peak river discharges as well as 20 cm sea level rise. The annual economic flood risk typically ranges between 1 and 100 Myanmar Kyats (MMK)/m²/y for the current land use situation. Climate change roughly doubles the economic risk. Spatial developments, however, especially those indicated in the JICA

masterplan 2040, multiply the calculated risks in these developed areas with a factor of 100 or more. Significantly higher damage occurs if no additional protection is provided.

- b. The calculation of the costs (CAPEX) for strengthening the different (weakest) dike sections with the following assumptions:
 - i. Earthworks supply and construction costs: Clay 20,000 MMK / m³ (USD 14), and Sand 16,500 MMK / m³ (USD 12)
 - ii. Land Acquisition Costs: Excluded
 - iii. Channel Closings requiring hydraulic structures: ~25m channel width: 1414 Million MMK (USD 1M), ~25 – 50m channel width: 1475 Million MMK (USD 1.1M), and ~50 – 100m channel width: 4950 Million MMK (USD 3.5M)
 - iv. Annual Maintenance Costs: 0.1% of initial investment
 - v. 5-year Periodical Maintenance Costs: 3% of initial investment value
 - vi. Net Present Value: Discounted at 6% up to 2040

Along some of the weakest links, dike enforcement also requires the technical adjustment of local hydraulic structures.

- c. Even when the height of dikes is increased, there will be a residual annual flood risk. The sum of the investment costs for dike strengthening (b) and the calculated remaining risk after the dike strengthening are calculated. An economic optimum is obtained when the sum of CAPEX and the remaining economic flood risks is minimal. For each of the 20 distinguished unit areas (*Figure 5*), this results in the following proposed safety levels with associated investment costs (for the future scenario 2040 with climate change and spatial developments). The total CAPEX is roughly 140 M USD.

Table 108: Total estimated CAPEX for shortlisted measures program 1

Unit Area	Current Flood Protection Level Fluvial	Current Flood Protection Level Coastal	Proposed Flood Protection Level	CAPEX Cost (Million USD)	B / C Ratio (for Land use 2040 scenario)	Annual Affected People Before / After
UNIT_01	<1:2	1:70	100	17.6	4.5	20905 / 1024
UNIT_02	<1:2	<1:25	200	9.9	8.8	2087 / 147
UNIT_03	<1:2	<1:25	200	8.6	96.1	3305 / 287
UNIT_04	<1:2	<1:25	200	18.6	11.3	39360 / 549
UNIT_05	<1:2	<1:25	200	33.8	0.8	4270 / 215
UNIT_06	1:39	<1:25	200	8.4	9.7	1829 / 773
UNIT_07*	<1:2	<1:25	200	23.2	20.1	1200 / 356
UNIT_08	1:15	<1:25	200	32.8	1.3	554 / 302
UNIT_10	>1:200	1:40	200	1.7	5.3	113 / 70
UNIT_13	1:35	<1:25	200	9.8	1.7	2058 / 1017
UNIT_14	>1:200	<1:25	200	7.2	0.4	312/208
UNIT_15	<1:2	1:33	200	1.4	26.9	230 / 136
UNIT_18	<1:2	<1:25	50	7.1	4.3	13260 / 922

- d. Above table also gives the calculated Benefits over Costs ratio (B/C) as well as the number of affected people before and after the investment. For the latter, the same population spread as today has been used because of lack of information about future population growth and spread. The non-listed unit areas have a B/C ratio smaller lower than 1, meaning that from an economic perspective it does not make sense to invest in dike enforcements there. In these areas the present protection level is such that the remaining affected area is small and/or has low economic value compared to the dike strengthening investments required to increase its protection level.
- e. If all the dikes are raised to the new optimum levels, then the water levels in the delta system under extreme conditions may be impacted. This is studied by raising the respective weakest link sections in the model. Extreme water levels rise from almost nil to 0.35 m at

some river sections, during a 1 in 200 year high discharge event, because of the backwater effect. This effect is due to smaller cross-sectional flow areas and less space for temporary water storage (inundated land) giving higher water levels when going upstream. In the final design stage this effect needs to be compensated for, for example by adding another 10 cm to the design height of most dike sections that need reinforcements.

- f. While the economic rationale for dike enforcements is absent in some unit areas, there may still be a good reason to do so. The reason for this then is to reduce the number of people affected by flooding.
8. To select and prioritize measures under the (domestic) Water Availability (storage and supply) Program, the spatial distribution of the unmet water demand was compared with the potentially available surface or future piped water resources. The areas with the most difficult water supply options are the smaller villages and sparsely populated areas in unit area 5 (between Pan Hlaing river and Twante Canal), the rural communities in unit area 7 (those that are not likely connected to the new water supply system of New Yangon City), and the villages and sparsely populated areas in unit area 8, including Kawhmu Town and Kungyangon Town. Dala is not considered here as this town is assumed to be connected to Yangon Water Supply System in the (near) future.

The total of the unmet water demand in the selected rural areas ranges between 0.025 and 0.075 m³/day/hectare. The total number of affected people (today) is around 200,000 persons. From a longlist of measures, the following types of measures contribute most to the Vision's targets:

- a. Villages: rainwater harvesting (RWH) on neighborhood level including 1 lined pond (500 m³ storage capacity) servicing approximately 30 households. The pond utilizing locally aligned materials and with a RWH roof over the pond is filled under gravity. Water from the pond is then distributed to the households through a pressurized pipe distribution system. The total CAPEX cost to apply this solution across the villages in the selected rural areas is estimated in the order of 30 - 35 Million USD or ca. 200 USD/person.
- b. Standalone households: rainwater harvesting using house roofs and storage tanks (15 m³ storage capacity). It has been considered that a locally aligned and durable rainwater capturing solution (i.e. glass reinforced or other forms of durable plastic tanks) can be developed for a cost in the order of 2000 USD/Household or 500 USD/Person. The total estimated CAPEX cost for standalone houses in the selected rural areas is estimated in the order of 44 million USD. Currently adopted RWH solutions often utilize fewer durable materials i.e. low grade plastic, clay pots and tarpaulin / bamboo lined storage tanks. These materials offer a lower cost investment, however, in exchange for a shorter service life.
- c. Kawhmu and Kungyangon Towns: rehabilitation of existing ponds and development of new lined ponds. Based on the total stored water volume requirement of 45,000 m³ and 67,500 m³ for Kawhmu and Kungyangon respectively, the upper bound CAPEX cost to develop new ponds is estimated at approximately USD 3M. This excludes the cost of a distribution pipe network from the large ponds to the households, which in the assumed absence of any distribution networks in both towns, is estimated in the range of USD 4M for Kawhmu and USD 7.5M for Kungyangon.

The benefits associated with an increased availability of higher quality domestic water supply are typically socio-economic related. Because these benefits are assumed to be the same for all people in the focus areas, the various shortlisted measures and engineering solutions can be further evaluated and prioritized based on cost difference only.

9. An investigation has been undertaken in coordination with the Drainage Management and Irrigation Program to assess the opportunities to increase agricultural production via optimized water supply solutions. Unit Area 8 consists primarily of agricultural land even though it suffers from a lack of freshwater in the dry season in most of the area. Many drainage canals on the south and southeast, flowing into the Yangon River and the ocean, have no control structures which can block out the

saltwater from flowing into the channels. As a result, most of the agricultural areas in Unit 8 are limited to rainfed agriculture only, especially in the southeast.

Transforming the agricultural land from rainfed-only to irrigated agriculture would support the growing of a second or even a third crop. It could be expected that the production value per hectare would double. Different measures have been conceptualized, such as modifications to the existing drainage network, including adding control structures, and solutions that benefit from the natural tidal behavior of the water system, letting in freshwater into certain channels during low tide. The latter can be explained as follows:

- There is often no distinct freshwater layer: as a result of the highly dynamic property of the system, there is almost no stratification, and as such, no substantial difference in salinity in the surface and the bottom layer.
- As a result, farmers often let in freshwater during low tide because at this point in time, saline (sea) water is temporarily flushed out by the river discharge and the water that is let in during this time window is often freshwater (depending on the long term salt intrusion and location of the inlet).
- In conclusion, at high tide it is generally easier to bring in surface water under gravity. However, during high tide, there is an increased likelihood that this water is saline. Conversely, during low tide there is less head available, but a larger likelihood that the water is fresh (hence this practice is currently applied by local farmers). Further upstream, the water is always fresh, so timing is of less importance as the tidal influence is also much smaller or absent and the available head is constant.

The financial benefits for transforming the eastern part of Yangon South into irrigated agricultural land is estimated to be more than 50 million USD. To achieve this, all the currently open creek mouths must be closed, including gated barrages probably equipped with pumping stations for sufficient drainage capacity, to let the saltwater out. This option has not been further elaborated as optimization of agricultural production not only depends on water security but on many other aspects as well, which are not the topic of this RWSS.

10. To develop measures that fit under the objectives of the Drainage Management and Irrigation Program, it is of crucial importance to understand the interconnectedness of the existing drainage network, including all permanent and temporary control structures and their current state of maintenance (operationality). It was not the original intention of the regional water security study to go into that level of detail. However, it turned out to be important to control pluvial flooding and explore freshwater storage. A dedicated flow model is developed that comprises of all channels and structures of the drainage network in Yangon South. Based on the model output, it follows that:

- A 1 in 1 year rainfall event causes less than 1% of the modelled area (Yangon South; unit area 8) to be flooded with more than 60 cm during the peak of the rainfall event. After 1 day this has been reduced to 0% with isolated spots of inundated land; after 2 days all rainfall has been drained out through the drainage network.
- For a 1 in 10 year rainfall event, these percentages are respectively 34%, 15% and <1%, meaning that it takes more than 2 days for all the water to flow out.

Increasing the capacity (deepening and/or widening) of the existing channels improves the drainage capacity. It also offers the opportunity for more water storage, which in combination with additional control measures can be used for irrigation purposes. On the other hand, channel deepening may enhance saltwater seepage and widening may face land-ownership issues. Also, pluvial flood risks are most eminent at greater distances from the outlet structures, requiring channel enhancements for long stretches.

As a consequence, solutions need to be tailored to the local situation. Excessive rainwater may be stored locally rather than being drained out and lost. The analysis done for the Water Availability (storage and supply) Program suggests the need for such water storage near Kawhmu and Kungyangon Towns where the pluvial inundation depths are largest according to the model. In other locations farmers may be willing to surrender a small part of their land to increase the storage or

transport capacity of the canal, in case freshwater can be provided in sufficient amount to plant an additional crop.

Under the Weakest Links Program, the closure of some of the open creeks is already foreseen. Also the existing outlet structures at the end of most drainage canals have been designed for 1 in 50 year events at best, which means that many of them will need to be adjusted to be effective under the proposed safety level of 1 in 200 year event. The total CAPEX costs for adjusting and building these outlet structures for unit area 8 is estimated at 8 to 19 million USD. Some of the new outlet structures need a small increase in their design drainage capacity (ranging from 1% to 15%) to accommodate for the extra drainage capacity required to drain the excessive pluvial floods. This can be combined when designing these structures as part of the Weakest Links Program.

No-regret measures

11. To reach the list of recommended no-regret measures, synergy between programs and practical implementability define the final selection. Investments in freshwater facilities function optimally when protected against damaging floods. The same applies for improved drainage and increased agricultural activities. Similarly, construction of sluices related to the flood protection program may play a functional role for creating freshwater storage in creeks and canals for domestic or agricultural use. As such the combined application of the programs for flood protection, freshwater storage and drainage improvement in a particular area is preferred and fits the integrated approach followed under IWRM. This combination will improve the well-being and water security in the unit by providing the communities with freshwater and flood security. This will enhance the health and productivity in the rural communities and will protect households and enterprises from flood related damage.
12. The first no-regret measure concerns the eastern part of South Yangon (West) Region (Unit 8). Here, the analysis showed good opportunities for integrated solutions from all three programs. Flood protection will have most benefits for the expanding area around Dala. CAPEX costs are estimated at 32.8 million USD with a Benefit/Cost ratio above unity (1.3), which however is lower than that in some of the other unit areas. The adjusted outlet sluices that need to be modified under the flood safety improvement measures can be designed to allow bidirectional regulated flow to let freshwater in for beneficial flooding and freshwater provision to towns and agriculture. The drainage canal system can then be expanded and equipped with level control structures to enhance drainage during rainfall events, but also to distribute and store the freshwater for domestic and agriculture use. No CAPEX estimate is available for the drainage program due to lack of detailed data. Towns and communities will be equipped with freshwater storage and distribution measures suitable to the type and location of the community, making optimal use of rainwater harvesting possibilities and the improved drainage system. Estimated CAPEX costs of the freshwater programs total almost 60 million USD. Detailed factsheets are available in Appendix C.
13. The second no-regret measure focuses on Pan Hlaing Island (Units 3 and 6). It will benefit significantly from dike improvements that increase its flood safety level to a 1 in 200 year event. The agricultural production is already benefitting from Mezali sluice freshwater delivery in the dry season, and the eastern part of the Island is urbanizing rapidly. So, the value of agricultural, domestic and industrial assets is high and is expected to increase. Total CAPEX estimate for the dike improvement program is 17 million USD with a Benefit/Cost ratio of more than 50, which makes this type of investment economically very attractive. The drainage system is already well developed, but potentially there are lessons learned from the improved drainage program applied in Unit 8 that can also benefit this area. The Pan Hlaing River Vision and Strategies project (Arcadis, 2019) already mentions the opportunity to add additional freshwater storage reservoirs along the closed Pan Hlaing River, to increase the total area of irrigated agricultural land. It is expected that the Urban and Industrial area in the south-east will benefit from the Greater Yangon urban water supply scheme, but the rural communities will benefit greatly from the proposed freshwater program in this area.

14. The third no-regret measure focuses on Nyaungdon Island (Units 4,5, and 7). Interconnectivity between the units, implies that a unit can only be protected against flooding if the other units are also protected. Therefore, the complete island is recommended to be protected to a 1 in 200 year event protection level, maintaining the possibility for beneficial flooding (meaning regular fluvial floods accepted, but extreme destructive flood events effectively avoided). Associated dike improvements would require a CAPEX of about 76 million USD and have an overall benefit-cost ratio of around 9. The cost-benefit ratio is used here as economic indicator. Net-present value (NPV) and Internal rate of return (IRR) could have been used as well. The B/C-ratio however provides more insight in the effectiveness of investments than the net-present value, and the IRR which is related to NPV. Part of this investment is expected to be provided by the New Yangon City Development Corporation (for Unit area 7; the eastern part of Nyaungdon Island). The drainage system is already well developed, but potentially there are lessons learned from the improved drainage program applied in Unit 8 that can also benefit this area. The rural communities on the Island will benefit greatly from the proposed freshwater program in this area.
15. Finally, dike improvements in Units 1, 2, 10, 15, and 18 are suggested as no regret measures, because they affect a large number of people or have a high benefit-cost ratio. However, not all measures can be designed and implemented at the same time as that would probably over-ask the responsible implementing departments.

Next steps & action plan

16. The scope of this project is limited to the conceptual development of measures to improve the water security of the project area. Since the focus has generally shifted from regional to local types of measures (such as the upgrade of an existing water pond at neighborhood level, or increasing the height of 1 km dike), some of the measures have been worked out at pre-feasibility level (see for example cross-sections with bill of quantities in the attached Fact Sheets). Nevertheless, for each of the proposed no-regret measures, additional feasibility studies are required to provide the local information required for decision-making. (The implementation of the strategy requires this refinement to provide confidence to the parties and stakeholders involved regarding the course and direction of the next steps.
 - a. Program 1: For the dike strengthening program, further, detailed data collection on existing flood defense profiles (i.e. dike crest, toe of trailing and leading slopes, slope gradients), open channels (cross-sectional dimensions and peak/low flow characteristics), assessment of existing hydraulic structures (structural, organizational) and land ownership in the area behind the dikes is required. This should also include the data collected through an Environmental and Social Impact Assessment (ESIA). These steps also pertain to the upgrade of existing or introduction of new drainage structures within the reinforced dikes.
The dike strengthening program can be expanded upon to include multi-functional dikes so as to maximize the benefit of the investment. This may include adapting the dikes for additional purposes such as commercial and/or residential waterfront developments, underground car parking in highly commercial area and environmental habitats, to name a few. Stakeholder consultants would be required to assess the most effective form of multi-purposing to be adopted based on planned future land use and community expectations. The responsibilities of embankments are with IWUMD who is expected to be the owner of this program in close collaboration with DWIR, Yangon Region and YCDC. However, actual roles, responsibilities and ownership will be confirmed while preparing the further studies.
 - b. Program 2: For the water supply and storage program the following steps are envisaged:
 - Confirm water supply and demand requirements for up to 2040,
 - Confirm capacity and condition of existing ponds and other water supply infrastructure,
 - Design development of water supply measures on household, village and town level,
 - Define roles and responsibilities (ownership) of measures/investments in particular of relevant governmental organizations including DRD, YCDC, YRG, IWUMD and DWIR
 - Procurement to market.

Irrigation Water supply in Unit Area 8 requires an assessment of the available freshwater supply in the Twante Canal for irrigation purposes as well as a comprehensive analysis of the lower limits of the salt front in the Yangon River (and possibly Toe River) as an additional source of water supply. Further numerical modelling can assess the most effective means of distributing the increased water supply across Unit Area 8 to non-irrigated land, including the assessment of flow control structures. Estimated CAPEX costs for the envisaged measures can then be compared against the increased land output associated with the increased irrigation.

- c. Program 3: Drainage measures to reduce the impact of pluvial flooding and increase freshwater storage for agriculture have now been considered for Unit Area 8. Additional data collection is required to finetune the model (crest heights, land levels, channel alignments and dimensions) and confirm the measures. Measures under Program 3 for Unit Area 8 include increasing capacity of outlet structures through the ring dikes (following local measures implemented under Program 1). Other measures to manage pluvial flooding within Unit Area 8 shall be integrated with the measures aimed to increase water supply for irrigation within Unit Area 8. The next steps to derive these measures are detailed under Program 2.
SOBEK models could be extended for the other Unit Areas to be able to better quantify pluvial flooding risks and determine measures to increase drainage and/or increase water supply for irrigation. Such measures would then similarly need to be developed further towards a pre-feasibility and feasibility stage. Furthermore, roles and responsibilities of governmental organizations need to be discussed and defined, in particular, potential key departments like IWUMD, DOA, DWIR, and YRG.
17. A programmatic approach has been proposed, whereby the procurement of the different measures under each program are combined within individual Unit Areas or groups of Unit Areas. A coordinating organization needs to be mandated to manage this programmatic approach. Various departments need to be mobilized to integrate and implement the various measures within each Unit Area, to ensure funding is suitably allocated and lessons learned are carried forward.
 18. Based on the outcomes of the RWSS presented here, an update is required on the detailed cost-recovery of the proposed measures and on the financial sustainability including ecosystems, disaster risk reduction and operational program management costs.
 19. The three programs and the no-regret measures all focus on structural infrastructural investments while certain enabling and non-structural measures would also assist in realizing the objectives of the strategy. Such non-structural measures would result in improved functioning of the structural measures with more benefits to water security across the Yangon Region in the long term. These include:
 - Capacity building and awareness raising: Often a first step towards changing people's behavior and could lead to material improvements in water resources use and management. Relevant topics include water quality, pollution impacts and solid waste disposal, reuse/recycling of water, sustainable use of water at household level and storage practices like rainwater harvesting, risks and consequences of fertilizers and pesticides, and alternative farming systems.
 - Planning, policies and regulations: Development of zoning plans, integrated plans towards economic growth for the region. Policies and regulations are required to set an enabling environment for IWRM and water security.
 - Governance and coordination between different departments (from different ministries and committees and within ministries and committees) and between different levels (union, regional and city level) and formation of water user groups led by related departments.
 - Studies, monitoring & data management: Hydro Informatics Centre (HIC) can function as main information data bank for IWRM ensuring all data is shared and available where necessary.
 20. It is recommended to develop a monitoring plan to assist in regularly updating the strategy implementation and measure prioritization. The key objectives of the monitoring plan are to:

- Allow the accuracy of the numerical hydrodynamic model to be verified over the long term and aid in supporting decisions in the future. This is particularly important as the changing conditions of climate are observed,
 - Monitoring the overall system to assess trigger points that would instigate the implementation of or change to a proposed measure under the strategy implementation plan.
21. The main items that are recommended to be monitored are as follows. Further detailing of these will be required as part of the strategy implementation plan:
- River flood levels,
 - Coastal flood levels,
 - Rainfall intensity,
 - Saltwater intrusion concentration levels, particularly within the rivers surrounding unit areas where current rural water supply for domestic and irrigation use is through river and groundwater extraction,
 - Rate of urbanization against the JICA report from which estimated damages in the risk assessment and consequential benefit / cost ratios have been derived,
 - Expansion of YCDC water supply network to urbanized areas located near to Yangon City.

1.5 Report reading guide

A reading guide is provided in Figure 4 on the next page. This overview of the 8-chapter report depicts each chapter in a box with further information on its content. Furthermore, key components of the chapter are highlighted in **bold** allowing for a quick and easy search. Detailed information on the execution of the analyses can be found in the chapters and appendices.

1. Introduction

Objectives and background of the project. General approach and summary of conclusions.

2. Framework for Analysis

Assess current safety level



Selection and prioritization of new measures



Assess impact of no-regret measures

3. Baseline situation

- Overview of **the abiotic delta system**, including system elements, river discharges, water levels, salinity, meteorological conditions, and general flooding behavior
- **Threshold assessment for flood and freshwater security**

4. Autonomous changes in water security

- **Planned developments and measures** and their **impacts**
- Assessment of **future climate change scenarios** and their **impacts**
- **Flood risk assessment**
- **Fresh water demands** for **agricultural** areas and **rural** communities.

5. Vision & Strategies

Vision & targets

Strategy and proposed programs

6. Concretization of measures



- Program 1 **Weakest links**
- Program 2 **Water availability**
- Program 3 **Drainage Management and Irrigation**

7. No-regret priority measures

- **Shortlisted measures**
- General prioritization of measures
- **Evaluation of prioritization** of measures
- Reflection of program synergies and feasibility

8. Next steps

- **Action plan:** from pre-feasibility to feasibility
- **Monitoring plan**

Figure 4: Reading guide scheme

2 FRAMEWORK FOR ANALYSIS

2.1 Introduction

Many local measures in the Yangon Region are interrelated and have important impacts on each other and on the greater Ayeyarwady delta system. For this reason, planned projects must be dealt with in an integrated way by studying the cumulative impacts of local works and plans region wide. Such integral approach requires the use of numerical hydrodynamic simulation models that enable the assessment of the cumulative impact of proposed measures in the water systems, planning and design of water related infrastructure, and their relation to river flows, floods, tides, storm surges and salinity intrusion. The models developed under RWSS (IADS-B) are used to assess these impacts. Flood and freshwater security issues not included in the model, like river morphology, water quality (except salinity), socio-economic, and environmental impacts require expert judgement.

This chapter describes, how, using the model results, the present, baseline situation is assessed, and how the proposed measures are assessed and prioritized to achieve a list of no-regret measures. The models used are described in detail in Appendix B.

2.2 Assessment Framework

To quantify improvements in flood and salinity intrusion related water security, it is important to first assess the present situation. To do this, an Assessment Framework is used that is also applied to analyze the impact of planned measures and future scenarios. This results in an insight in where the present safety level is insufficient compared to the desired levels. New measures are then identified that aim to increase the flood security levels. To distinguish between the large number of possible measures and to reach a shortlist of no-regret measures, a separate Selection and Prioritization Framework is used. Finally, the original Assessment Framework is used to assess and quantify the (combined) impact of these proposed no-regret measures.

This Section explains the Assessment Framework for flood and salinity intrusion related water security parameters. Some important terms are defined below and further elaborated on in the next Sections.

- **Indicator:** Indicators are clearly defined parameters which can be either quantified with the numerical model (the hydraulic indicators) or determined via expert judgement (the socio-economic and environmental indicators).
- **Thresholds:** Each hydraulic indicator has its own so-called 'threshold value' that can be used to determine if, or under which circumstances, the actual situation of that indicator is acceptable. The set of indicators and their threshold values make the model output relevant for decision-making.
- **Unit Areas:** The project area is divided into unit areas to obtain more detailed information about the flood and freshwater security for specific areas and specific sectors. Such detailing is required to justify measures that aim to improve the water security situation for these areas and sectors.
- **Models:** Computer based hydrodynamic models that can simulate the water levels, flows and salt intrusion for relevant situations. The models are run with different boundary conditions such as upstream flow, wind surge levels at the coast, tides and rainfall.
- **Return Periods:** The probability that events such as floods, rainstorms or cyclones will occur is expressed as a Return Period (RP). As the inverse of probability (generally expressed in %), it gives the estimated time interval between events of a similar size or intensity. For example, the return period of a flood might be 100 years; otherwise expressed as a "1 in 100 year event", or its probability of occurring being "1/100 per year". This means that, in any given year, there is a 1% chance that it will happen, regardless of when the last similar event was. Any proposed measure to improve the water security is only effective for a limited range of events. A dike, for example, will not eliminate floods, but it will reduce the probability of floods.

Using these components, the Assessment Framework comprises the running of the numerical models for different scenarios. Each scenario is characterized by a unique event (or combination of events) with a certain return period (1 in x years) or probability of occurrence (1/x per year) reflected in a change to the model boundary conditions. The results are assessed by comparing the calculated indicator levels with the threshold set for each respective indicator. Besides the probability of flooding, also the flood

extent and flood depth are assessed. This results in the quantification of flood safety levels in terms of return periods of events that exceed the agreed threshold, as well as an identification of which land areas are affected, for each unit area. In this way the safety level of different unit areas can be compared, and the impact of proposed measures can be quantified.

2.2.1 Indicators and Thresholds

Data to specify and propose indicators and their related threshold values was collected from a selection of stakeholders within the Myanmar government and those from the private sector with a direct stake in flood and freshwater security of the Greater Yangon Region. In the Inception and Step 1 of the project, the Water Security Indicator Framework that was developed under RWSS (IADS-B) was evaluated and updated based on discussions in the inception workshop on October 24, 2019, the consultative group on December 3, 2019, the workshop on December 5, 2019, the meeting with representatives of Environmental NGO on December 5, 2019, and the team consultations (see appendix A for most Minutes of Meeting). The indicators that are agreed upon are:

- Fluvial floods: river water level at the lowest sections of the embankment around a unit area [m+MSL];
- Pluvial floods: inundation depth of water accumulated at lowest areas separated for urban and non-urban areas [m];
- Storm surge floods, or coastal flood: river water levels at the lowest sections of the embankments around a unit area [m+MSL];
- Water shortage/salinization: salinity level in the river/estuary branches (ppm at the riverbed);
- Environmental impacts: qualitative score expressing impact compared to baseline situation [-]; and
- Socio-economic impacts: qualitative score expressing impact compared to baseline situation [-].

Fluvial Flood Indicator



Fluvial or Riverine flooding is most likely to occur in the middle- and upper delta where high river discharges from upstream will cause a rise of the water level between the embankments. Flooding occurs when water levels in the river rise because of rainfall in the Ayeyarwady River

basin causing the embankments to overflow. In this study no other dike failure mechanisms such as foreshore erosion, piping or inner/outer slope instability, are considered.

Consequently, the most appropriate indicator is the water level in the river. To simulate the water level indicator, the *overland flow model* is used (Appendix B). The model is run for different representative events with increasing return periods as described in Section 2.2.4.

The threshold value for this indicator is the height of the levee at the weakest (i.e. lowest with respect to the water level) point. This indicates when and where the embankment will overtop first. Breaching of dikes is not considered. The method of assessing this point and the moment of first flooding is explained in Section 3.3.1. Also important are the spatial extent of the flooding, the resulting damage, and the number of affected people. These aspects are therefore assessed as well (Section 4.5).



Pluvial Flood Indicator

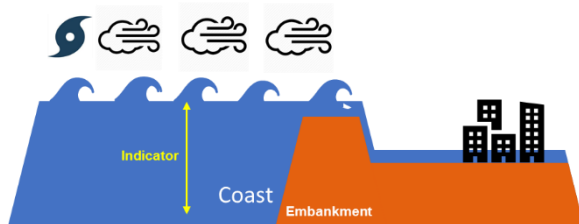
Pluvial or Rain induced flooding is the most common kind of flooding that occurs on a regular base in the project area. The drainage capacity of the different unit areas can be insufficient to drain the large amounts of precipitation during rainy season and medium to high discharges from upstream.

Drainage sluiceways must be closed when water levels in the river become too high. In combination with extreme precipitation, areas will then flood, until the drains and sluices can be opened again to let the water flow out under gravity.

The inundation depth is the indicator used here, which is simulated with the *overland flow model* (Appendix B) for different representative rainfall events with increasing return periods.

The threshold values for this indicator are set at 30 cm for urban areas and 60 cm in non-urban area units. This value was set based on workshop discussions. Included in the analysis is a threshold for the total percentage of the unit surface area (in %) where this critical inundation depth occurs at the peak of the rainfall event (as simulated with the model). A threshold value of 10% is assumed, and 5% and 20% are being used in the analysis to examine the sensitivity of this choice.

Storm Surge Flood Indicator



Coastal flooding such as during cyclones, can have a disastrous impact on the people who live and work in the Ayeyarwady Delta. The traumatic experience with Nargis in 2008 is forever engraved in the collective memory of the population.

The combination of a storm surge, high tide during spring tide and extreme rainfall, results in extreme

water levels in the downstream area of the delta and therefore the highest probability of a disaster in the southern part of the Yangon Region.

The indicator is the storm and tide induced water level on the coast, which can be compared with embankment heights to assess the risk of failure or overtopping. This can be simulated with the overland flow model (Appendix B). The model is run for different representative storm events with increasing return periods.

The threshold value for this indicator is the height of the levee at the weakest (i.e. lowest) point. This indicates when and where the embankment will overtop first. Breaching of dikes is not considered. The method to assess this point and the moment of first flooding is explained in Section 3.3.1. The spatial scale of the flooding, the resulting damage and the number of affected people are assessed as well.

Water Shortage / Salinization Indicator



At present, most water that is extracted from the various river branches is used for irrigation. In the future, however, the demand for freshwater will increase due to the expected expansion of irrigated areas (more food production) and more water needs for domestic and industrial purposes. The most severe “freshwater scarcity” situation occurs during extreme low river discharges from upstream in combination with spring tide. When this situation occurs, the least amount of freshwater is available from upstream, in combination with a relatively large degree of salinity intrusion into the delta, rendering

the water unusable for most purposes in many locations.

The applied indicator here, is the distance that the ocean's saline water ingresses in the branches of the delta rivers. The *salinity model* is run for different representative low flow events with increasing return periods as described in Appendix B.

The threshold value for this indicator is whether the salinity boundary, defined as a salinity level of 0.5 PSU (from YCDC, based on WHO standards) at 1 m depth below the water surface, has reached a certain intake location. The depth of 1 m below the water surface is chosen because most water extractions today take place from the surface.

Aspects Influencing the Environmental Indicator

Many potential measures in the water system have an impact on the environment surrounding it, either through the intended changes in hydrological or water quality status or through side-effects that may create less suitable situations for the natural environment. Loss of connectivity between channels and rivers, for example when a barrier is erected, will have an impact on fish migration (biotic impact) and on sedimentation patterns (abiotic impact). The diversity in possible impacts and the fact that some impacts may be positive to one species while negative to another, make it impossible to develop a specific quantitative indicator within the context of the present project. However, to include the environmental impacts in the evaluation of possible measures and projects, expert judgement will be made of the impacts based on all available data and generally available knowledge and experience from other projects.

During the workshops and focused group discussions, participants made important contributions on what needs to be considered as environmental impact (Appendix A):

- Biodiversity (flora and fauna): several species of fish (e.g. Seabass and Hilsa) migrate through the project region. Both have an environmental and economic value. The Hilsa goes to freshwater for spawning. The smaller fish are caught in the main river, while larger specimens are caught in the ocean.
- Mangroves are found on the south-western part of Unit Area 11 (near Pyapon River). These mangroves limit coastal erosion and have a high ecosystem value.
- Fresh/saltwater interface: the construction of sluices may change the upstream ecosystem. The brackish water zone could be replaced by a clear-defined fresh/saltwater interface, depending on such sluice's operating schedule.
- Sediment Regime change: the sediment regime alteration and changing water velocity resulting from a project can impact the environment.
- Base flow ('environmental flow') was mentioned as it encompasses ecosystem surfaces such as sustaining and limiting sediment changes. Some areas within the project area are inherently connected to flooding and local agriculture might be dependent on it.
- Erosion: both riverbank and coastal erosion are considered important for the ecosystem.
- Water Quality: Increases in pollution loads in waterways resulting from increased loads or reduced flushing, have a negative impact on the environment.
- Invasive species: some people consider fish farming more economically valuable than dry agriculture. Therefore, many farmers pump river water into their fishponds. This has introduced invasive species into the area, such as tilapia, due to their higher economic yield compared to other fish species.

Aspects Influencing the Socio-economic Indicator

Measures that aim to improve flood and freshwater security will likely also have socio-economic impacts. Here, the focus is on unwanted impacts. As with the environmental indicator, socio-economic impacts are very diverse and will affect different parts of communities differently. For example, measures that lead to an increase in property value may impact land-less users negatively because landowners may change the land use to one that is not compatible with the (unofficial) present use. Also changes in salinity distribution may be acceptable to households connected to piped water supply but may be less acceptable to households depending on nearby water sources (surface or groundwater). The diversity in possible impacts and the fact that some impacts may be positive to some while negative to others, make it impossible to develop a specific quantitative indicator within the context of the present project. However, to include the socio-economic impacts in the evaluation of possible measures, expert judgement will be made of the impacts based on all available data and generally available knowledge and experience from other projects.

During the workshops and focused group discussions, the participants made important contributions regarding the aspects influencing the socio-economic indicator for the consideration in the expert's judgement:

- Health and sanitation: When there is a flood or a drought, health and sanitation will be significantly impacted due to water quality issues.
- Water Quality: Pesticides, fertilizers, and pollutants of industrial origin impact use of the water. An intervention could imply that water becomes stagnant (e.g. behind a sluice or dam) and that consequently less water becomes available for domestic use.
- Affordability: A pumping station and a retention pond could help increasing water quality and water availability, but this requires capital investments. Cost-recovery of the measures is therefore important.
- Navigation: Changes in the river system may occur due to construction of sluices or other measures that may alter hydraulic and morphological patterns in the river system, hence affecting navigability through changes in connectivity and water depth. Increased sedimentation may lead to increased downtime and cause restrictions in the access to docking areas.
- Economic benefits of floods: it is mentioned by stakeholder and supported from literature that floods have a beneficial impact on fisheries species migration and habitat, amongst others for spawning. Changes in the flood frequencies may negatively affect these benefits.
- Employment: system measures will change the economic environment causing certain sectors to benefit and others to suffer. A bridge may increase access to education and health facility, but also may have a negative impact on those working in shipping, for example.
- Social inclusion: Measures are often aimed at providing services to certain target groups, for example piped drinking water to urban dwellers. These measures should not reduce the access to drinking water by other groups. Measures that provides equity by also providing improved approaches for rural dwellers are therefore preferred.

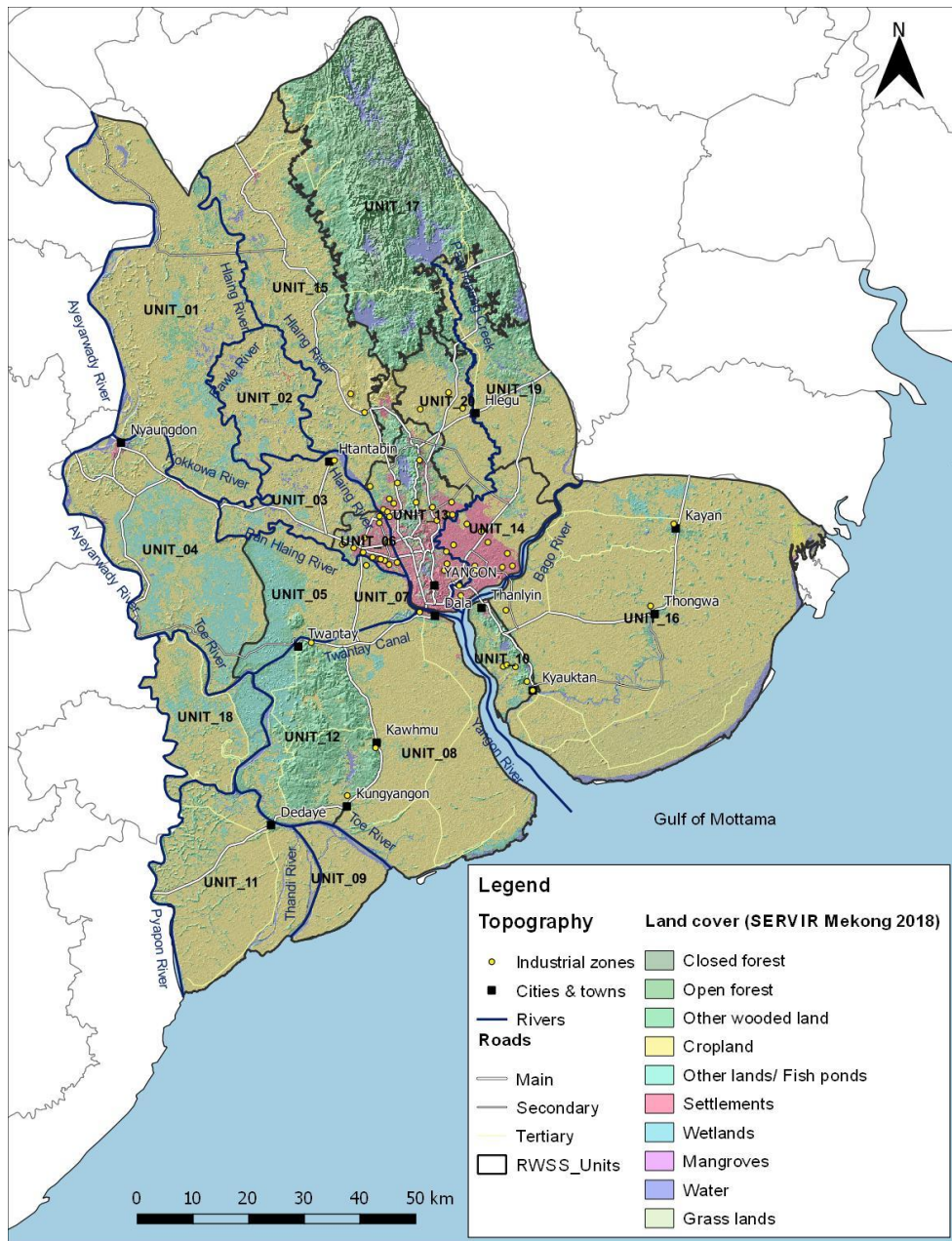


Figure 5: Twenty unit areas within the RWSS project area

2.2.2 Project unit areas, sub-areas and characteristics

Selection of unit area boundaries

Criteria for the selection of the boundaries of the unit areas are:

- Together they must cover the whole project area,
- Each has a specific land use (preferably mono-sectoral),
- Presence of natural boundaries by river branches, embankments, or natural higher land, and
- Planned measures that may change the characteristics, e.g. New Yangon City Development.

The result is a selection of 20 unit areas with unique characteristics in land use, population density and occupation (Figure 5). Some unit areas are dominated by agriculture areas, whilst other areas are urbanized with a dense population and the appearance of industrial zones.

Socio-economic information per unit area

For all unit areas, information about population and land use types is given in *Table 1*. The population values are determined from the Myanmar Census 2014 (Department of Population, 2014) and the population distribution from Worldpop (Worldpop, 2018). The rain-fed and irrigated land cover classification map (IWMI, 2014) is used to give an estimate of the division of land use types within the unit areas. In the northern unit areas, relatively large areas with irrigated agriculture prevail, probably because of the availability of freshwater (two crops possible per year). The southern unit areas generally rely on local rainfall as the main source of freshwater (rain-fed agriculture; one season crop per year only). More details on agriculture demands are provided in Section 4.6.2 and Appendix E.

Table 1: population and land use of the RWSS unit areas

Unit	Population [x 1000]	Population density [no./km ²]	Irrigated paddy	Rainfed paddy	Wetland and fishponds	Forest	Urban	Flood Plain	Waterbody
1	229	180	42%	41%	1%	8%	0%	1%	8%
2	70	204	35%	46%	1%	6%	1%	3%	7%
3	87	299	53%	30%	4%	3%	1%	0%	9%
4	196	221	38%	13%	26%	8%	0%	1%	14%
5	87	236	40%	28%	18%	3%	0%	0%	10%
6	767	8518	21%	25%	0%	33%	17%	0%	5%
7	142	1468	21%	70%	0%	1%	3%	0%	4%
8	388	361	12%	83%	2%	0%	1%	0%	1%
9	38	189	35%	57%	0%	0%	0%	0%	8%
10	213	1612	41%	31%	0%	9%	12%	0%	7%
11	151	198	66%	21%	1%	5%	0%	1%	6%
12	144	231	26%	12%	5%	50%	1%	0%	5%
13	3381	9365	14%	3%	0%	35%	41%	0%	7%
14	1324	458	55%	10%	0%	13%	19%	0%	2%
15	376	394	50%	32%	0%	15%	1%	0%	2%
16	621	260	80%	15%	1%	0%	1%	0%	2%
17	133	89	4%	4%	0%	81%	1%	0%	10%
18	78	197	74%	4%	6%	3%	1%	1%	11%
19	160	332	57%	13%	0%	25%	3%	0%	2%
20	13	39	71%	8%	1%	16%	3%	0%	1%

RWSS sub-areas (focus areas)

As requested in the terms of reference of the project, and confirmed through stakeholder consultation sessions, development, selection, and prioritization of measures has been done for three sub-areas namely Nyaungdon Island, Pan Hlaing Island and Yangon South (see *Figure 6*). The choice for these three focus areas is supported by the results from the analysis for the whole project area which showed that the water security challenges are most urgent and demanding here.

Nyaungdon Island is located south of the Kokkowa and Pan Hlaing River and north of the Twante Canal. The western boundary is the Ayeyarwady River. The occupation of the area is dominated by agriculture (paddy cropping) and fisheries (aquaculture). This area is divided into three unit areas, all currently with a dominant agricultural function (4, 5 and 7). Between unit areas 4 and 5, a natural boundary (height)

is present that originates from former river branch deposits. Unit 7 covers the area currently under planned development by the New Yangon Development Company (NYDC).

Pan Hlaing Island is located north-east from Nyaungdon Island, with the Kokkwa River as a boundary in the north, the Hlaing River in the east and the Pan Hlaing River in the south. This area is divided into two areas: unit area 3 and unit area 6. The land use of unit area 3 is dominated by agriculture and fisheries which might change due to future expansion of Yangon City. Unit area 6 represents large industrial zones such as Hlaing Thar Yar and residential areas which are under the administration of Yangon City. The industrial zones are located directly at the Pan Hlaing River in the southern part of the unit area.

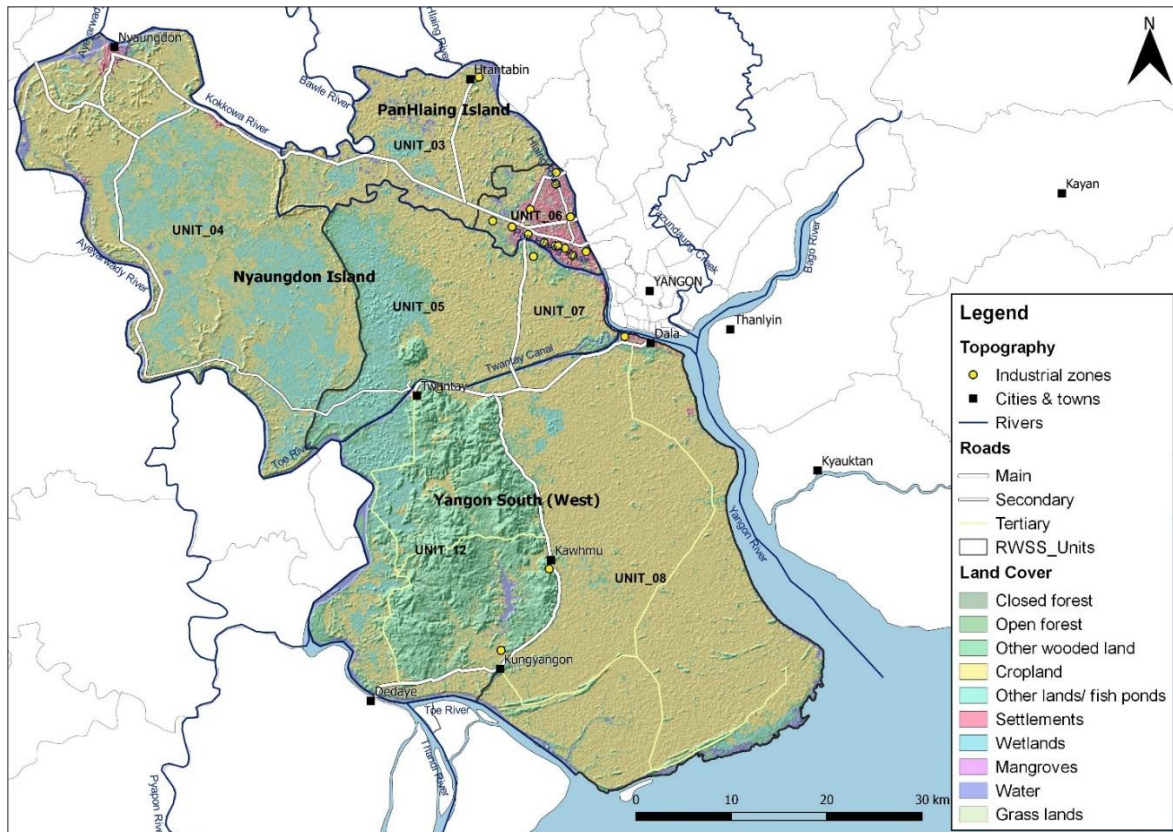


Figure 6: Map indicating two sub-areas RWSS

South Yangon (West) is the area located south of Twante Canal with the Toe River as natural boundary to the west and the Yangon River to the east. It comprises two unit areas: 8 and 12. Unit area 8 is part of the second phase of the New Yangon City development identified by the New Yangon Development Company. Currently the sub area is dominated by rainfed paddy cultivation and small rural towns and villages. Dala is the largest town in this area, close to Yangon, which is expected to expand rapidly after the construction of a bridge connecting Dala with Yangon (construction has started).

As unit 8 is relatively large it is not likely that the complete area will be urbanized in 2040, which is the time horizon for the water security vision and strategy (Chapter 5). For unit area 12, hardly any new urbanization is expected until 2040. This unit area is partly a hilly landscape with some small-scale reservoirs. The largest town is Twante which is located on the edge of the higher grounds.

Consultation with stakeholders confirmed the need to focus on these sub-areas for enhanced water security. The baseline description of these areas, its characteristics, socioeconomics, and future developments are given in Chapters 3.4 and 4.2.1.

2.2.3 Model application

In the RWSS (IADS-B) project, the methodology and supporting tools were developed (Arcadis, 2019). A combination of three numerical hydrodynamic models was developed that covers respectively the tidal system (hydraulics), the intrusion of saltwater at high tide, and the flooding mechanisms of the project area.

- The *channel flow model* is setup specifically to accurately simulate the water level and discharge (distribution) in the Great Yangon Region for situations where inundation is not occurring (or not the focus).
- The *overland flow model* allows for the simulation of inundation in the complete Greater Yangon Region. The applicability is therefore flooding focused (i.e. pluvial, fluvial, coastal flooding).
- The *salinity model* is at present only applicable for the simulation of salinity intrusion. This model is only calibrated for low river discharge situations because such conditions are expected to be governing for scenarios concerning salt intrusion.
- In addition to the models developed under IADS-B, A *drainage network model* has been developed under the project to simulate the flow of water through the detailed network of irrigation and drainage canals, including the many hydraulic structures, in unit area 8 (Yangon South).

In the RWSS (IADS-B) final report it is shown that the model(s) simulate the physics and the general hydrodynamic behavior in the Greater Yangon Region reasonably accurate. Yet, a model on this scale and for such complicated physical system is never final and requires constant calibration and improvement. For RWSS, the following adjustments to the model and/or post-processing are made.

Riverine (fluvial) flooding

The accuracy of the flooding model is very sensitive to the schematization of the (height of the) embankments. For a large part of the Greater Yangon Region Lidar data are available to accurately determine not only the location of the embankments, but also their elevation. For the Toe River, no Lidar data are available and SRTM data is used instead (SRTM, 2020). The lack of detail in both horizontal and vertical direction of this dataset gave inaccurate results for the fluvial flooding events in this area. One of the consortium members (TBS) mapped the dike sections along the Toe River, from Nyaungdon to 21 Mile (the connection point to Twante Canal). Using a combination of local reference points on the ground and spatial drone measurements, the topography along the embankment sections was mapped in high detail (Appendix B). The field data collected in this way was used to improve the heights in the 2-dimensional overland flow model. This overland flow model is applied for flood simulations in which overtopping of embankments occur. In this way inundation patterns are simulated as well as the impact that inundation of the hinterland has on the river flows (effect of local water storage).

A similar lack of detailed topographic data was observed for the embankments along the Ayeyarwady River to the north of Nyaungdon (including the natural flow diversion zone from Ayeyarwady River into Upper Hlaing River). In addition, the bathymetric river data here is limited to a few cross-sections only. Both data limitations have impact on the (simulated) overflow along this river section at high river stages. Based on previous model results (RWSS IADS-B), it is estimated that the overland flow model underestimates the overflow for the “lower-high” river discharges, most noticeable for river discharges up to a return period of 5 years. Especially the substantial overflows towards Patheingyi River to the west and Upper Hlaing to the east, requires attention when further developing the models in the future. The underestimation is mitigated in the model by manually forcing these specific overflow discharges scaled to the discharge at Pyaw. This was based on available data from DMH, the so-called Q-Q relations (DMH, 2019).

For the more extreme high river discharges (Return Period 5 years and more extreme) the overflow discharges (into Patheingyi and Upper Hlaing rivers) do occur automatically to some extent in the model via overbank flow. Combined with the above ‘forced additional discharges’ in the model, this probably

leads to an overestimation of the overflow discharges and thus underestimation of the flood discharges in Ayeyarwady River downstream of these overflow locations. As this only happens during these more extreme flood discharges, further model improvement is currently not possible due to lack of relevant measurements. For more moderate floods, no proof of such underestimation of flood discharges and flood water levels in Ayeyarwady River was found.

Pluvial flooding

For the pluvial simulations some (schematized) processes were added through post-processing:

- The mesh size covering the overland areas within the overland flow model is relatively coarse (900x900 m). Therefore, it only includes the large scale (>1km) topographical rainfall run-off. Anything with a smaller physical scale is not included. This means that small (connecting) waterways, streams, creeks and ditches, that would realistically impact the distribution of water within the unit area, are not modelled. Similarly, linear elements such as small levees, dikes and road embankments, that would impact the distribution of water on a local scale, are also not modelled.
- Drainage locations that are still significant on the modelling scale, but physically not included, were assessed using a memo on flood tables for Yangon City (RHDHV, 2019b). Of the 82 known drainage locations, 77 are allocated to a RWSS unit. The tide-averaged drainage capacity for different Return Periods is accounted for by subtracting the drained (precipitation) volume from the computed inundation per unit area. This capacity depends on the (average) hydraulic head, which would be an overestimation in case of storm set-up. This is not accounted for in this analysis.
- Dike sections or creek mouth closures that aim to keep the high water out of a certain area limit the natural drainage of local rainfall. An important assumption in this respect is, that dike heights and embankments along creeks inland are equal to the height of the main dike ring near the mouth of the creek. As this may not be the case in all circumstances, natural drainage via creeks and small waterways is underestimated. As a result, pluvial inundation is overestimated in areas, where this drainage was not included in the list of known drainage locations.
- The simulated inundation maps were evaluated manually using satellite imagery, to determine if any of the above shortcomings needed to be compensated for.

Consequently, the simulated pluvial inundation only provides reliable outcomes when considered on a large (regional) scale. For a more detailed pluvial flooding analysis, a separate more detailed model was set-up for unit area 8, using the RWSS model data for its boundary conditions. This *detailed drainage model* has been developed with SOBEK2 software including all water channels within the unit area (Appendix B). This model includes the land elevation and simulates the water flow through the channels. This provides the water levels and discharges in the channels over time, with the possibility to derive the inundation depth on the land during and after a rainfall event. The model therefore supports identification of pluvial flood prone areas and locations where mitigating measures could be developed.

Water scarcity / salt intrusion

A combination of the *channel flow model* and the *3D salinity model* is used to simulate salt intrusion. The channel flow model is used to simulate the discharge distribution through the delta for the full range of low discharge events with different return periods, including peak freshwater extraction.

The 3D salinity model is used to simulate the salt intrusion over time for a selected number of low river discharges, to limit the use of this computationally heavy and very complex model. Salt intrusion for each return period is then computed using interpolation along extreme value distribution fits per river section, which makes the process not only computationally demanding, but also not applicable for basic or intermediate-level modelers.

2.2.4 Return periods

In general, flooding occurs only under extreme conditions, when river discharges are high (fluvial flooding), rainfall is intense (pluvial flooding), or during storm surges and/or spring tide (coastal flooding). The seasons for high river discharges and coastal storms are different, so events do not

coincide. Intense rainfall can occur in combination with both. Salinity intrusion moves further inland in situations with the lowest river discharges and highest tide.

As natural conditions are variable, flood hazards are expressed in terms of their probability or frequency of occurrence. Model output (e.g. water levels, inundated land areas and river discharges) is generated for a range of return periods to assess the four water security issues considered (fluvial, pluvial and coastal flooding and water scarcity). These return periods are determined using the most comprehensive, detailed historical data records available and appropriate methodology following expert judgment. Detailed statistical analyses on the available data sets are presented in Appendix B. Here the main results are summarized.

For both the fluvial and water scarcity models, the available data used for determining the governing hydrodynamic river boundary conditions are based on time series covering the period 1966-2015 (DMH, 2017). These time series are analyzed statistically for both the high river discharges (high discharge as function of return period and discharge wave shape) and low river discharges (low discharge in combination with persistency as a function of return period). For the rainfall assessment, the ERA5 dataset is used (Copernicus Climate Change Service, 2017). The cyclone return period is derived from a scaled 2008 Nargis cyclone event, using information on wind velocity and air pressure, based on the Holland model (Holland et al., 2010).

Fluvial flooding boundary conditions

Representative high river discharges for different return periods are determined based on 50 years of available daily discharge time series data for the various boundary inflow regions (Pyay, Bago, Pazundaung Creek and Hlaing). The following return periods are determined: 1:1 (meaning one time per year); 1:2 (meaning 1 time per two years and so on); 1:5; 1:10; 1:15; 1:20; 1:50; 1:75; 1:100; and 1:200. To obtain the discharges related to each return period, an extreme value analysis (annual maxima) is applied, using a Gringorton plotting position and applying a Gumbel fit. The resulting peak discharges for given return periods (*Table 2* for Pyay) are then used to construct high river discharges representative for the various river inflow regions and accounting for a typical river discharge distribution over time, referred to as the “shape of the river flood wave”.

Analysis of the data showed that there is a certain degree of correlation between a high discharge at Pyay and a high discharge at Bago. For the simulation, therefore, at both river boundaries, discharges having the same return period are used. As the discharge at Bago is small compared to the discharge at Pyay, its impact is limited. For conservative purposes, a “timing” of the flood waves is applied with the peaks of the flood waves from both rivers coincide near Yangon City.

The average shape of the river flood wave is determined by using the shape of various discharge waves from the available historical timeseries dataset. From this, for each return period, a unique flood wave peaking at the determined return discharge is constructed and used as the inflow boundary condition. The flood waves arriving at the different boundary inflow locations accounted for a representative, yet conservative, lag derived from examining the lag during the ten highest discharge years at Pyay.

Table 2: Obtained discharges for given return periods at Pyay according to the Gumbel distribution.

Return period [years]	1	2	5	10	15	20	50	75	100	200
Discharge [m ³ /s]	31,166	39,481	44,522	47,860	49,743	52,077	55,206	57,024	58,311	61,405

Coastal flooding boundary conditions

The coastal flooding event, while occurring less frequently than an isolated extreme rainfall event, represents extreme flooding and therefore a high probability of a disaster in the southern part of the Yangon Region. It is quite ambiguous to statistically analyze the severity of cyclones, relative to their

return period, as many variables such as the cyclone track, landfall location, time of landfall, peak pressure drop and peak gust wind speeds, determine the experienced severity and its consequences. In this project therefore a real-life cyclone event is adopted: the Nargis cyclone of 2008.

The return interval for the coastal flooding model is based on 13 years of observation at Elephant Point covering 32 coastal surge events. On this data, a statistical analysis showed that Nargis can be considered a one in hundred years coastal surge event (RHDHV, 2019). From this, a study-specific method to generate a range of cyclone events with different return periods is adopted. By means of scaling the (peak) wind velocity and pressure drop within the eye of the cyclone, synthetic cyclone events are generated, while using the tidal phasing of the Nargis event.

To scale the wind and pressure, a statistical analysis is performed using the cyclone characteristics of the Indian Ocean from 1842 to 2019 (NOAA, 2019). Using a Peak Over Threshold and Weibull-based Extreme Value Distribution, the cyclone characteristics are then analyzed. *Table 3* includes the peak wind velocity and peak pressure drop per considered return period. The cyclone track, spatial extent, relative build-up, and relative decay have been kept identical to the associated characteristics of Nargis, 2008.

Table 3: Synthetic cyclone events with different return periods

Return Period [1 in X years]	Wind velocity [km/h]	Pressure [mBar]
RP 25	102	995
RP 50	121	987
RP 100 (Nargis, 2008)	167	962
RP 200	195	940
RP 500	222	924
RP 1000	235	914

The synthetic cyclones with the properties as presented above are fully recreated in the model, using a spider-web forcing with spatially and temporally varying wind velocity and air pressure, based on the Holland model (Holland et al., 2010).

The method of adopting the Nargis cyclone track and scaling with statistics on wind and air pressure is a simplification. It gives a good first order, conservative estimate for the impact on the water levels within the southern Yangon Delta, especially when taking the complexity of the interaction with land features / geometry into account. The local cyclones show a counterclockwise orientation. With the Nargis track moving from west to east, roughly following the coastline, the wind forcing results in the most conservative setup along the coast and finally within the Yangon Estuary. Due to the funneling of all water fluctuations in the Yangon River, the mouth of the Hlaing River is most sensitive for extreme coastal water level set-up.

Coastal and Fluvial flooding frequency

The frequency of high-water levels due to high river discharges or coastal storms is not equal to the flooding frequency in the different unit areas. Each unit area is protected by natural levees and artificial embankments (such as dikes). The location where the outside (river) water level exceeds the local height of the levee “first”, is the weakest point in the levee of the unit. This is not necessarily the lowest dike section, because the water levels around the unit areas are not level. The weakest location is the location where the water starts to inundate the unit area first.

The frequency of flooding is determined by plotting the water levels in the river for the different high-water frequencies as assessed at the model boundaries. The frequency at which the water level in the river exceeds the threshold level is the flooding frequency of the unit area. Often, this needs interpolation, because the models are run for a limited set of boundary conditions, each representing a specific frequency of occurrence. Figure 7 presents an example for unit area 15 (north of Htantabin Town). It shows the calculated and predicted water levels in the river near the weakest dike location for different return periods (blue line), compared with the dike height at the weakest point (horizontal orange

line). It is observed that both the lines cross at an event corresponding to 1 in 140 years return period. The red dotted line in the figure represents an altered situation, for example when an intervention is implemented somewhere in the delta system. In the example given, this intervention leads to a higher flood frequency (return period now becomes 85 years). High water level due to coastal storms or river discharge have different frequencies, so the analysis is done separately for coastal and river floods using the same approach.

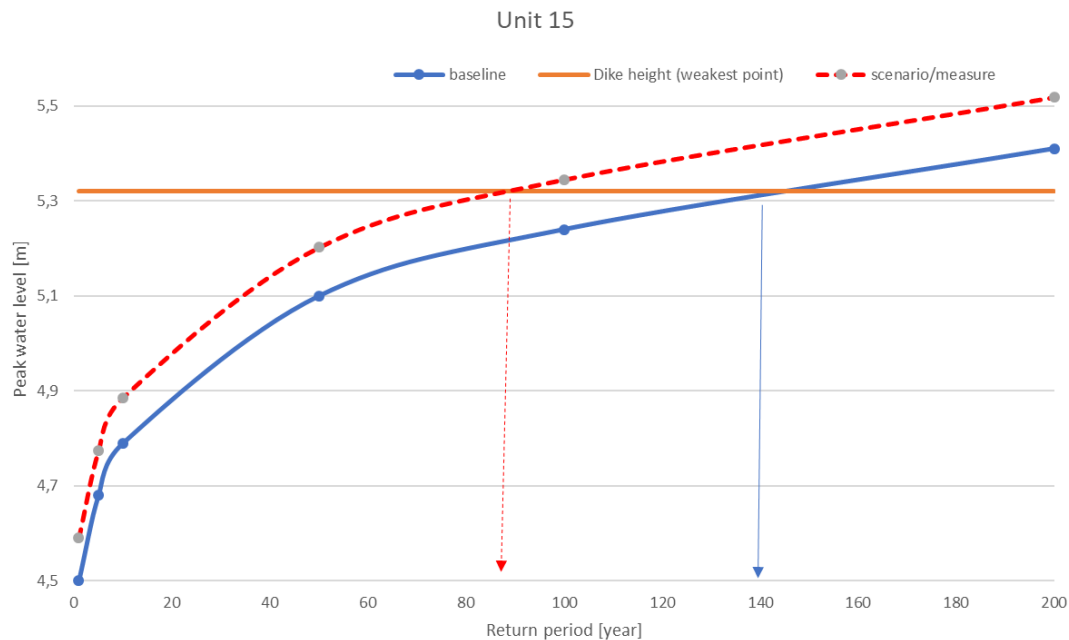


Figure 7: Flooding frequency example for unit 15

Pluvial flooding

For the extreme rainfall model, the choice was made to use the ERA5 dataset owing to its high temporal resolution. The temporal resolution of the ERA5 rainfall data is 3 hourly. The first step in the rainfall analysis was to aggregate the time series to larger time steps to derive rainfall extremes for different durations (i.e. 3, 6, 12, 24, 48 and 72 hours).

Subsequently, an extreme value analysis was applied for each duration: the Peak over Threshold (PoT) values were used to derive return values for return periods of 0.2 years (i.e. a frequency of 5 times per year) and 1 year, whereas the annual maxima were used to derive return values for return periods of 2, 5, 10, 25, 50, 100, 250, 500 and 1,000 years. The Generalized Extreme Value distribution function (GEV), which describes the relation between return period and associated rainfall depth, was used to fit the data. Table 4 shows derived empirical return values for the whole project area.

Table 4: Derived return values of rainfall (mm) for the whole area

Return period (years)	duration					
	3 hrs	6 hrs	12 hrs	1 day	2 days	3 days
0.2	14.6	26.0	37.1	60.8	105.9	147.7
1	30.8	54.8	79.7	124.9	185.7	233.3
2	39.7	70.0	103.4	162.0	230.6	283.8
5	53.0	94.2	136.8	208.1	284.2	335.4
10	62.2	110.8	158.9	237.0	320.0	369.5
25	75.2	134.3	189.3	275.8	370.4	417.9

Return period (years)	duration					
	3 hrs	6 hrs	12 hrs	1 day	2 days	3 days
50	84.9	152.1	211.3	302.6	406.5	451.7
100	94.6	169.8	232.6	327.7	441.2	483.5
250	107.5	193.5	260.1	358.5	485.4	523.0
500	117.3	211.5	280.3	380.2	517.6	551.1
1000	127.2	229.7	300.1	400.7	548.9	577.7

For the pluvial flood calculations, these return period values are then used to derive design *hyetographs* as boundary conditions for the pluvial flooding analysis. An illustration of how this is done is presented in Appendix B.

Water scarcity

For the water scarcity model, a stationary inflow boundary condition is forced at each of the four inflow locations of the model, with a representative spring tide at the coastal boundaries.

To establish the relation between low discharge events and their return period, a Weibull function is fitted to discharge events below a once per year discharge minimum at Pyay. In addition, the return period also includes the length of the low discharge event, as longer low discharge events result in progressively more salt intrusion. The length of a low discharge event is characterized as the period from the first moment the discharge drops below the yearly minimum, until the yearly minimum multiplied by 1.4 is exceeded again (i.e. a discharge 40% above the considered yearly minimum). In this way, low discharge events, where the system is not able to recover fully, are considered a single (adjoined) event.

A low discharge event is thus described as a certain low discharge (m^3/s) in combination with a duration or persistency (days). The resulting return period for a range of low discharge events, defined by a discharge and a duration, is shown in *Table 5* for Pyay. As the boundary during the water scarcity model is stationary, no wave shape nor lag is used. When multiple combinations of discharge and duration have a similar return period, the event with the longer duration is used. Because the incremental reduction in considered river discharge per event is relatively small, a longer duration of the event is generally governing when looking at the degree of salt intrusion.

Table 5: Return period (1 in X year) for a range of low discharge events

River discharge Pyay	≥ 15 days	≥ 25 days	≥ 35 days
< 2250 m^3/s	1	1	1
< 2000 m^3/s	2	2	2
< 1750 m^3/s	2	3	4
< 1500 m^3/s	4	5	7
< 1250 m^3/s	7	12	24
< 1000 m^3/s	13	37	150

From the table it follows, for example, that an extreme low river discharge at Pyay of 1500 m^3/s which lasts for more than 25 days, has an estimated return period of 1 in 5 years. Appendix B presents a detailed review of the applied model boundary conditions including detailed information on how the return period and boundary conditions for each indicator is established. For each return period the salinity boundary is plotted on a map that can be used to assess how frequent the saltwater will ingress past any location in the study area.

2.3 Selection and Prioritization of Measures

The assessment framework allows for the quantification of the present or future flood security or saline intrusion levels. However, the framework does not directly identify measures.

Based on the Baseline assessment and the assessment of the situation in 2040, a good insight is available in the prevalent conditions that can be expected related to floods and salinity intrusion. A Vision for the region and its flood and freshwater security objectives, described in Chapter 5, identifies the targets to be achieved. Programs of measures, or strategies, are explored and collected, resulting in a long list of possible measures. However, not all possible measures make sense. This Section describes the method to select a list of measures that makes sense (the “shortlist”), described in Chapter 6. Then, because the shortlist of selected sensible measures is still too long to implement at the short term (i.e. years), a prioritization methodology is described that is applied to reach a list of no-regret measures. Chapter 7 describes the shortlisted measures and prioritization of the measures.

2.3.1 From Longlist to Shortlist

Considerations to select the most appropriate measures from the long list include benefit-cost ratio, possible overlap with other investment programs, and implementability.

To evaluate whether the costs and efforts related to flood control measures are worthwhile, a flood risk assessment is done. It combines the frequency of floods with the impact floods have in terms of damages to determine a theoretical yearly average risk. Note that this is a theoretical average used for analysis purposes only. It can be expected that years with and without damages will alternate with the more extreme events happening less often. This approach is described in more detail in section 4.5.

The benefits of flood protection measures are then expressed as a reduction of the yearly theoretical flood damages because of the implementation of the measures. The costs of the measures can also be expressed as a yearly cost and then compared with the benefits. Although in theory every unit area could be protected with extreme flood protection measures, higher dikes will not be cost efficient after a certain protection level is reached, because the costs for the additional protection will not be balanced by increased reduction in potential damages. The assessment will thus also indicate which flood protection level is recommended, giving the best benefit/cost ratio.

For those unit areas where a dike improvement is not cost effective, but where floods happen more frequently than societally desired, alternative solutions may be sought that will bring relief to those people affected most by floods. This will require more local solutions than can be derived in this regional study. As such it is recommended to analyze the not shortlisted units in a follow-up project.

The regions that are mentioned in existing urban masterplans, or where private sector is expected to make investments (New Yangon City for example), are excluded from the list, as it can be expected that these investments will already be taken care of. Also, regions that are surrounded by year-around fresh rivers, and that can be expected to have easy access to freshwater, are excluded if it comes to measures to improve the freshwater availability.

The regional character of the project does not provide the detailed information required to develop detailed plans to improve the water availability challenges for individual towns or villages. In such cases, practical generic solutions are proposed based on what information is available. This will allow concrete measures to be proposed and interrelations with the drainage and flood protection programs explored.

The generic measures aimed to improve the water availability, are selected using a logical selection matrix. This approach is illustrated in Figure 8 that starts with the identification of the communities where the water demands are not met. Subsequently different solutions are proposed depending on the size of the community. This ensures that proposed measures are fit for purpose and implementable.

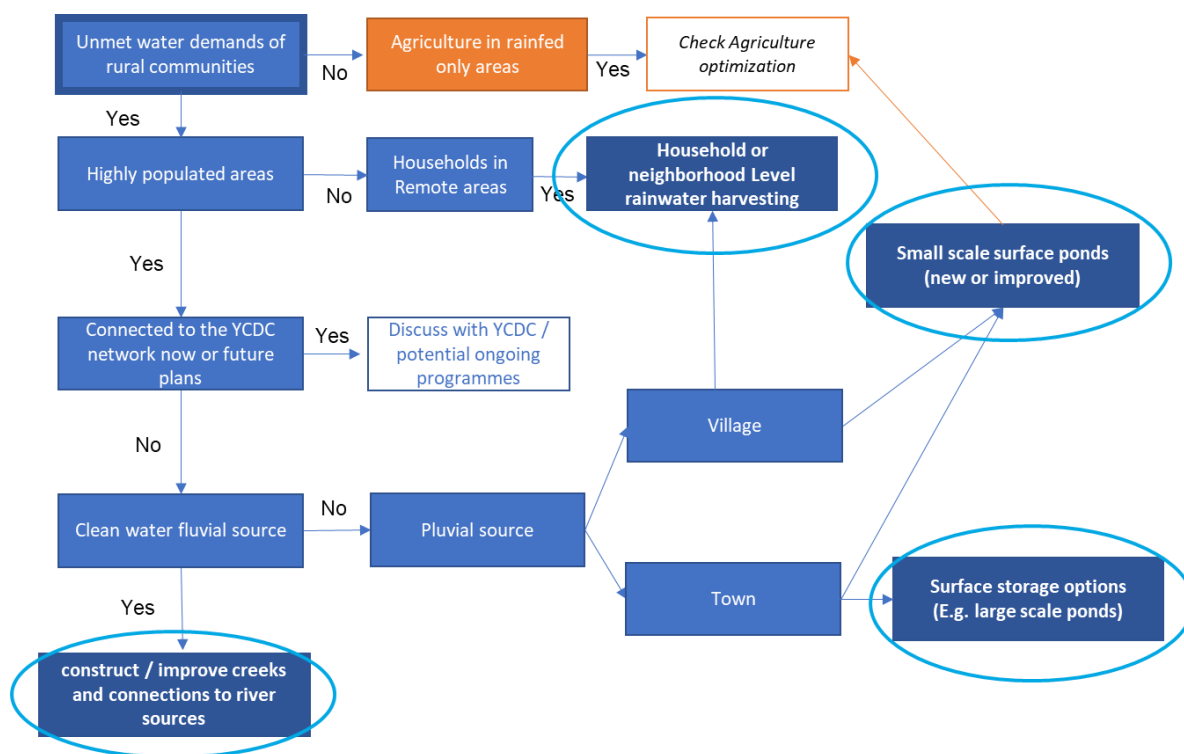


Figure 8: Selection framework to achieve water storage solutions

2.3.2 From shortlist to no-regret measures

From improving the water security situation perspective, all measures on the shortlist make sense. However, to be able to decide which measures can be given priority, the measures are ranked on several criteria:

- Synergy with other measures or programs, reducing the efforts required to get the project started, and possibly achieving extra benefits. Measures that in combination with other measures provide additional benefits will be prioritized.
- The relative contribution of the measure towards the objective as stated in the Vision and (if possible) quantified by the indicators, and the benefit-cost ratio. Those measures with the highest benefit-cost ratio will be prioritized.
- The (pre) feasibility to be implemented on the short term. As the objective is to identify no-regret measures, those measures that require further detailed assessment will not be prioritized. However, the detailed assessment is recommended to be executed in parallel with the implementation of the no-regret measures.
- The number and severity of safeguard issues related to the measure. Measures that need extensive assessment and resolution of issues are not prioritized, but it is recommended that this assessment is continued in parallel with the implementation of no-regret measures.
- Cost recovery options. Measures with attractive cost recovery possibility for investors will be prioritized.

The top ranked measures are proposed as no-regret measures.

The selected no-regret measures are then evaluated using the assessment framework described earlier to provide confirmation of their contribution to the Vision's targets for improved flood security and freshwater security. The evaluation is also intended to confirm that the combined effect of the proposed measures will not have any unforeseen negative (cumulative) impacts in other parts of the delta system.

3 BASELINE SITUATION

3.1 Introduction

To plan measures, it is important to be clear about the current system, how it is functioning and where problems and opportunities exist. Such a baseline description provides guidance to where measures could be considered and what the impact of these measures could be both locally and in other parts of the delta.

In Section 3.2 the physical abiotic system of the project area is described in terms of physical elements (e.g. river reaches, structures, defense works, water use), discharges, water levels, flow directions, salinity, groundwater, precipitation, and storms.

In Section 3.3 the possible threats are analyzed, when possible based on modelling results. These threats are related to flooding events, water scarcity and salt intrusion and groundwater quality and availability. This section provides the baseline assessment.

The characteristics of the focus areas (Pan Hlaing Island/Nyaungdon Island and Yangon South) are described in Section 3.4. This provides information on the land use, infrastructure, threats, and economic development.

A summary of the main findings is provided in the Summary of the baseline situation (Section 3.5).

3.2 Description of the abiotic delta system

3.2.1 Introduction

In this section the functioning of the delta system under different hydraulic circumstances is described, by evaluating the hydrodynamic conditions during typical dry and wet season conditions. High and low river discharges from upstream, tidal fluctuations at the coastal boundary and the movement of the saline water into the delta are explained.

After the description of the functioning under yearly representative conditions, the system behavior under extreme floods is explained. These extremes include floods (fluvial, coastal and/or pluvial) and droughts (water scarcity and salt intrusion).

In Figure 9 an overview of the different components of the delta system is shown. When looking at typical hydrodynamic behavior within the system, the area can be divided into three area types:

- The river dominated upstream area, roughly upstream from Nyaungdon. Water levels and discharges are predominantly determined by the upstream river discharge conditions (Pyay).
- A transition area in the mid-section of the delta, roughly from Nyaungdon to the Hlaing River in the east and from Nyaungdon to 21 Mile in the west. Water levels and channel discharges are still largely dependent on the upstream river discharges, but the tide is noticeable in flow velocities and water level fluctuations. Also, the seasonality of the river discharge plays a role here. In the wet season, this transition area shows more similarity to the river dominated region (see Section 3.2.7), whereas in the dry season this area is more comparable to the tide dominated region downstream. During wet season this mid-section is entirely freshwater, but during dry season part of the salt wedge enters this transition area.
- The region south of the transition area is tide dominated. While the tide averaged water level and tide averaged discharge are still largely dependent on the upstream discharge, the instantaneous water level and discharge are determined by the tide entering the delta from the south. During the wet season, the salt wedge (including the salt front) remains within this downstream area. During the dry season, this area is entirely saline.

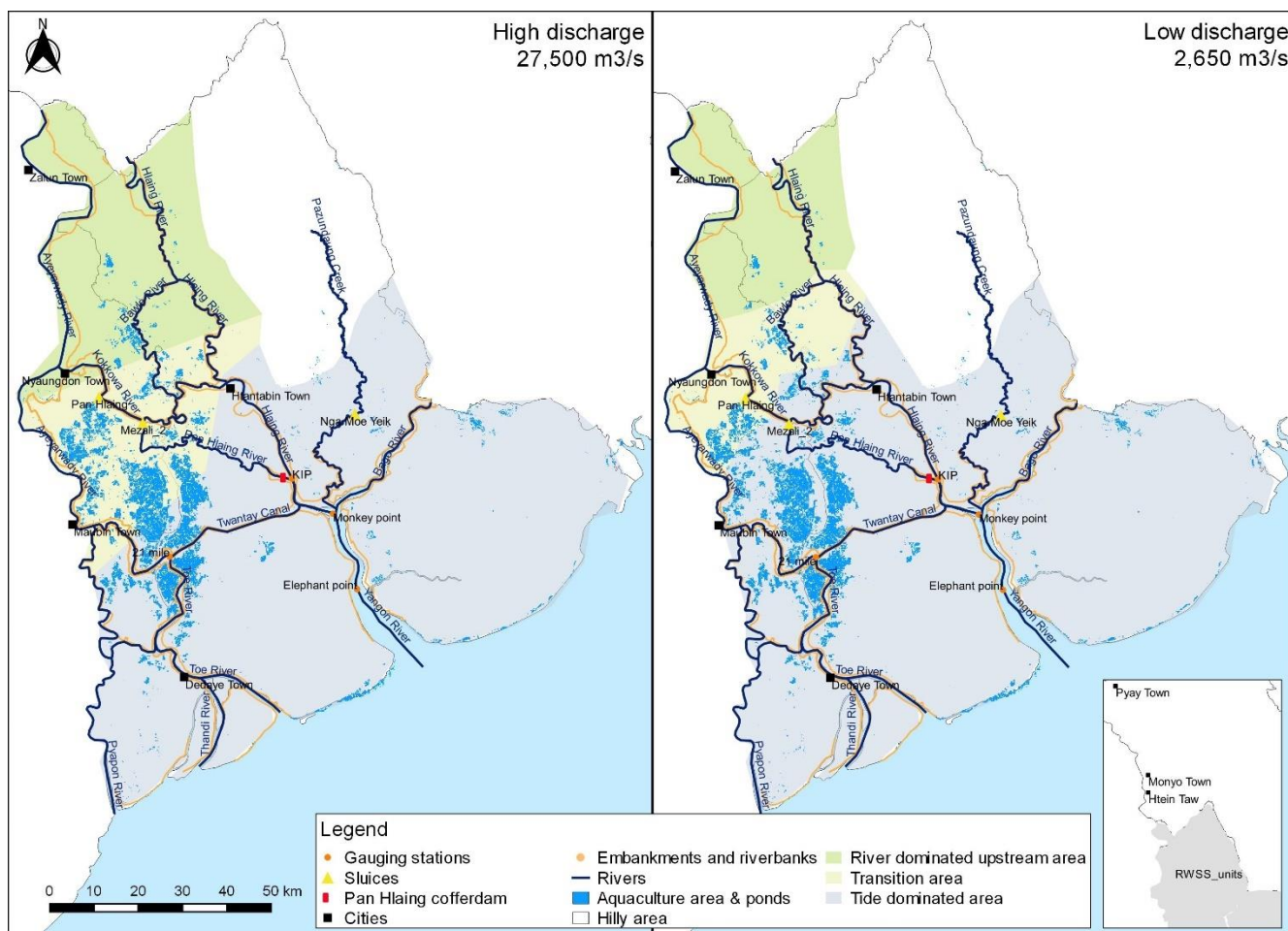


Figure 9: System overview

3.2.2 System elements

Rivers

The Ayeyarwady River is Myanmar's largest river, running from north to south. The section from Pyay to the river mouth is included in the study area. Between Monyo and Htein Taw a bifurcation towards the southeast and into Patheingyi River (to the southwest) exists, as well as a river stretch where bank overflow occurs over the eastern bank (refer to inset in Figure 9). The overflow only occurs when the water levels in the Ayeyarwady River reaches a sufficiently high level.

Following the Ayeyarwady, the next significant bifurcation is found at Nyaungdon. Here part of the river discharge flows east towards Kokkwa River, eventually flowing into the Hlaing River along with the Upper Hlaing River. The hydrodynamic behavior at this bifurcation is crucial as it largely determines the amount of freshwater available to the Greater Yangon Region. Downstream of Nyaungdon, the Ayeyarwady further bifurcates into the Toe River, which heads in southeast direction towards the coast at Dedaye.

Near Yangon, the Hlaing River flows directly to the west of Yangon City into the Yangon River which runs from the southern tip of Yangon City towards the sea, a length of just over 40 km. Finally, the Bago River flows into the Yangon River from the Bago-Sittaung river basin in the east. It must be noted that typical discharges in the Bago River are very limited compared to the typical discharges within the Ayeyarwady delta.

Two waterways are discussed in more detail, the Pan Hlaing River and the Twante Canal:

- The Pan Hlaing River connects the Ayeyarwady to the Hlaing River, roughly 14 km upstream of its mouth (which is the confluence with the Yangon River). At Mezali a sluice is located. The functioning of the Pan Hlaing River downstream of Mezali Sluice is fully controlled by this sluice and a temporary cofferdam near the downstream river mouth. This cofferdam is only present in the low water season to prevent silted and salty water to enter the canal. This part of the Pan Hlaing River is mainly used for irrigation and the contribution to the river discharge through the delta system is relatively small (<20 m³/s based on local peak irrigation demands (RHDHV, 2019)). It is also prone to the siltation with sediment from Yangon River during the wet season when the cofferdam is not present, and the upstream (Mezali) sluice is closed.
- The Twante Canal, which was excavated and completed in 1883, is a 35 km long, open channel that plays a crucial role in the waterway transport between Yangon and cities in the north of the country along the Ayeyarwady River. It directly connects the Toe River to the Yangon River. Tide-induced flow velocities in the Twante Canal can be quite significant, even over 2.5 m/s in extreme scenarios, which then will cause erosion of the bed. It can be expected that any measures within (or even closure of) the canal will have a significant impact on the tidal dynamics in the (lower) delta. Floods occur regularly in the areas that surround the Twante Canal, and as Yangon City is expanding towards the canal, it is expected that flood protecting measures will be required in the future.

Coast

The coastal domain of the project area is part of the Gulf of Martaban (or Gulf of Mottama), which is an arm of the Andaman sea. The coastal zone is found to be extremely tide dominated. Both the shape and the bathymetry of the Gulf of Martaban result in an aggressive flood tide moving from west to east along the coast with springtide ranging from 4 to 7 m along the coastline. The largest tidal range can be found in the Yangon River, between Elephant Point and Monkey Point, due to the funneling effect that further amplifies the local tidal range (the funneling effect is further addressed in Section 3.2.4). The main cause of the funneling effect is the inlet shape of the Yangon River. The width and depth of the inlet decrease towards Yangon, amplifying the tidal amplitude. As a result, the intrusion of the tide into the Yangon Delta is relatively large.

Current flood protection system

Within the project area, many dike lines, levees and embankments are present that limit flooding and improve the level of flood security. These structures range from large scale levees along the main river branches, to small dikes and local embankment reinforcements (*Figure 9*).

For early-warning, DMH applies a danger level at every gauge station, which are located in the main towns along the river. This danger level is not defined on statistical analyses of water levels or discharges but is specified by DMH together with the communities based on experiences from extreme events from the past. In other words, when the river reaches the danger level, it is likely that some parts of the area will be prone to flooding.

The IWUMD Hydrology Branch determines a high flood level for all embankments, with statistical analyses on water levels at the locations of the gauge stations. Based on these analyses, the required crest levels for embankments are determined, mainly for a return period of 1 in 50 years. These statistics do only consider locally measured water levels in a local vertical datum and do not consider upstream discharges with a corresponding return period. This approach is different than the approach of RWSS, that considers the entire river system behavior for one specific flood event. Therefore, the return periods derived for RWSS differ from the data of IWUMD in both methodology as well as vertical datum (local versus EGM2008). EGM08 is a more generally applicable vertical reference system in absence of a robust national vertical reference system (Arcadis, 2019).

Large structures

Many large and smaller structures are present to distribute, limit or otherwise control the flow through the delta system. The functioning of three of these structures that have a significant impact on the distribution of water through the system are mentioned below because of their noticeable impact on the

system behavior. For the smaller structures (i.e. drainage and irrigation related) the reader is referred to (RHDHV, 2019).

Mezali Sluice

The functioning of the Mezali Sluice is quite complex:

- During the dry season, the (vertical) tide is still noticeable in the Kokkowa River, although the water in the river near the sluice is not saline. No tide is present on the closed section of the Pan Hlaing River due to the downstream closure by means of a cofferdam during the dry season.
- During high tide, flap gates allow freshwater to enter the Pan Hlaing River, while during low tide the gates prevent water from the canal from flowing back into the Kokkowa River. As such a freshwater storage is created.
- During the wet season, Mezali sluice is closed by lowering the radial gates, preventing (fresh) river water from flowing through the Pan Hlaing River towards Yangon. The Pan Hlaing River now functions as a tidal creek.

Pan Hlaing Cofferdam

The Pan Hlaing Cofferdam is a temporary closure of the Pan Hlaing River just over 13 km upstream from its mouth near Yangon. It is rebuilt each year to keep sufficient water in Pan Hlaing River for irrigation purposes during the dry season. In addition, the tide can no longer enter the Pan Hlaing River upstream of the closure. This means that during dry season, the water level within the Pan Hlaing River is fully controlled by the operation of the Mezali sluice further upstream.

Nga Moe Yeik Sluice

To limit the intrusion of the tide (with related salinity) and storm surges into the Nga Moe Yeik reservoir, the Nga Moe Yeik Sluice was constructed in the Pazundaung Creek. It only allows for downstream (i.e. seawards or southwards) directed flow. Currently the tide-averaged discharge during wet season is in the order of 100 m³/s (RHDHV, 2019). The sluice is designed for a peak discharge of up to 400 m³/s.

Freshwater extractions

At present, most water that is extracted from the various river branches, is mainly used for irrigation. In the future, however, the demand for freshwater will increase due to the expansion of irrigated areas and more water needs for domestic and industrial purposes.

Water extraction out of the river system for irrigation purposes peaks during early February at 198 m³/s, spread over many locations, e.g. controlled/uncontrolled sluices, gates and inlets (RHDHV, 2019). In addition, fishponds are refilled once every three years using freshwater from the nearest river. Based on the communications with the Department of Fisheries, it is estimated that 80,000 acres (one acre is 4,047 m²) are refilled by approximately 1 m every 3 years (i.e. on average 108 Mm³ freshwater per year). Fishponds are mostly limited to Kungyangon (6%), Kawhmu (7%), Twante (66%) and Htantabin (21%) regions. No other (known) significant freshwater extractions are present in the system.

The most severe “freshwater scarcity” situation occurs during extreme low river discharges from upstream in combination with spring tide. When this situation occurs, the least amount of freshwater is available from upstream, in combination with a relatively large degree of salinity intrusion into the delta, rendering that water unusable for most purposes. This event is further quantified in Appendix B.

3.2.3 River Discharges

The fluvial behavior in the Greater Yangon Region is dominated by the discharge characteristics of the Ayeyarwady river. The river discharge is correlated to the monsoonal character of the Myanmar climate and therefore highly seasonal. From December to May, the river discharge at Pyay is well below 5,000 m³/s (Figure 10). From July to October, which is referred to as the wet or rainy season, the mean discharge is between 18,000 and 28,000 m³/s. June and November show a transition between these two periods.

The mean discharge at Pyay is found to be approximately 11,500 m³/s. But only during one month (June) the actual discharge is close to this number. In light of relevance to the functioning of the system within a representative range of river discharges, the discharges through the system are evaluated for a representative mean high discharge of 27,500 m³/s (wet season) and a representative mean low discharge of 2,650 m³/s (dry season) at Pyay. Below-given description of the high discharge and the low discharge situations, is based on the simulations with the RWSS computer model, using an average spring-neap tidal cycle on the coastal downstream model boundary. In the simulations it is assumed that fish-pond filling occurs over the period of one month, simultaneously with the peak extraction discharge for irrigation. The results of the simulations are summarized in *Table 6* and *Table 7* below. The tables are color coded to indicate where local fluctuation in river discharges indicate river dominated hydrodynamics (green), tide dominated hydrodynamics (blue) or a transition zone (grey).

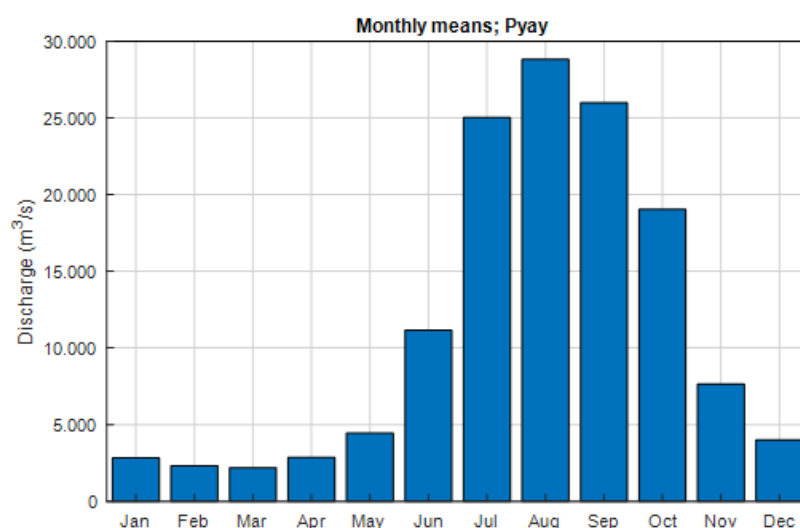


Figure 10: Annual monthly mean discharge at Pyay based on DMH (1979-2017)

Around 85% of the total discharge at Pyay reaches Nyaungdon, the remaining discharge flows to Patheingyi river (west) and towards Upper Hlaing (east). Discharge measurements (DMH and SHORE) and model simulations show, that at present the distribution at Nyaungdon is roughly 75%/25% of the remaining discharge, for both high and low flow conditions. The main part of the discharge continues downstream in Ayeyarwady River and the smaller part flows into the Pan Hlaing River towards Meiktila (east).

Moving further downstream to the bifurcation of the Toe river, the distribution is roughly 55%/45% for high discharge events and 59%/41% for low discharge events, with the dominant discharge leaving the Delta through the Ayeyarwady River south branches.

Table 6: Discharge distribution of branches in the eastern Ayeyarwady Delta relative to Pyay at high river discharge (27,500 m³/s at Pyay).

Location	Mean discharge [m ³ /s]	Tidal min. [m ³ /s]	Tidal max. [m ³ /s]	Percentage of total [%]
Pyay	27,500	27,500	27,500	100
Nyaungdon (upstream)	23,488	23,228	23,624	85
Nyaungdon (downstream)	17,578	17,496	17,655	64

Location	Mean discharge [m ³ /s]	Tidal min. [m ³ /s]	Tidal max. [m ³ /s]	Percentage of total [%]
Nyaungdon (towards Mezali)	5,910	5,505	6,062	21
Toe River	7,999	7,007	8,415	29
Hlaing River	7,896	-1,348	10,608	29
Yangon River	10,627	-42,011	36,679	37
Mezali sluice	0	0	0	-
Pan Hlaing (mouth)	0	-114	45	-
Twante Canal (west to east)	2,259	430	2,703	8

Table 7: System discharges during low discharge (2,650 m³/s at Pyay).

Location	Mean discharge [m ³ /s]	Tidal min. [m ³ /s]	Tidal max. [m ³ /s]	Percentage of total (mean) [%]
Pyay	2,650	2,650	2,650	100
Nyaungdon (upstream)	2,221	62	3,115	84
Nyaungdon (downstream)	1,668	858	2,090	63
Nyaungdon (side)	555	-1,301	1,129	21
Toe River	680	-3,104	2,221	26
Hlaing River	670	-10,025	5,221	25
Yangon River	826	-59,528	28,400	31
Mezali sluice	13	0	86	0
Pan Hlaing (mouth)	0	0	0	-
Twante Canal (west to east)	110	-2,686	1,142	4

About 28% of the tide-averaged river discharge flowing into the Toe River flows into Twante Canal towards Yangon (east) during high discharge while this is only 15% during low discharge. The remaining flows towards Dedaye (south). This again is determined by the conveyance capacity of Toe River and Twante Canal. The relative presence of the tidal forcing in both waterways is important for this. Also, the geometry and flow pattern at the bifurcation point influences the discharge distribution.

During a low to medium river discharge condition, the flow direction in the Twante canal alternates with incoming and outgoing tide, resulting in an eastward flow direction during outgoing tide (going from west to east). At incoming tide, the flow in Twante Canal is then in the opposite east to west direction. The flow velocities in Twante Canal during incoming tide are much higher than during the outgoing tide. However, the duration of this strong incoming tide is much shorter than the outgoing tide. As a result, the *tide averaged* flow direction is still directed towards Yangon.

During high river discharges, the situation can be different. At the location of Twante Township for example, during a river discharge at Pyay of 27,500 m³/s or higher, in combination with an average tide in the Yangon River, the combined tidal and river flow is directed eastwards over the full tidal cycle. This happens only a few times per year or less frequent. The high water levels in the Toe River under these extreme river discharge conditions 'push back' the tide. This push-back effect is observed

up to Twante Township. It should be noted that this is an extreme case and does not say anything about the flow directions further to the west, closer to the Yangon river. The model shows that at the eastern end of the Twante Canal, the flow is still directed to the west for a small amount of time during incoming tide, under such extreme river discharge conditions.

If the tide is strong, the above tide push-back effect will be smaller or absent. Under average spring tide conditions, for example, the flow still prevails in two alternating directions along the whole canal for a short period of the tidal cycle. With the above dominating physics in mind, it can be extrapolated from the results that for even more extreme river discharges, especially combined with the lower (neap, mean) tides, the flow direction can be in westward direction along the whole tidal cycle.

In summary: in almost all river discharge and tidal situations, the flow direction in the Twante Canal alternates, dominated by the strong tide in the Yangon River. However, there are certain (exceptional) situations where the flow can be continuously directed to the east for a full tidal cycle. This is the case with extreme high-water levels in Toe River (as a result of high river discharge), combined with lower tides. The model(s) that gave the physical insights behind this phenomenon have been fully calibrated under the RWSS (IADS-B) project (Arcadis, 2019).

During high river discharges the flow direction in the Twante Canal is continuously eastward towards Yangon. During low discharge, the flow direction alternates with incoming and outgoing tide, resulting in an eastward flow direction during outgoing tide (going from west to east). At incoming tide, the flow in Twante Canal is then in east to west direction. The flow velocities in Twante Canal during incoming tide are much higher than during the outgoing tide. However, the duration of this strong incoming tide is much shorter than the outgoing tide. As a result, the tide averaged flow direction is still directed towards Yangon. The flow in Twante Canal in this way also determines the distribution of the water in the Toe River at the western end of the canal. The complex and highly asymmetric flow pattern over the duration of the tide also influences sediment transport and related morphological responses. In other words, the short but strong incoming tide versus the long but more gentle outgoing tide is likely the main contributor to a net import of sediment into the Twante Canal (or any other river branch showing the same characteristics).

Up north, just over a quarter of the total discharge at Pyay reaches Hlaing River (29% and 25% respectively for high and low discharge). This is the cumulative discharge from the Kokkowa and Upper Hlaing River. There is no added discharge from Pan Hlaing as the tide-average flow is nil during high discharge, due to the closure of Mezali sluice, while Pan Hlaing River is closed off by the cofferdam during low discharge.

Finally, the discharge through the Twante Canal combined with the discharge through the Hlaing river, results in the discharge through the Yangon River at Elephant Point. This discharge amounts to 37% and 31% of the total at Pyay for high and low discharge events, respectively. The difference is mainly due to the difference in discharge through the Twante Canal.

So, in general, while the discharge through the Delta increases with an increasing upstream river discharge, a relatively higher percentage of the total river discharge flows directly south through the main river branches (Ayeyarwady River and Toe River). This means that relatively less freshwater is available within the Yangon region during high river discharge. However, it must be noted that freshwater dependent functions are invariably governed by the low river discharge conditions.

A visual overview of the discharge distribution through the project area for both the average wet season and average dry season is given in Figure 11.

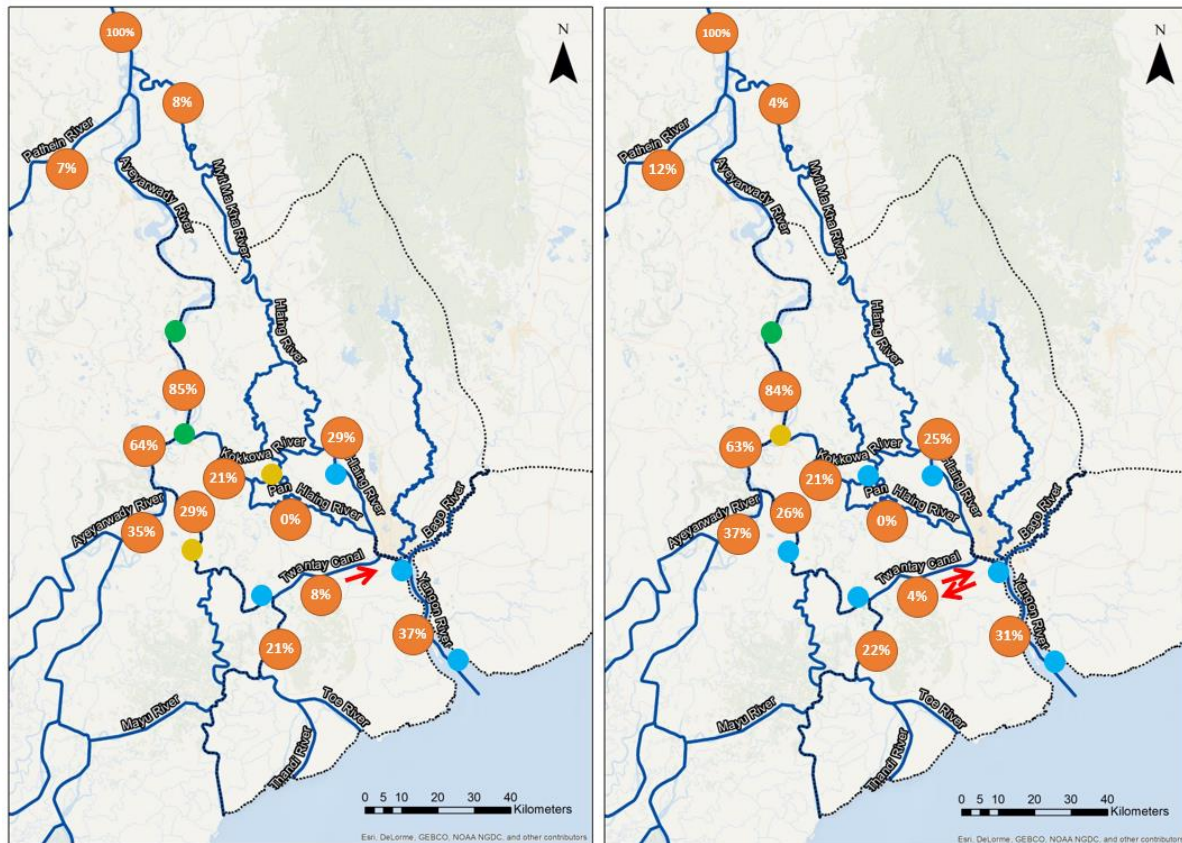


Figure 11: Discharge distribution wet season (left frame) and during dry season (right frame).

3.2.4 Water levels

All water levels presented in the tables below are referenced to EGM08 and include the average, the minimum and the maximum values over a spring-neap tidal cycle. The last column represents the local tidal range in meters, computed as the vertical difference between the local minimum and maximum values. The simulated water levels presented in the tables are the result of a model simulation with a mean high discharge of 27,500 m³/s and a mean low discharge of 2,650 m³/s at Pyay, in combination with a mean spring-neap tidal cycle. The same color coding is used to indicate river dominated (green), tide dominated (blue) or a transition zone (grey).

For the mean high-water discharge condition, the computed water level gradient over the Ayeyarwady river is around 7.0×10^{-5} (7.4×10^{-5} for high discharge and 6.8×10^{-5} for low discharge). This means that the water level drops nearly 1 cm over a distance of 100 m. For most other river discharge dominated (side) river branches within the system, the water level gradient is slightly less at 2.5 to 3.5×10^{-5} . Further downstream, the gradient fluctuates with the tide, but the tide averaged gradient further decreases towards the coast.

In general, moving southwards along the key locations in the study area, the river becomes more tide dominant and less river discharge dominant, as expected. However, there is a significant difference in this transition between high and low river discharge. In the tables, the locations with a tidal range larger than 1.5 m are marked blue, the other locations are marked light yellow. The tide reaches up to 21 Mile along the Teo River and Htantabin (the mouth of the Kokkowa and Upper Hlaing rivers) during high discharge. During low discharge it reaches upstream Maubin along the Teo River and upstream Mezali on the Kokkowa River. At low river discharge a vertical tide of almost 1.2 m is observed at Nyaungdon. This means that on both rivers, the vertical tide (i.e. tidal water levels) is observed roughly 50 km further inland at low river discharges, compared to the high river discharge events.

Another visible effect of the decrease in river discharge is the increase in tidal range in the Yangon River. While the tide on the coastal boundary is identical, the tidal range in the Yangon River increases by roughly 20% during low river discharge. Especially the ebb level is significantly lower, because the outgoing tidal (ebb) flow “benefits most” from a lower counterflow by the river.

Table 8: Water levels at key locations during high discharge (27,500 m³/s at Pyay).

Location	Mean water level [m EGM08]	Tidal min. [m EGM08]	Tidal max. [m EGM08]	Tidal Range [m]
Pyay	24.88	24.88	24.88	0.00
Zalun	9.88	9.87	9.90	0.03
Nyaungdon	6.88	6.80	7.01	0.21
Maubin	4.46	4.25	4.85	0.60
21 Mile	0.41	-1.04	2.10	3.14
Mezali	4.69	4.33	5.35	1.02
Htantabin	3.21	2.59	4.41	1.82
KIP	1.13	-0.61	3.94	4.55
Monkey Point	0.85	-1.09	3.86	4.95
Elephant Point	0.74	-1.19	3.63	4.82

Table 9: Water levels at key locations during low discharge (2,650 m³/s at Pyay).

Location	Mean water level [m EGM08]	Tidal min. [m EGM08]	Tidal max. [m EGM08]	Tidal Range [m]
Pyay	18.85	18.85	18.85	0.00
Zalun	2.09	1.87	2.32	0.45
Nyaungdon	1.62	1.19	2.36	1.17
Maubin	1.06	0.13	2.35	2.22
21 Mile	0.38	-1.39	2.25	3.64
Mezali	1.07	-0.05	2.83	2.88
Htantabin	0.96	-0.23	2.84	3.07
KIP	0.64	-1.46	3.87	5.33
Monkey Point	0.61	-1.55	4.06	5.61
Elephant Point	0.59	-1.51	3.89	5.40

Water level time series for a full spring-neap tidal cycle are presented in the figures below for both the high and low river discharge events at the locations Zalun, Mezali, Maubin and Monkey Point.

At Zalun the computed water levels are river dominated during high and low river discharge events (no fluctuations on hourly scale). Yet, there is some minor influence of the tide even at Zalun due to a backwater effect.

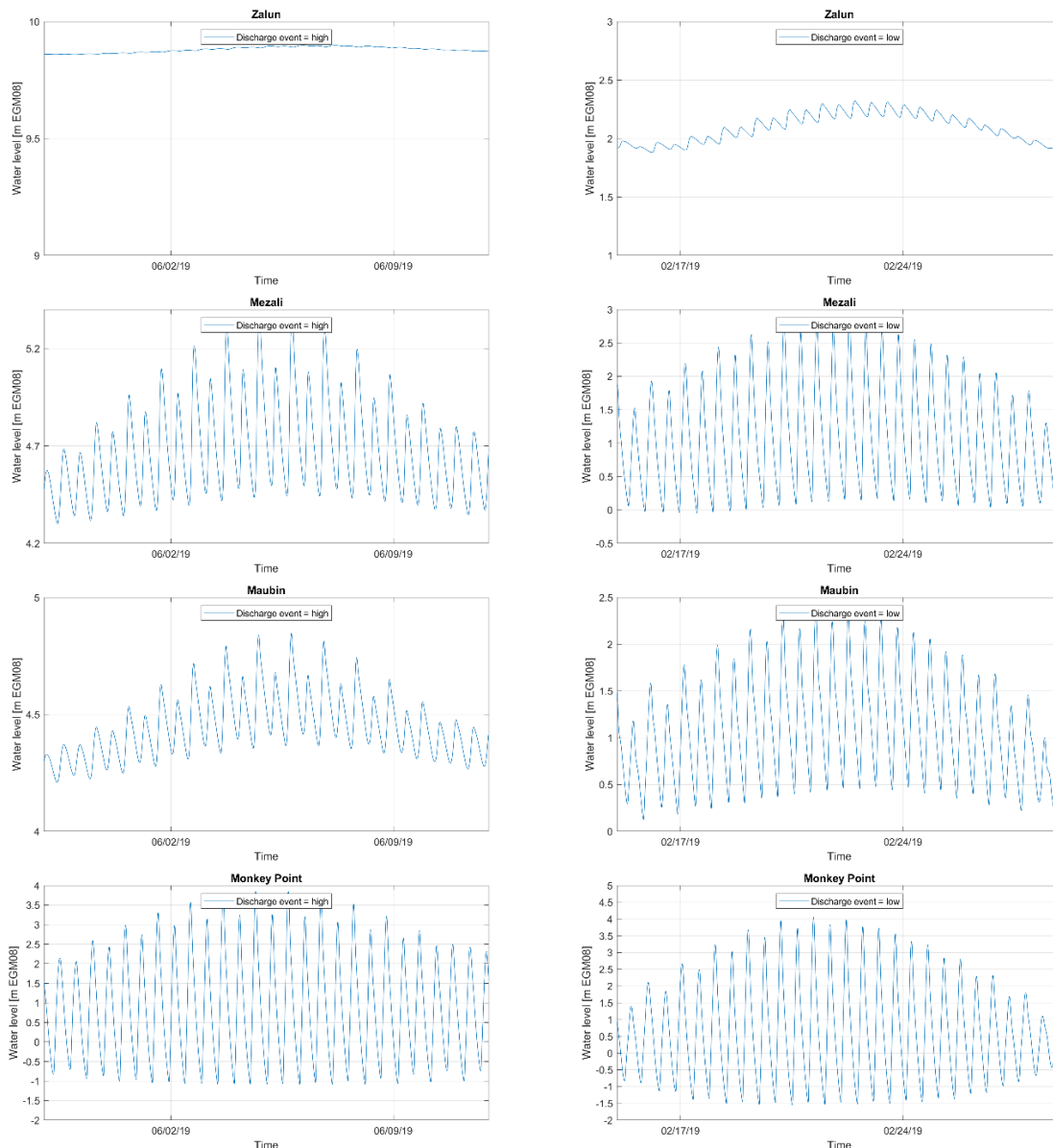


Figure 12: Water level time series for Zalun, Mezali, Maubin and Monkey Point (top to bottom) for both the high (left) and low river discharge events (right).

Conversely, at Monkey Point, the system is tide dominated for both low and high river discharge situations. The tidal signal is hardly changed by the river flow; only the spring-neap effects are slightly more pronounced during low river discharge.

For Mezali and Maubin the local hydrodynamics are dependent on the considered river discharge event:

- During high river discharge, the hydrodynamics are river dominated. Only a fraction of the tidal amplitude remains. The largest remaining amplitude is caused by the backwater effect of the spring-neap tide effect.
- During low river discharge, the hydrodynamics are more tide dominated. More than half of the tidal amplitude present at the coast, can now still be observed at Mezali and Maubin.

3.2.5 Salinity

The salinity content depends on the one hand by the forcing of saltwater into the delta from the sea. On the other hand, freshwater from the rivers upstream force the saltwater to flow back. The degree of salt

intrusion into the delta is subject to the continuous interaction between these two forces. Hence, the behavior of the salinity is different under high and low river discharge conditions. The degree of intrusion of saltwater (defined as 0.5 PSU and higher) into the delta is strongly correlated with the degree of intrusion of the tidal effects. The lower the freshwater discharge, the further the intrusion of salinity upstream.

To understand the salinity dynamics in the delta system, time and depth variations are also important. The relevance of time variation is threefold:

- Salt intrusion into a river branch has a short-term fluctuation that follows the instantaneous motion of the tide. It intrudes with the incoming tide and is pushed back with the outgoing tide. The time period for this fluctuation is just over 12 hours (semi-diurnal tide).
- A longer-term fluctuation is caused by the spring-neap tidal cycle (lunar cycle). During spring tide, the tidal forcing is relatively large and so is the associated salt intrusion. Pushing back the salinity takes roughly 1.5 to 2 times as long, the average intrusion increases steadily during the build-up to spring tide. Conversely, the process is inverted again during neap tide where a smaller tidal forcing leads to a slow retreat of the average intrusion length. Hence, the time period for this fluctuation is roughly 14 days.
- An even longer-term fluctuation is related to the seasonal variation in river discharge. A reduction of the river discharge leads to an increase in intrusion of salt, whereas an increase in river discharge leads to a push back of the salinity front. It takes roughly a month (or at least two full spring-neap tidal cycles) for the intrusion length to adjust to a new river discharge regime. The period of this fluctuation is a year, the full monsoonal cycle.

The depth variation is important because saltwater is heavier than freshwater. This means that the saltwater intrusion is strongest along the bottom of the river. This process is especially prevailing during the intrusion of saltwater and is less pronounced during its (seaward directed) retreat. It also means that deeper (parts of the) rivers are more sensitive to salt intrusion. The shape of the cross-channel profile is important too. Because it is mainly the freshwater that is pushing back the salinity, this is enhanced if this force is applied effectively. For instance, if a certain freshwater discharge is available, this can push back the salt more effectively if the cross-section profile of the river is small. The result is a substantial tide-averaged flow (force) that works against the tide and against the salt intrusion.

In the study area, salt intrusion mainly occurs along two rivers:

- The Yangon into Hlaing into Kokkowa/Upper Hlaing River;
- The Toe River.

As the salinity intrusion is most important during low river discharge events, the salinity intrusion into these rivers is evaluated for the low 2,650 m³/s (at Pyay) discharge event. At fixed locations, the salinity fluctuates because of the tide effects. The calculated minimum and maximum salinity levels (at the bottom) are shown in *Figure 13*.

The salinity intrusion front moves 10 km into the Hlaing River during ebb and 30 km into the Hlaing River during flood. The salinity intrusion front fluctuates between Toe River km 40 and Toe River km 60. For the evaluated river discharge regimes, no saltwater enters the Toe River from the Yangon River via Twante Canal (Twante Canal connects to Toe river at approximately Toe River km 67) as the predominant flow in the canal is from west to east. However, during even lower discharge scenario's, this may be different as described in Appendix B.

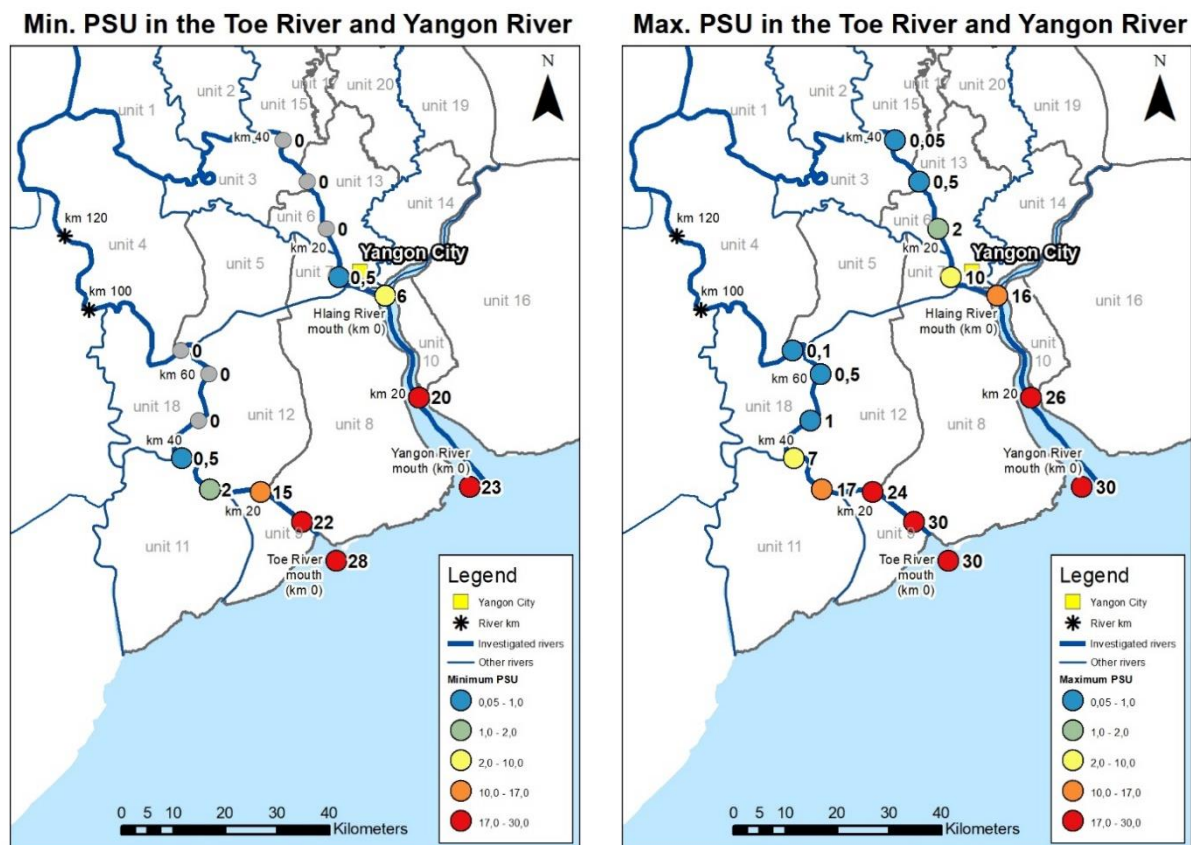


Figure 13: calculated salinity levels during low river discharge

3.2.6 Meteorological conditions

Precipitation

The precipitation in the Greater Yangon Region is heavily dominated by the monsoonal character of the meteorological conditions in Myanmar, especially in the coastal region. Three seasons are identified:

- The cool, dry monsoon (late October to mid-February);
- The hot, dry intermonsoon season (mid-February to mid-May);
- The rainy monsoon (mid-May to late October).

The distribution of the rainfall is shown below, which resembles the river discharge distribution shown in Figure 10. More than 95% of the annual precipitation, which on an average is more than 5,000 mm, occurs in the wet season.

Areas are drained through both controlled and uncontrolled creeks or outlets. The (natural) drainage is often not sufficient to drain all local rainfall immediately. Rainwater flows towards the lower sections in the unit areas. Especially in the rural and more inland areas, where natural drainage is not always present or has been poorly maintained over the years, these lower parts are prone to frequent (pluvial) flooding. During the more extreme (less frequent) pluvial events, also the parts where drainage is present may suffer from temporary pluvial flooding.

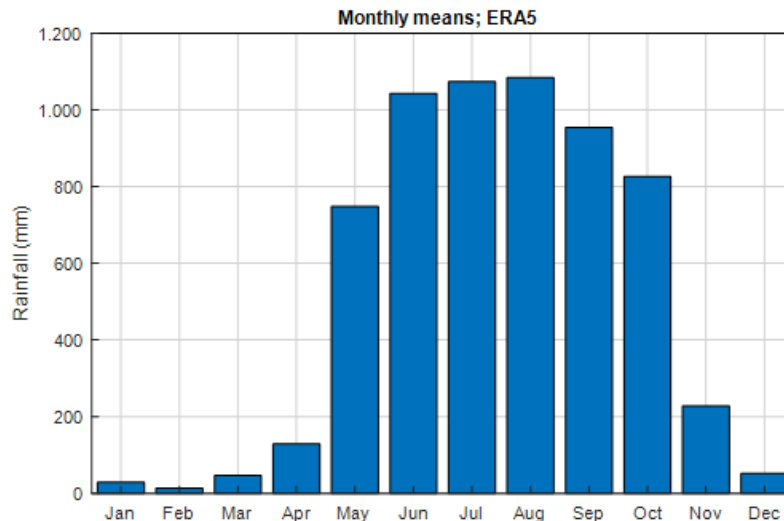


Figure 14: Monthly means for rainfall based on ERA5 over 1998-2018.

Wind and cyclones

The yearly wind conditions are dominated by the local monsoonal character. Especially, the rainy monsoon period of mid-May to late October is generally accompanied by persistent south-westerly winds of 2 – 10 m/s (Figure 15). This persistent wind forcing results in a water level gradient into the Gulf of Martaban and into the Yangon River. This local set-up functions as a seasonal component in the water level fluctuation. For the coastal flood security situation, however, cyclone events are more relevant because these events rise the water levels significantly higher.

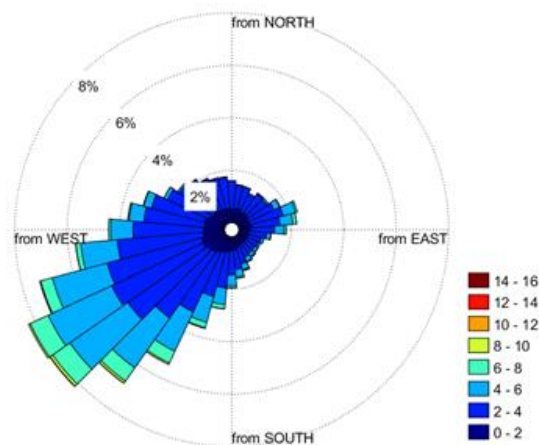


Figure 15: Average wind direction and wind velocity near the Yangon River mouth based on ERA5 over 1998-2018.

The coastal zone is subject to tropical cyclones. Cyclones typically occur in April to early May and late October to end November, just before or after the rainy monsoon period. The wind surge due to the monsoon wind is not yet present at that time or has already gone. These cyclone events can be considered extreme events and generate significant storm surges that are aggravated by large waves. During Nargis, the most destructive recent cyclone in the area, the storm surge was up to 5 meters high with superimposed waves of 2 m high (Fritz et al., 2010).

3.2.7 General flooding behavior

For high flood events, simulations with the RWSS model show the transition from fluvial event dominated to coastal event dominated. To illustrate this, Figure 16 shows the computed peak water

levels for a 1 in 100 years fluvial event and a 1 in 100 years coastal event. The plots show the peak water levels along the western Ayeyarwady-Toe River route (left) and along the eastern Ayeyarwady-Kokkawa-Hlaing River route (right - see map in Figure 9 for locations). Upstream of 21 Mile in the Toe River (near the entrance of Twante Canal) and at the Htantabin (the confluence of Kokkawa River and Hlaing River), the 1 in 100 year flood events are river discharge dominated. Downstream of these points it is the coastal flood event that determines the flood safety. These observations are in agreement with (Deltares, 2020).

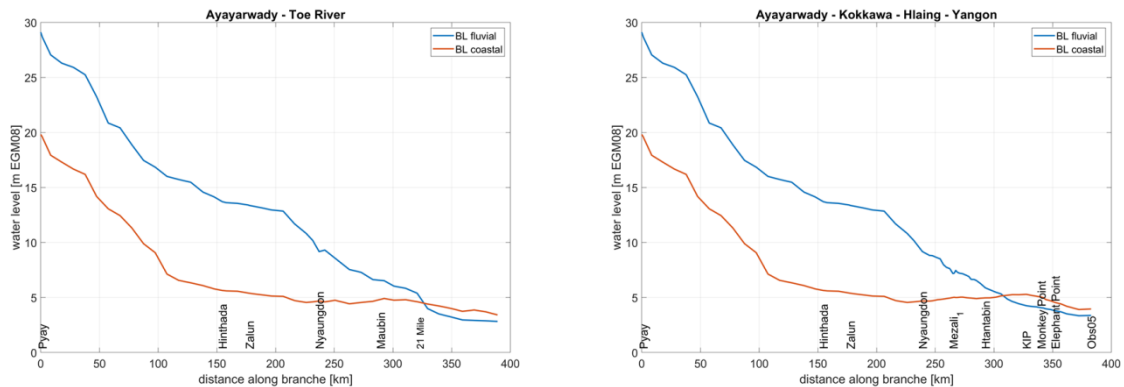


Figure 16: Peak water levels 1 in 100 years fluvial (blue) and coastal (orange) event.

In extreme events large areas may be flooded. In the maps below the calculated flood maps for fluvial (Figure 17) and coastal flood (Figure 18) events having a probability of occurrence of 1 in 100 years are shown. For the fluvial flood map also the direction of the inflow of water is indicated, to show how flooding of dikes along Ayeyarwady River and Toe River may cause deep inundations. In the extreme flood events this water flows over land towards the east.

A cyclone with probability of 1 in 100 years (only wind, no rainfall included in the simulation, shown in the left panel in Figure 18) causes less extended flooding than the river flooding with the same probability, but in these events, flooding happens with mainly saltwater. In addition, the same cyclone event was forced in combination with rainfall. In this simulation, a rainfall event was forced comparable to a 1 in 10 years pluvial event (ECMWF, 2019), making the combined coastal and pluvial event comparable to Nargis (2008). Furthermore, in this simulation, drainage of pluvial water during the storm surge was reduced accounting for the reduced head during the storm surge, based on the SOBEK model (described in Appendix B).

The calculated peak inundation is shown in Figure 18 in the right panel. It shows that the inundation has increased significantly compared with the situation without rainfall. When comparing the simulated inundation maps to the observed inundation maps due to the Nargis event (Figure 19), both maps agree very well. All coastal units are largely flooded, except for Unit 12 and Yangon City, which are located at a higher elevation. The inundation in the northern half of the delta is more limited to local (low-lying) areas. While the model result shows these spatial differences as well, the simulated flooding is more severe. This is likely due to overestimation of the reduction of the drainage which was accounted for, as this was determined based on the SOBEK model of Unit 8, a coastal unit, where this reduction is more dominant than in the more northern areas.

A more detailed overview of the flooding characteristics as well as the security levels per threat and/or combined threats is described in Appendix B.

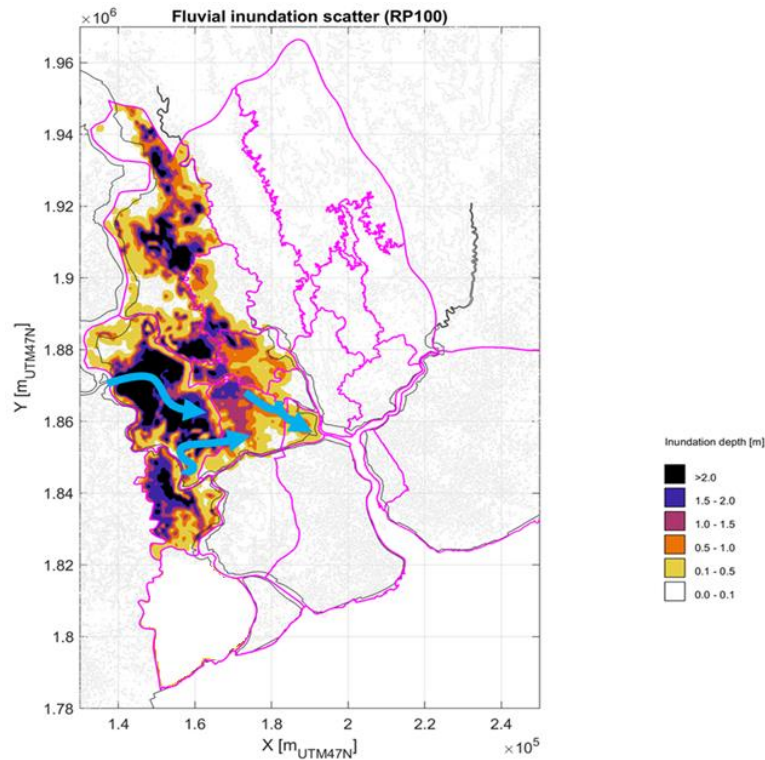


Figure 17: Flooded areas and direction of overland flow in case of a simulated river flood event with a probability of 1 in 100 years

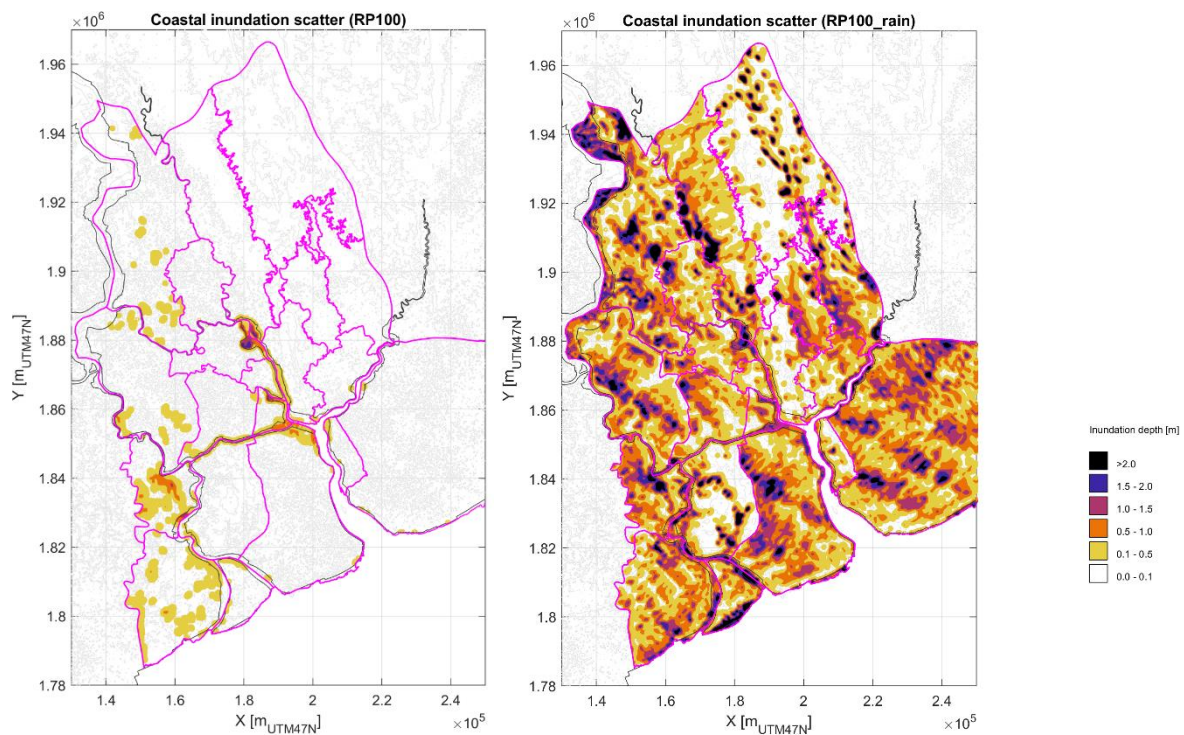


Figure 18: Coastal inundation map for a cyclone event with a probability of 1 in 100 years (without rainfall on the left, with a 1 in 10 years rainfall on the right)

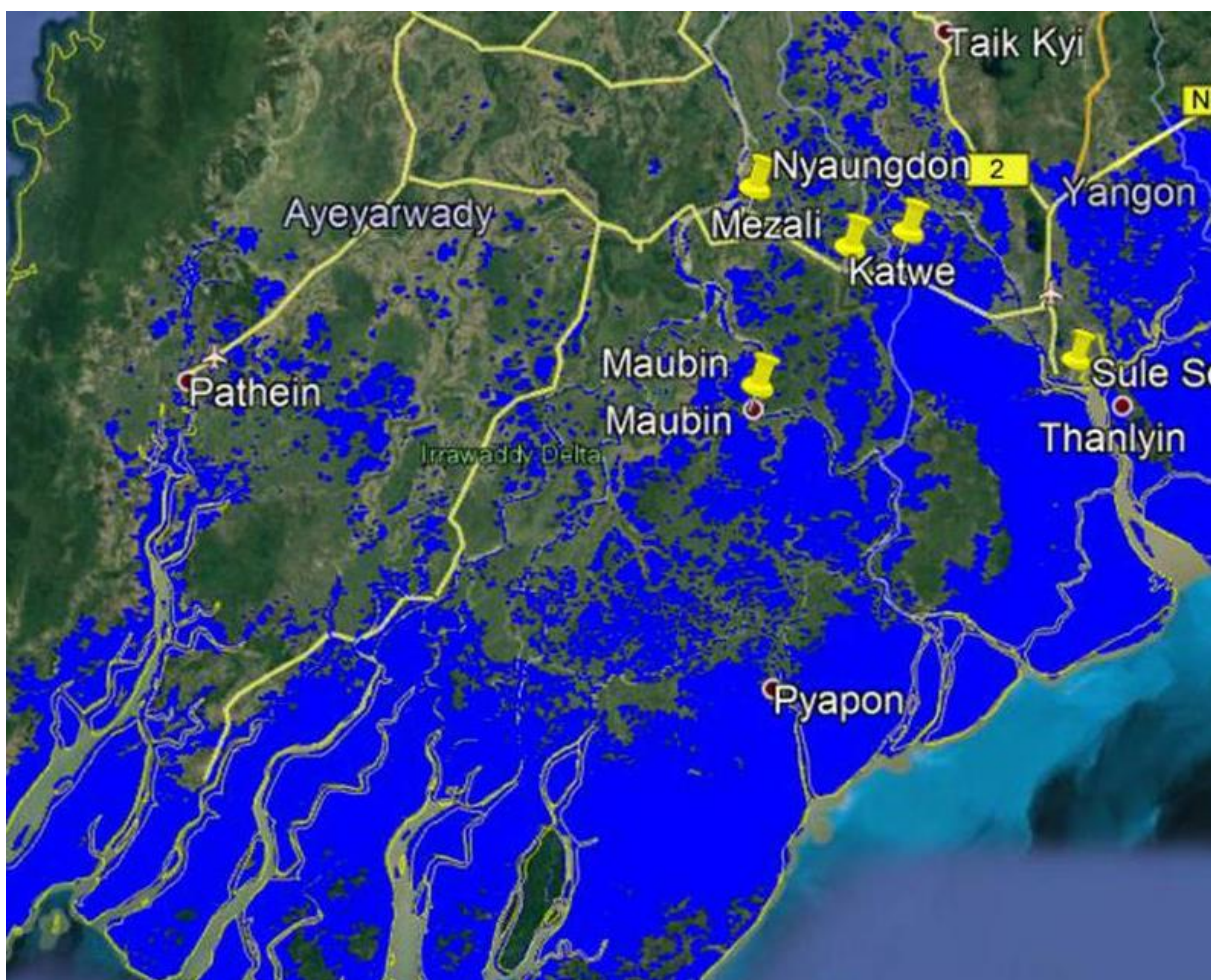


Figure 19: Digitized flooding extent due to Nargis (2008) event, based on satellite imagery (background: Google Earth)

3.3 Baseline assessment

3.3.1 Approach

Present flood- and freshwater security levels are determined by assessing the probability of exceedance of threshold values for each indicator. The threshold value reflects the value of the indicator when it is considered to become a serious threat. The selected threshold values, discussed in section 2.2.1 were presented and discussed with stakeholders during the second project workshop in December 2019 (Appendix A):

Model runs with boundary conditions describing 5 in 1 (five times per year), 1 in 10 year, 1 in 25 year, 1 in 50 year, and up to 1 in 1000 year events are used to estimate the probability of exceedance of the threshold value for flooding, storm surges, rainfall and salinity. For the flooding events, also the flood extent, damage and number of affected people are assessed. An overview of all applied boundary types and forcing types is given in Table 10 (more detailed information is provided in Appendix B).

Table 10: Overview of all external boundary forcing

Boundary type	Forcing type
Upstream river: Ayeyarwady at Pyaw	Ayeyarwady River discharge (flood wave or constant) for different return periods
Upstream river: Bago	Bago River discharge (flood wave or constant) for different return periods

Boundary type	Forcing type
Upstream river: Pazundaung Creek	Constant representative discharge (0 - 100 m ³ /s). Based on operation of Nga Moe Yeik Sluice, resulting in a tide-averaged discharge during the wet season in the order of 100 m ³ /s.
Coastal boundary	Spring-neap tidal cycles. Seasonal variation of the sea level at the boundary is included in the boundary condition.
Freshwater extraction(s)	None / Peak freshwater extractions for irrigation and aquaculture
Wind and atmospheric pressure	None / Spatially varying (varies with return period)
Precipitation	None / Spatially forced (varies with return period), including evaporation and infiltration
Drainage	Natural drainage and schematized large-scale drainage. The model is too coarse to model the drainage. RHDHV calculated the tide-averaged drainage capacity per return period, which is subtracted (post-processing) from the computed peak inundation volume per unit (RHDHV, 2019).
Salinity	30 ppt on coastal boundaries

Riverine and coastal flooding analysis

Each unit area is protected by natural levees and artificial embankments (such as dikes). The heights were schematized for the RWSS model using a combination of SRTM and LIDAR data (Arcadis, 2019). The location where the outside (river) water level exceeds the local height of the levee “first”, is the weakest point in the levee of the unit. This is not necessarily the lowest dike section, because the peak water levels fluctuate around the unit areas as a result of the river gradient, river bends and/ or any changes in river cross section. The weakest location is the location where the water starts to inundate the unit area first. An example of how this weakest point is determined is visualized in Figure 20. It shows the modelled dike heights along the unit area’s perimeter (the blue ‘spiky’ line) and the manually interpreted (smoothed) local dike heights (the red line). The Figure further shows the computed water levels along the perimeter of the unit area for different return periods (the different dashed lines). For one return period water level, there is one location where water levels exceed the interpreted dike heights (indicated with the orange arrow). This procedure has been done manually for each unit area, resulting in an identification of the weakest location. The moment of exceedance of the dike height at the weakest link, is a first estimate of the flood probability for the associated unit area. For unit area 5 this appears to be more frequent than 1 in 2 years. However, more important are what area is flooded and how deep.

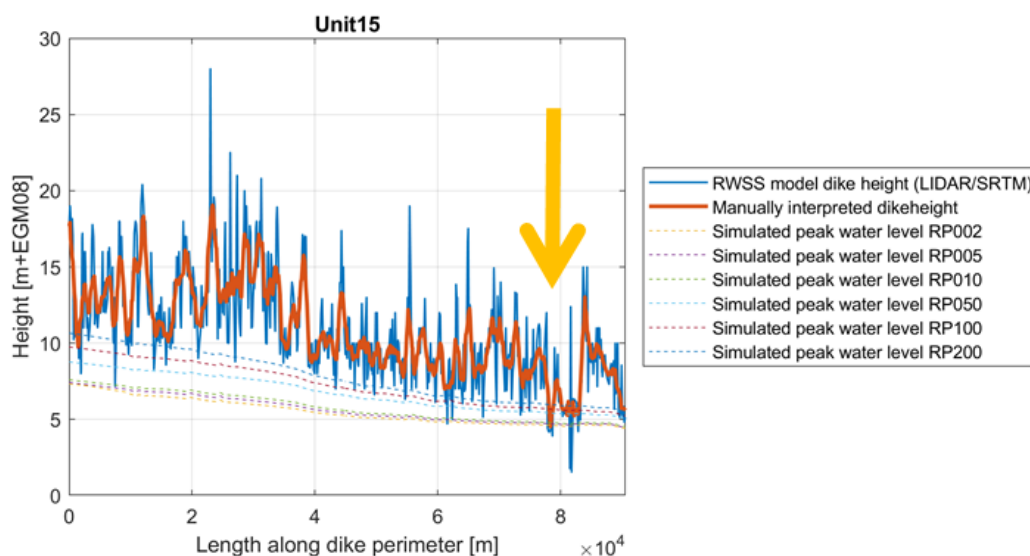


Figure 20: Simulated water levels in the river compared with dike heights for unit 15.

An example of a map with identified weakest links plus an inundation map is shown in Figure 21, for an extreme flood event with a return period of 1 in 200 years (unit area 15). Although the flood frequency is high due to local depressions in the embankment, the flooded area is very small, even at an extreme

flood event. So, it is not enough to only look at return periods of floods per unit area but also to look at the size of the area that is flooded (and to what depth) adjacent to the overtop location in order to assess the flooding severity.

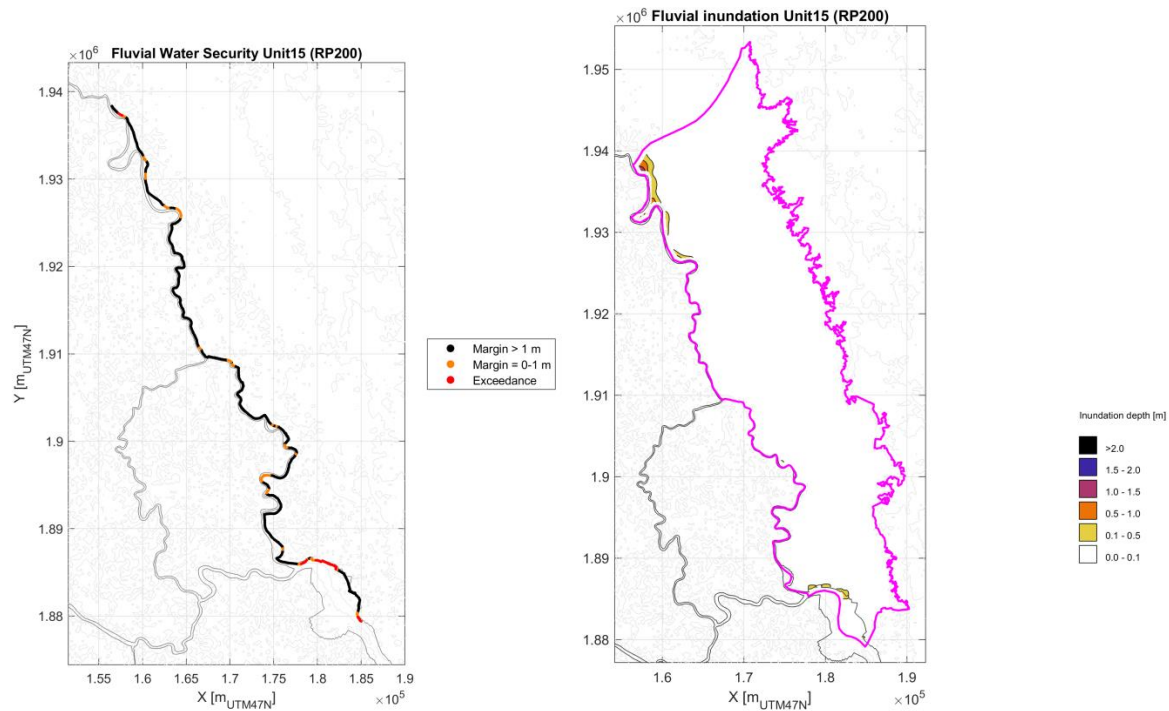


Figure 21: Dike safety Unit 15 for RP200

Pluvial flooding analysis

The predominant land use in each unit area is used to determine the threshold for the inundation depth: 0.3 m for urban and 0.6 m for rural areas. It is assumed that above this threshold, the socio-economic functioning of this area is severely limited and/or evacuation becomes a necessity. Whenever the inundation depth criterion is exceeded for a certain percentage of the RWSS unit area, the unit 'fails', determining the level of water security from a pluvial flooding perspective.

The peak inundation properties are simulated per unit area. The model, as described in Section 2.2.3, includes only the large scale (>1km) topographical features, accounting for *known* drainage.

Water scarcity analysis

The analysis for water scarcity is twofold. Firstly, the impact of (peak) freshwater extractions is simulated using the *channel flow model*. Freshwater extractions for all known irrigation use and aquaculture are accounted for. Currently, the peak freshwater extraction is computed to be approximately 250 m³/s, occurring during the first half of February.

Secondly, the salt intrusion into the Yangon delta over time is simulated for multiple continuously low river discharges using the 3D salinity model. The evaluation of the upstream salt intrusion along the following two main river branches moving into the Yangon Delta is presented:

- The Yangon River into Hlaing River into Kokkowa/Upper Hlaing River branch (key location: Kokkowa intake (Katwe));
- The Toe River (key location: Maubin).

The salt intrusion is evaluated along the longitudinal axis of these rivers, starting at the Hlaing River mouth and Toe River mouth, and following an upstream direction. The maximum intrusion length of the salt wedge along the axes of these rivers is computed as a function of return period. The frequency of occurrence for the salt front reaching a pre-defined key-location per unit area, often the most downstream freshwater intake for the unit, determines the water level security from a water scarcity point of view.

3.3.2 Fluvial flooding

For a range of high river discharges (e.g. discharges related to return periods of 2, 5, 10, 25, 50, 100 and 200 years) the river floods have been simulated throughout the study area. The peak water levels during each event associated with a specific return period have been collected in *Table 11*. As can be observed, mainly the upstream locations (Nyaungdon, Mezali and Maubin) are impacted by the fluvial event and show a significant increase in water levels with an increasing return period.

Table 11: computed water levels Fluvial flooding (Baseline)

Fluvial flooding			River high water level [m+EGM] (Baseline)						
Return period [year]	Discharge [m ³ /s at Pyay]	Tide	Nyaungdon	Mezali	Maubin	KIP	Monkey Point	Twante 3.5M	Elephant Point
2	39481	Average spring	8.31	6.22	5.74	4.07	3.93	4.13	3.71
5	44522	Average spring	8.72	6.51	6.01	4.09	3.96	4.18	3.71
10	47860	Average spring	8.88	6.76	6.17	4.11	3.97	4.20	3.72
50	55206	Average spring	9.11	7.30	6.45	4.22	4.01	4.31	3.77
100	58311	Average spring	9.17	7.47	6.55	4.25	4.01	4.36	3.79
200	61405	Average spring	9.20	7.61	6.63	4.32	4.02	4.48	3.81

For each unit area the dike heights are compared with the computed water levels along the considered dike section(s) for the considered return periods. This indicates the weakest links and first moment that the dikes will be overtopped. The simulations also calculate flooded areas and inundation depths. *Figure 22* shows the results in terms of flood hazard level for fluvial flooding (RP) and the flood maps for different return periods.

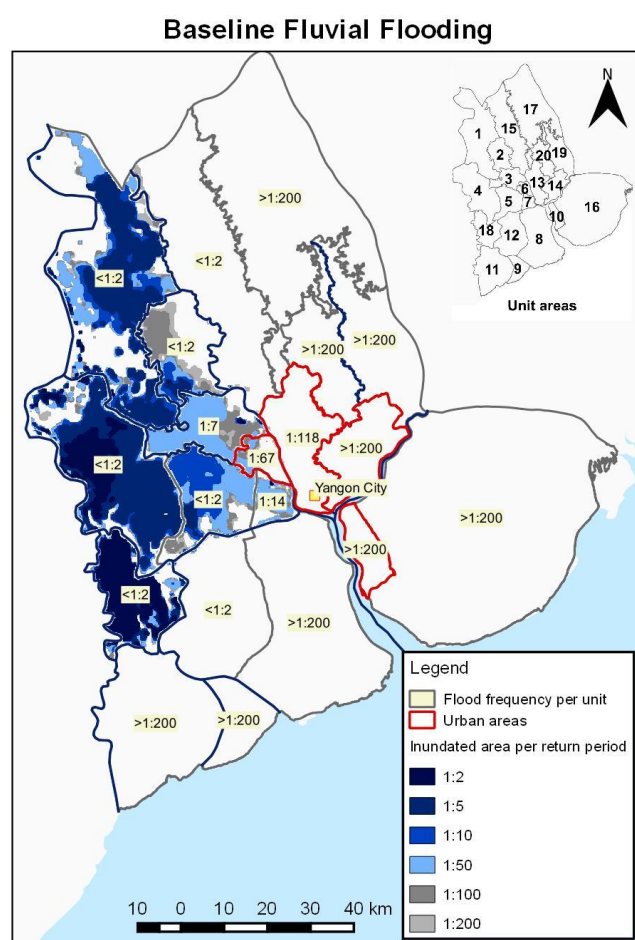


Figure 22: Flood maps for fluvial flooding for different return periods and flood frequency per unit.

There is a large spatial variation in fluvial flood safety. Unit areas along the Ayeyarwady River and its primary river branches (Kokkowa, Hlaing and Toe rivers) are most susceptible for fluvial flooding. These

areas all have a flood probability of around 1 in 10 year or more frequent. The flooded areas and inundation depths are extensive, except for the units 12 and 15, which have relatively higher elevated land showing frequent flooding, but of small areas only (as shown in *Figure 21*).

Most other coastal and eastern unit areas show a fluvial flood security level of 1 in 50 year or higher and flooded areas due to river floods are small.

3.3.3 Coastal flooding

The coastal flood safety is analyzed by simulating (synthetic) hurricane events with a varying severity. As described in Section 2.2.3, cyclone Nargis was scaled to represent cyclone events that occur 1 in 25, 50, 100 and 200 years, on average. This was done by scaling the wind velocity and pressure drop, while keeping the cyclone track identical to Nargis.

The peak flood levels during each event associated with a specific return period are presented in *Table 12*. As can be observed, all locations except for Nyaungdon are impacted significantly, especially during the more severe coastal events.

Note that the 1 in 100 years event as shown here is comparable to the Nargis event based on wind and pressure forcing. The simulated flooding levels are comparable to the levels found in (RHDHV, 2019).

Table 12: Flood table Coastal flooding (Baseline)

Coastal flooding			River water level [m+EGM] (Baseline)						
Return period [year]	Discharge [m ³ /s at Pyay]	Tide	Nyaungdon	Mezali	Maubi	KIP	Monkey Point	Twante 3.5M	Elephant Point
25	4500	Average spring	7.74	4.49	4.51	4.07	4.05	3.95	3.69
50	4500	Average spring	7.74	4.49	4.51	4.32	4.29	4.19	3.90
100	4500	Average spring	7.74	5.00	4.82	5.28	5.11	5.15	4.54
200	4500	Average spring	7.74	6.00	5.43	6.13	5.78	5.88	5.09

Figure 23 presents the water level fluctuations going from south to north along the Yangon River towards Yangon City, at Elephant Point, Monkey Point and Htantabin, respectively. The blue graphs show the baseline water level signal (identical hydrodynamic conditions, but no wind forcing), and the other graphs show the water level with cyclone forcing. As is the case with the tidal signal, the impact of the cyclone is amplified when moving into the delta, mainly due to funneling of the storm surge effect (on top of the funneling of the tide that was already present). In other words, the simulated peak water levels not only increase with increased wind forcing, but also when moving into the Yangon Delta (KIP), before decreasing again (Htantabin).

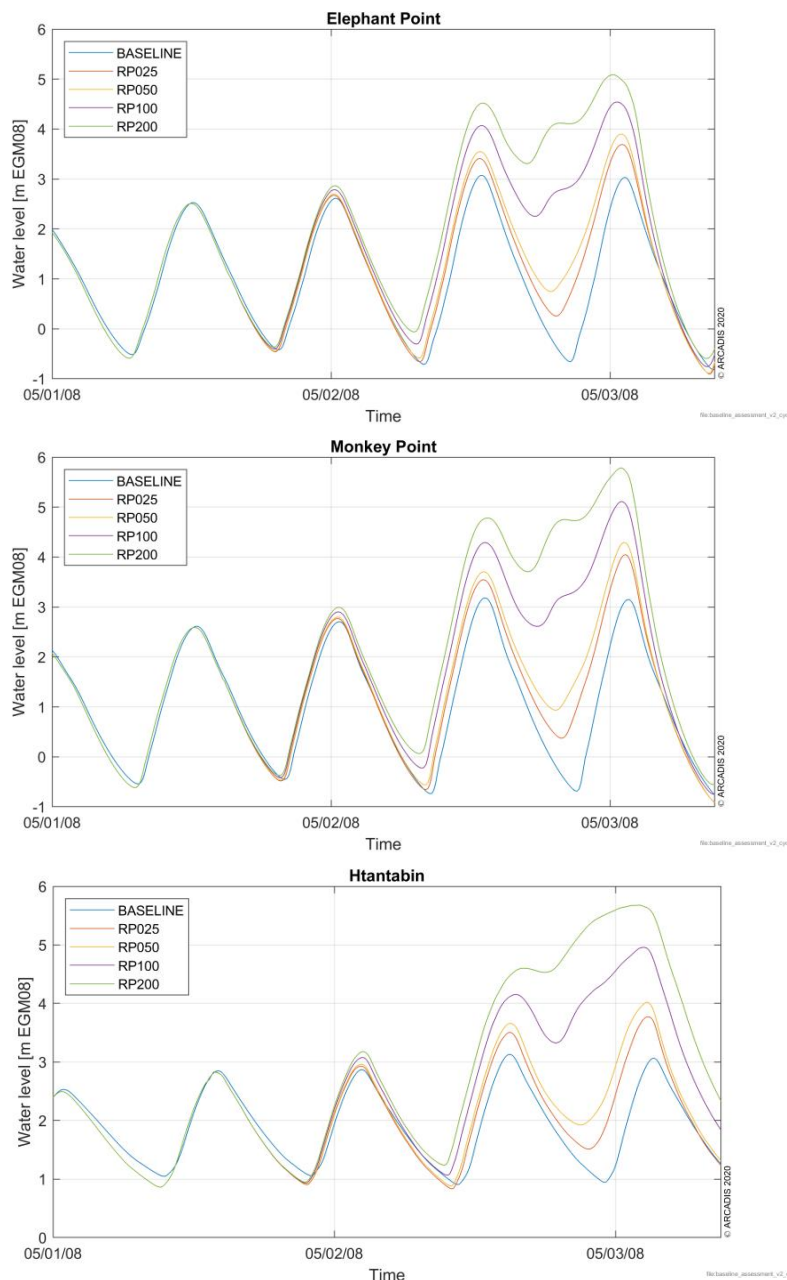


Figure 23: Simulated water level time series at Elephant Point (upper frame), Monkey Point (middle frame) and Htantabin (lower frame).

Subsequently, the computed peak water level during the passage of the cyclone is compared to the local dike heights to get an indication of the frequency of flooding due to storm induced high-water levels. To a large degree this methodology is comparable to the analysis for the fluvial flood hazards. For more details see Appendix B.

Figure 24 gives an overview of flooded areas due to the storm induced flooding and the moment of first inundation (flood frequency) per unit area. Nargis (2008) is considered to be representative for a 1 in 100 years storm. Effectively, this means that all units that have a computed level of safety of 1 in 100 years or less, are predicted to have been overtopped at one or more locations along the dike section. This is confirmed by recreated inundation maps of the disastrous Nargis event based on satellite imagery.

Similar as for the fluvial flood hazards, there is a large spatial variation in the project area in the frequency of overtopping of embankments and dikes. The most extensive flooding due to storms is

found in the coastal areas in the southwest and upstream along Yangon River due to the funneling effect. Further upstream, more towards Nyaungdon where the river profiles become fairly constant, the storm surge effect dampens and consequently the flood frequency and flooding extent due to storms reduce.

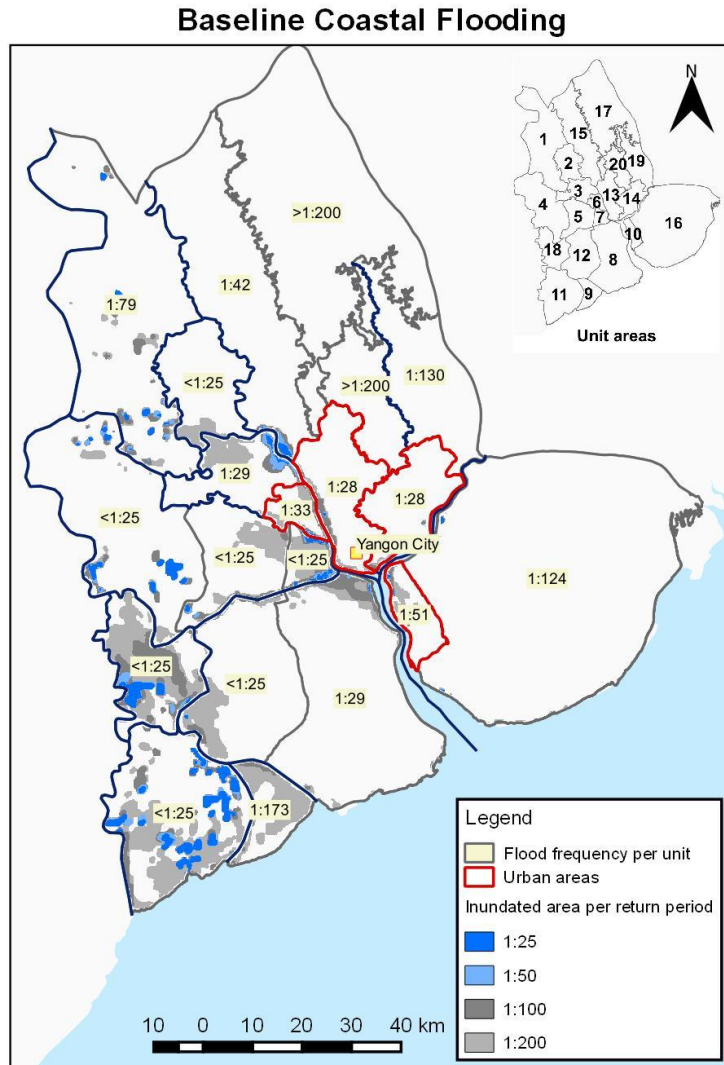


Figure 24: Flooded area and return periods of first flooding by coastal flooding for the unit areas

3.3.4 Fluvial and coastal floods combined

Figure 25 shows the envelope of flood extent and flood frequency when the results of fluvial flooding (Section 3.3.2) and coastal flooding (Section 3.3.3) per unit area are combined. These events are stochastically independent, and a cumulative flood hazard level can be determined by adding the probabilities of flooding due to high river discharges and storms. The map shows that due to the combination the flooding frequencies and flood extent increase.

The flood safety for the unit areas along the Ayeyarwady River and its main branches is determined by the fluvial flood safety. The water safety in the coastal region is governed by the frequency of coastal flooding.

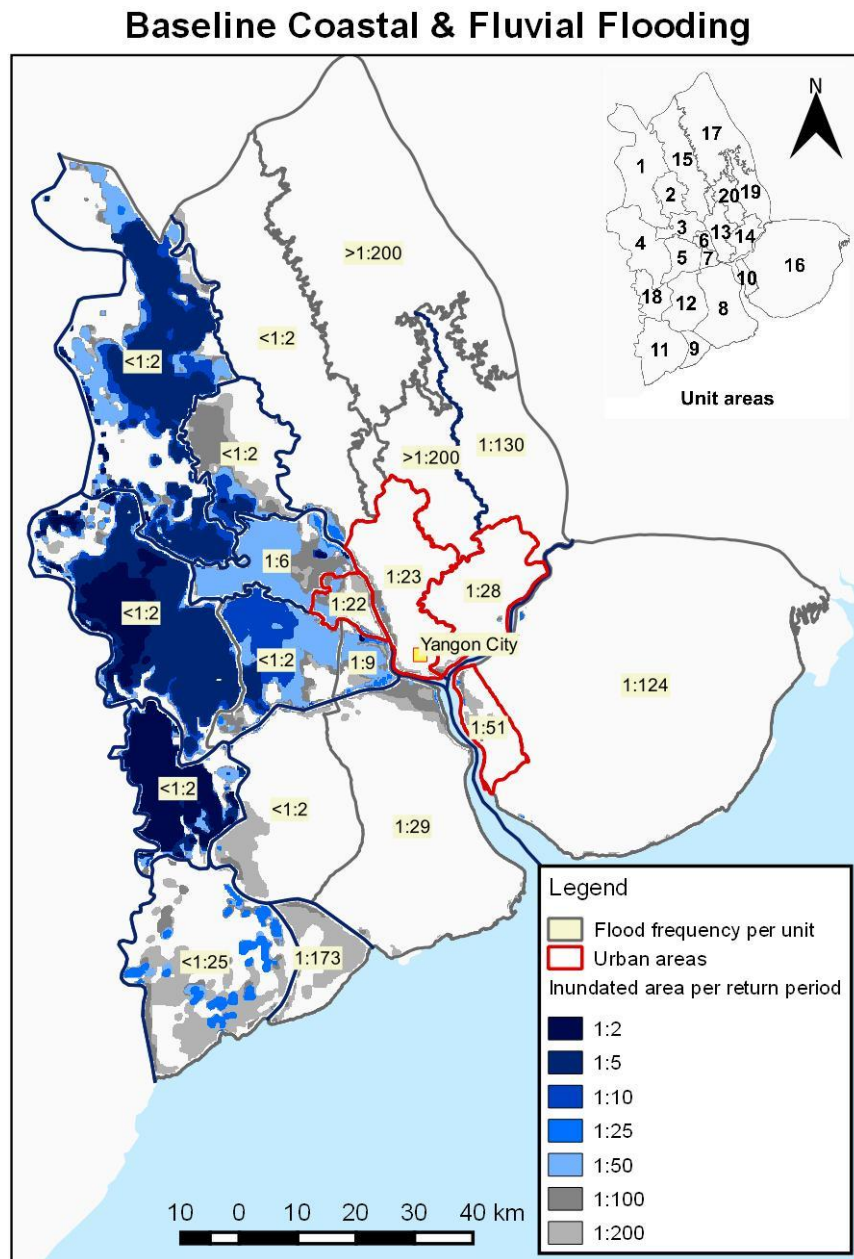


Figure 25: Return periods and maximum flood extent (envelop of fluvial and coastal flooding) taking into account riverine and coastal flooding for the unit areas

3.3.5 Pluvial flooding

When evaluating the model results per unit area using their respective values for the threshold inundation depth, the extent of pluvial inundation can be evaluated for each return period, expressed as a percentage of unit area. The results are collected in *Table 13*.

The following can be observed:

- No significant inundation is calculated during the pluvial event occurring 5 times a year.
- Based on a discussion with the Consultative Group, where different inundation extents were presented, it was agreed that an inundation extent of more than 10% of the respective unit area is expected to limit social and/or economic functioning of an area. Following this criterion, all but unit area 14 still function during a 1 in 2 year event.
- Using the same criterion, Unit areas 5 through 9, 11, 12, 17 and 18 do not experience any problem even during a 1 in 1000 year event. Pluvial flooding is not a water security problem at these locations.
- In contrast, the northern unit areas 1 and 2, as well as the areas more to the east, unit areas 14, 15, 16, 19 and 20, are more sensitive to pluvial flooding. Unit area 10 is also sensitive but to a lesser degree.

Table 13: Percentage of unit area with an inundation above the threshold value per return period (years)

RWSS Unit	0.2	1	2	5	10	25	50	100	250	500	1000
Unit01	0%	1%	6%	8%	10%	14%	17%	19%	22%	23%	25%
Unit02	0%	2%	6%	9%	10%	14%	16%	19%	23%	25%	27%
Unit03	0%	0%	0%	1%	1%	1%	2%	4%	7%	10%	11%
Unit04	0%	0%	1%	3%	3%	5%	6%	8%	11%	13%	15%
Unit05	0%	0%	0%	0%	0%	1%	2%	2%	3%	4%	5%
Unit06	0%	1%	5%	6%	6%	6%	7%	8%	9%	9%	10%
Unit07	0%	0%	1%	1%	1%	2%	3%	4%	5%	6%	5%
Unit08	0%	0%	0%	1%	2%	2%	3%	4%	6%	7%	7%
Unit09	0%	0%	0%	0%	0%	0%	0%	1%	1%	1%	2%
Unit10	0%	3%	6%	8%	8%	10%	10%	10%	11%	12%	13%
Unit11	0%	0%	2%	4%	5%	6%	7%	7%	7%	8%	9%
Unit12	0%	0%	1%	1%	2%	2%	2%	3%	3%	4%	4%
Unit13	0%	3%	7%	10%	10%	11%	13%	13%	14%	15%	15%
Unit14	0%	4%	14%	18%	20%	26%	31%	35%	39%	41%	44%
Unit15	0%	4%	9%	11%	13%	16%	17%	20%	21%	23%	24%
Unit16	0%	1%	10%	14%	18%	21%	23%	26%	29%	30%	31%
Unit17	0%	2%	4%	6%	6%	7%	8%	8%	9%	9%	9%
Unit18	0%	0%	0%	1%	1%	3%	5%	6%	8%	9%	9%
Unit19	0%	2%	8%	15%	18%	24%	28%	32%	36%	38%	40%
Unit20	0%	2%	6%	8%	10%	15%	17%	19%	21%	23%	25%

As a sensitivity analysis, the level of rain induced inundation hazard was computed for multiple criteria for the inundation extent. Figure 26 shows an overview of the computed return periods for pluvial inundation when an extent of 5%, 10% and 20% of the unit area is adopted as the spatial criterion, a spatial visualization of Table 13. It shows that the pluvial flood security level is quite sensitive to the choice of threshold value for area inundated deeper than 0.3 or 0.6 m. Note that, after manually checking simulated inundation patterns using satellite imagery, the hazard level within the (mountainous) unit 17 was manually adjusted to 1 in 200 year event. This appears to be in better accordance with the actual level of pluvial hazards in this unit.

Based on consultations with key stakeholders, it was confirmed that the areas to the northeast of Nyaungdon, Yangon City and the area to the south east of Yangon are particularly sensitive to pluvial

events. Pluvial inundation that limits socio-economic processes are said to occur regularly and in recent memory. This means that, for the level of water security, the 10% extent criterion has been applied.

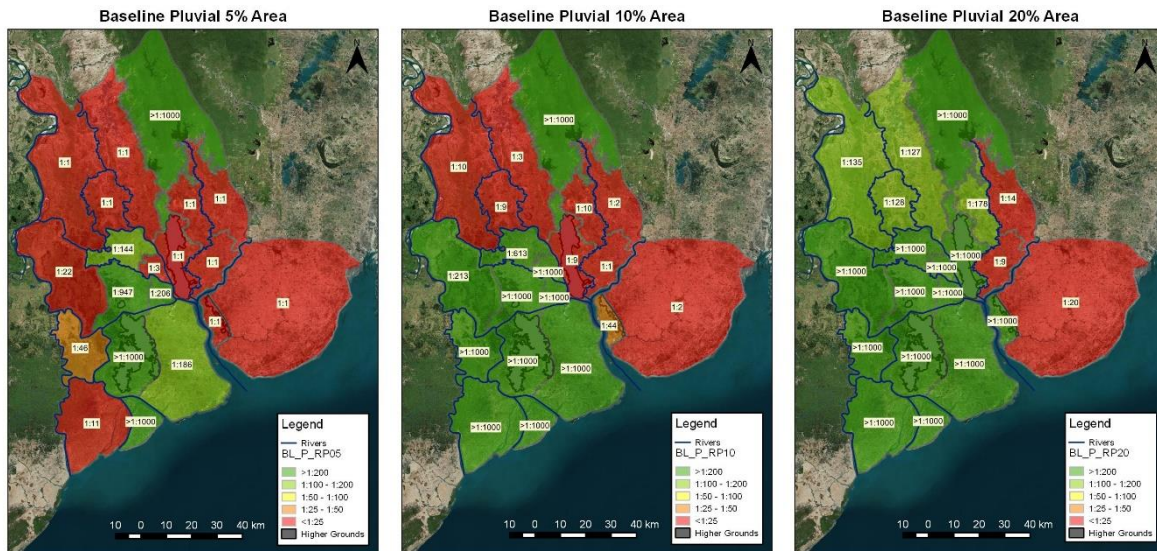


Figure 26: Pluvial flood security level for multiple inundation extent criteria

Finally, the spatial distribution of the pluvial inundation is shown in Figure 27.

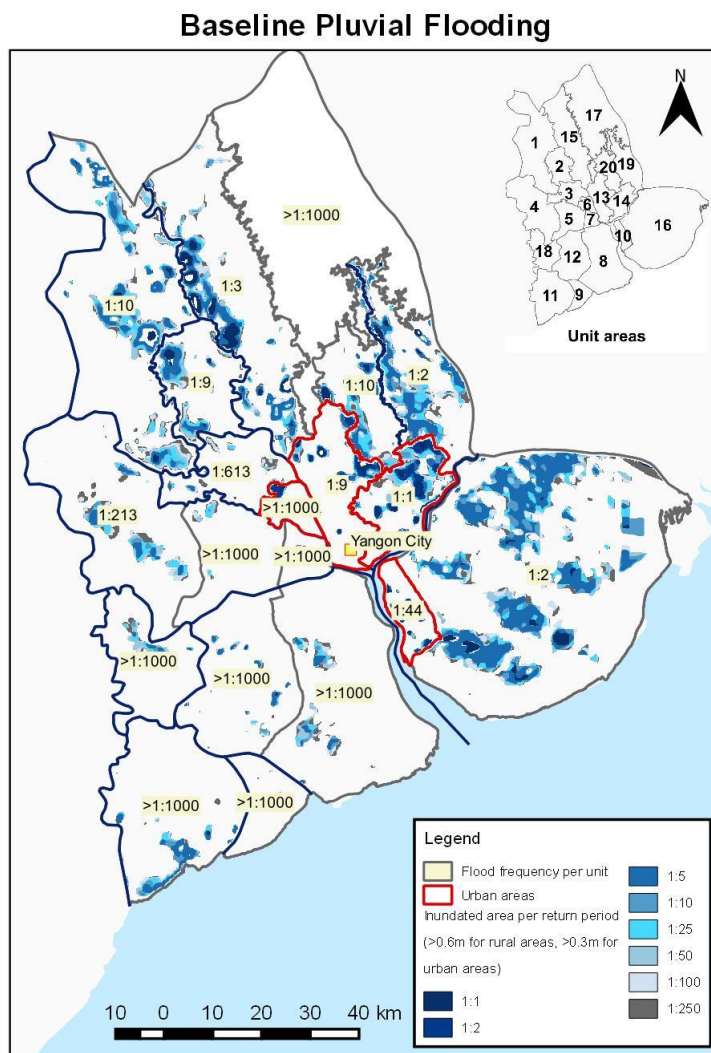


Figure 27: Spatial distribution of pluvial inundation. Pluvial flood security levels based on 10% criterion.

3.3.6 Water scarcity and salt intrusion

To assess the salt intrusion, first, the discharge distribution during a typical low river discharge and peak fresh-water extractions were computed. Table 14 shows the river discharges for a representative low river discharge at Pyay (2,250 m³/s) for a situation without extractions and with peak freshwater extractions (mainly for irrigation purposes). The impact in the relevant river sections is relatively small with a decrease of 30-40 m³/s, roughly 12-16% of the combined extraction discharge in the entire Yangon Region. This small impact is because most extractions are located further downstream and/or more to the west and therefore have negligible impact on the discharge through the river sections considered. The increase at Mezali is a result of the extractions along the Pan Hlaing River. Because this river is closed off by a cofferdam in the east in the model during the dry season, filling of this river can only occur via Mezali Sluice.

Table 14: Tide averaged discharges with and without peak extraction discharges (2,250 m³/s at Pyay)

Location	Discharge [m ³ /s] (no extractions)	Discharge [m ³ /s] (peak extractions)	Difference [m ³ /s]
Pyay (Ayayarwady)	2250	2250	0
Nyaungdon (upstream)	1970	1970	0
Nyaungdon (downstream)	1560	1560	0
Kokkowa (west)	410	410	0
Mezali sluice	0	15	+15
Kokkowa (east)	445	405	-40
Toe River (Maubin)	510	480	-30
Hlaing River	390	360	-30

The salinity intrusion over time was computed with the model including salt, for three discharges at Pyay (750 m³/s, 1250 m³/s and 2250 m³/s). These discharges can be considered as an extremely low, a very low and a mean low discharge, respectively. As the simulations including salt are very time consuming, discharge distributions over the different river branches and canals have been simulated using hydraulic simulations without salt for the 1 in 2, 5, 10, 50, 100, and 200 year low discharge events, including peak freshwater extractions. From the combination of simulation results with and without salt, the intrusion length upstream was assessed along river axes of Toe River and Kokkowa River, as a function of the return period. For interpolation between return periods, a Weibull extreme value distribution fit was applied.

Figure 28 and Figure 29 show the computed position of the salt front (0.5 PSU) at the moment of maximum intrusion as a function of return period for both considered river branches; the Hlaing / Kokkowa River and the Toe River. It is represented with the blue line which is a Weibull fit through the available model results. Note that the model results are valid for fixed return periods. This is because fixed river discharges were forced at Pyay that do not necessarily scale linearly to the discharges in the Kokkowa River and Toe River. It is the effect of a non-linear distribution of river discharge and extractions across the entire Delta. Hence, the three data points in the figures below are the result of identical range of discharges at Pyay (2250, 1250 and 750 m³/s) but correspond to different return periods within their respective river branch. This means that interpolation of model results is possible, but only per individual river branch.

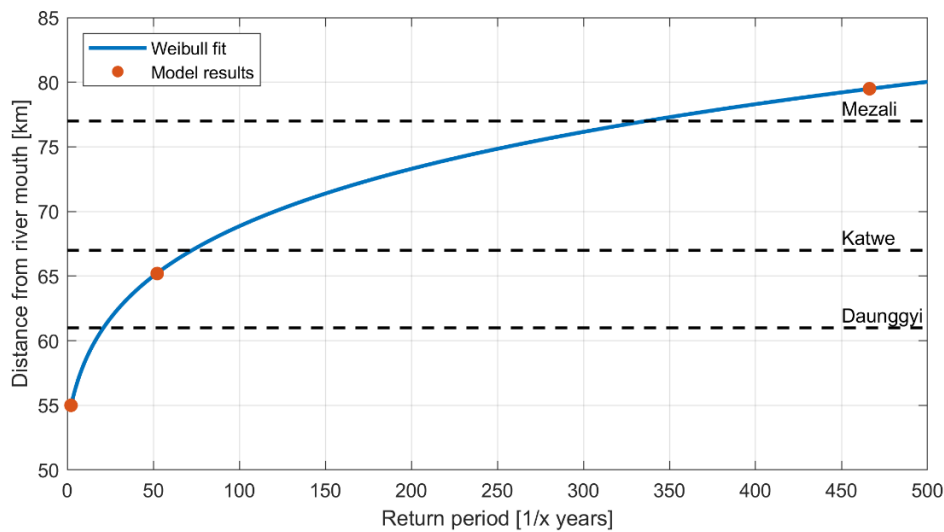


Figure 28: Location of the salt front into the Hlaing River and into Kokkowa River as a function of return period

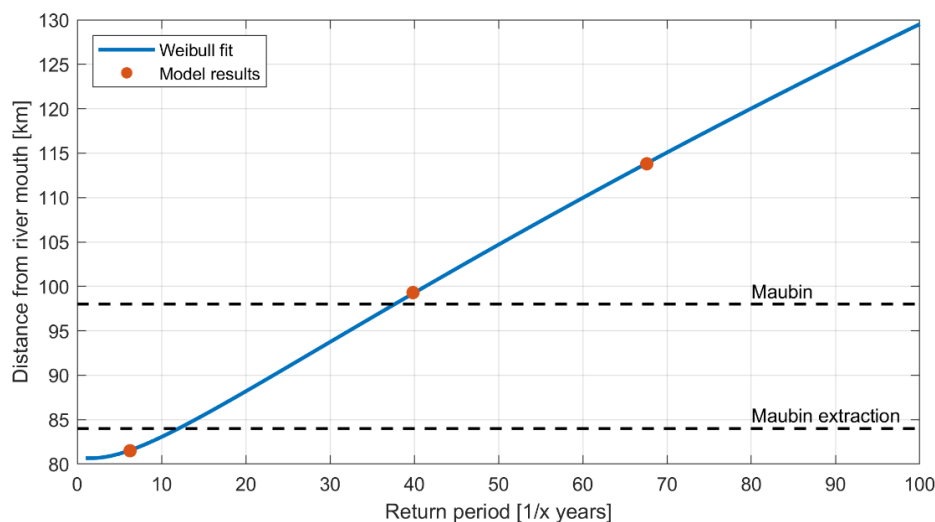


Figure 29: Location of the salt front into the Toe River as a function of return period

Because the Hlaing river mouth is located about 45 kilometer from the sea along the Yangon River, the Figures indicate that, currently, the 1 in 1 year event locations from the sea for both river sections are 55+45=100 and 81 km, respectively. This implies that the salt front reaches these points probably annually, indicating similar or more frequent occurrences for all selected output (key) locations seaward from these points. The reason why the salt front enters the Yangon-Hlaing River further inland than the Toe River is probably because the Toe River discharges more freshwater from the Ayeyarwady River. Another reason is that the Toe River is connected to the Yangon River via the Twante Canal, roughly at km 65, transporting saltwater during flood tide to Yangon River.

The “shape” of the curves in Figure 28 and Figure 29 differs. This is an effect of the differences in shapes of both river mouths / estuaries. The cross-sectional area reduces significantly from Hlaing River into the Kokkowa River, which implies that the further the salt front moves inland, the more effective a freshwater discharge can push it back. For the Toe River, the cross-sectional area is fairly constant, resulting in a more linear fit relation.

The return periods of salt intrusion during dry season at key-locations are shown in Figure 30:

- The key location of the Kokkowa intake (Katwe), roughly 67 km upstream from the Hlaing River mouth, is reached by the saltwater Indicator once per 72 years, on average.
- The key location near Maubin, roughly 84 km upstream from the Toe River mouth, is reached by the saltwater indicator once per 12 years, on average.
- For all other key locations, further downstream, the return period is 1 in 1 year or more frequent (1:1).

The duration of the salt intrusion at a certain location is very difficult to predict and depends on many factors, ranging from the salt front just touching during a phase in tidal cycle to the front actually reaching or passing the location for the complete tidal cycle. The duration of the low upstream flow period is important. In general, the removal of salt requires twice the time of the low flow period in which it first occurred. Example: when upstream flows increase after a one week salinity period, it needs another two weeks to flush the salt, leading to a total of about three weeks of salt intrusion.

Baseline salt intrusion

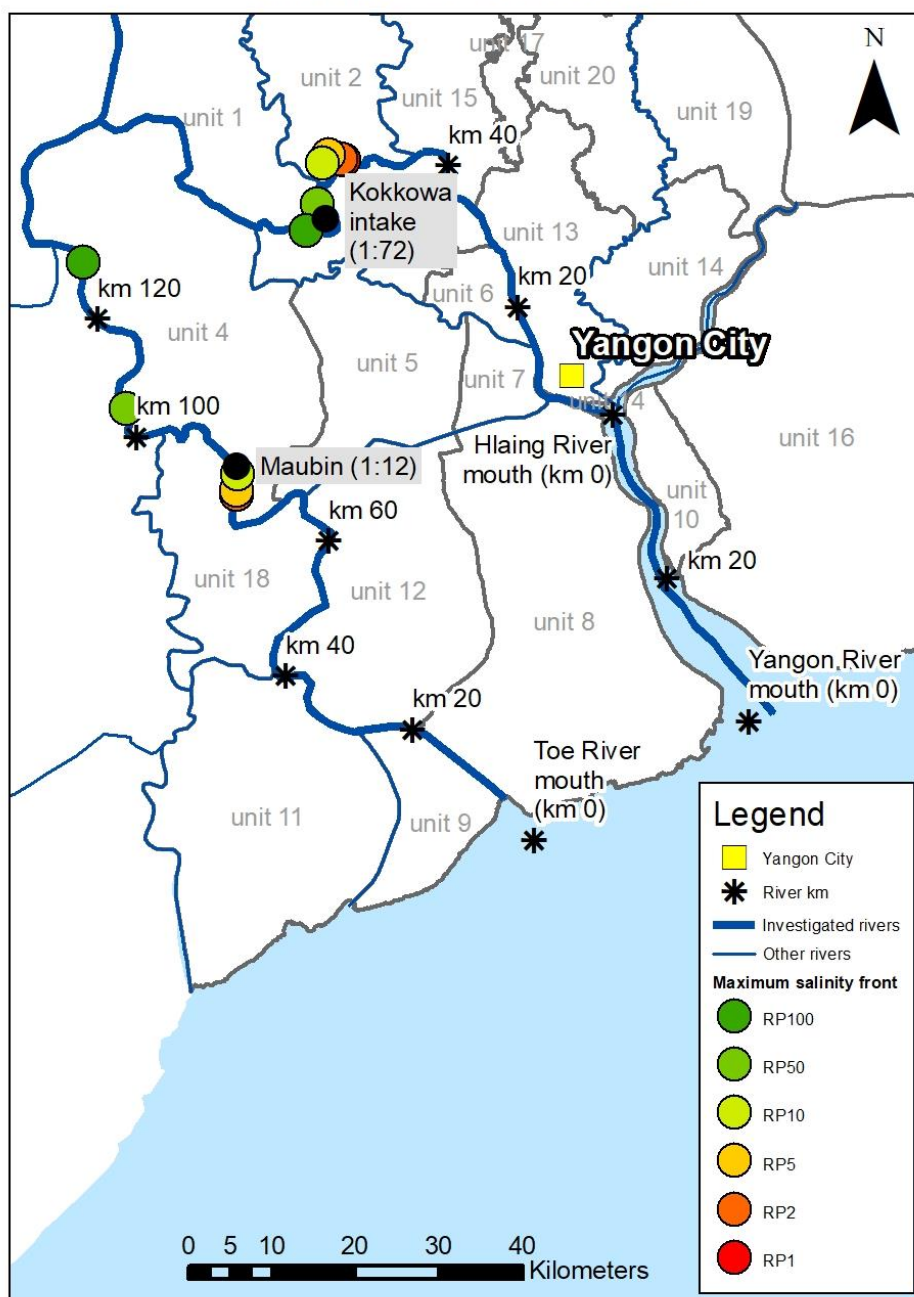


Figure 30: Return periods of salt intrusion during dry season at key-locations

3.3.7 Groundwater quality and availability

The relative importance of groundwater has steadily risen throughout the Ayeyarwady Delta due to population growth, agricultural development, and the pollution of surface waters.

According to fieldwork, the amount of groundwater tube-wells have increased exponentially over the last 20 years. It is estimated that roughly 350,000 tube-wells are now present throughout the Delta (no estimate available for RWSS project area). Most of these are shallow domestic wells (between 30 to 100 meters deep) and are situated in either the Alluvial Geological Formation or the Ayeyarwady Geological Formation. They are privately owned, unregistered and unregulated.

While a national groundwater monitoring system is on its way (Thant Zin, 2017), currently there are no continuous measurements of the hydraulic head throughout the delta. Therefore, interpolations derived from Static Water Level (SWL) and Pumping Water Level (PWL) data found in well-logs provided by the IWUMD, YCDC and DRD, provide a first insight in anthropogenic influence on the groundwater system (Figure 31) (IWUMD, 2020, YCDC, 2020 and DRD, 2020). The data point at an already pronounced decline in hydraulic head in and around Yangon city.

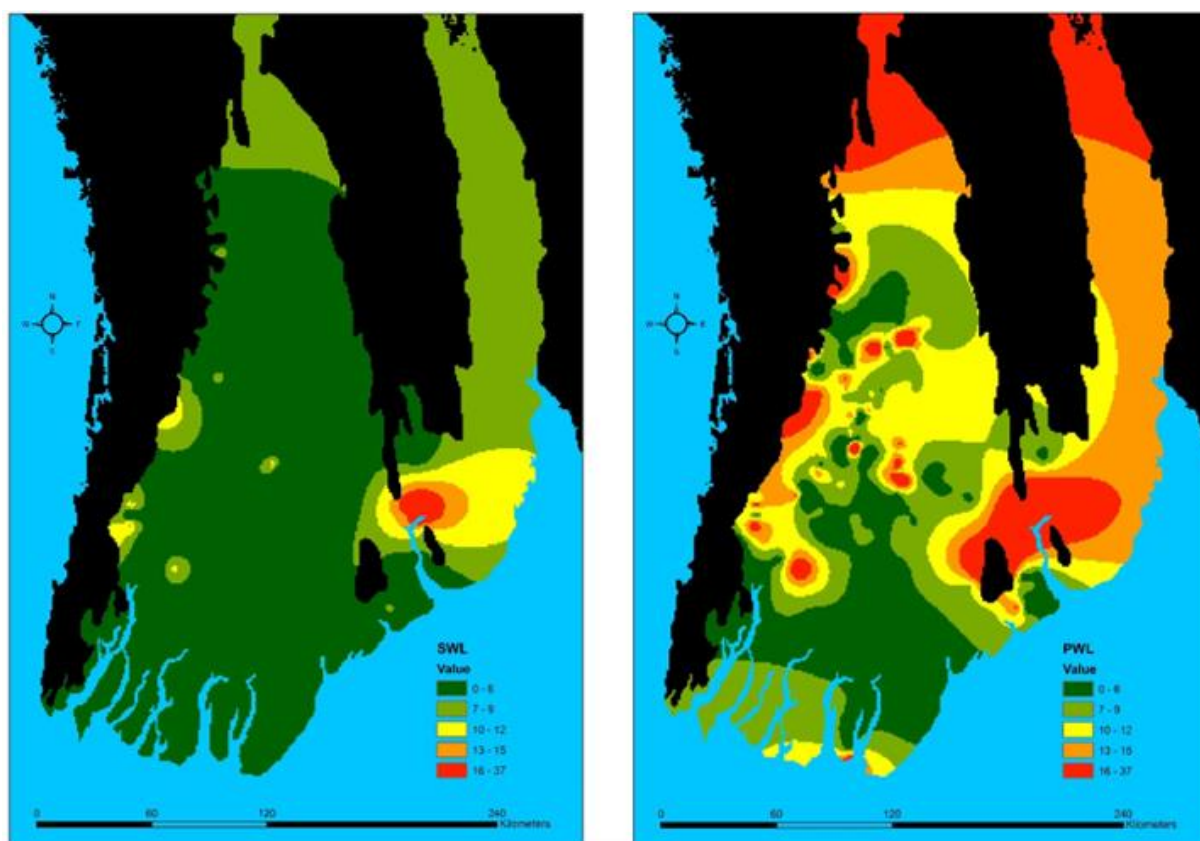


Figure 31: SWL (left), PWL (right) in the delta.

With the notable exception of Yangon, the impact of groundwater extractions has become significant only recently. Extractions are concentrated around cities and near paddy rice exploits that produce a dry season crop. While the general preference for agricultural and domestic water consumption is precipitation/surface waters, a high groundwater dependency has established itself further away from the rivers due to its relative convenience and low costs. It has been reported by multiple parties that it was becoming increasingly difficult to extract sufficient water during dry season, indicating unsustainable use of groundwater resources.

The best quality water is being extracted from the deeper ground layer of the Ayeyarwady Formation, while the quality of the shallower groundwater, in the Alluvial Formation, is highly spatially variable with respect to its arsenic and iron content. Furthermore, saltwater intrusion is known to be an issue, be it poorly understood.

To get insight in the extent of saltwater intrusion a 3D-variable density groundwater modelling study is currently developed at the University of Utrecht. This model is not expected to be operational on short notice and is developed independently from RWSS. Incorporating the effects of relative sea level rise (RSLR) through paleo-reconstructive modelling methods, this model may possibly be useful as a tool to compute future groundwater salinity scenarios. To safeguard valuable and, in some cases, vital groundwater resources it is important to get a better understanding of the effects on the groundwater system in a drying climate, projected sea level rise and the effect of groundwater extractions on both the water table and the groundwater salinity (Goofers, 2020).

3.3.8 Sanity check baseline fluvial flooding

Validation with Google Earth Engine (GEE) (Using Sentinel-1 dataset) took place to do a sanity check of the fluvial flood baseline modelling results. Google Earth Engine can be used only for visualizing the water extent or water occurrence, so the following restrictions are valid:

- The depth of water cannot be defined using this source;
- The images also show the water surfaces that were already present before the inundation event, so existing ponds and paddy fields are also reported as inundated areas;
- Inundation caused by rain (pluvial flooding) and inundation from the river (fluvial flooding) cannot be discerned; and
- Data quality of Sentinel 1 depends on several factors such as its frequency and polarization, which are unknown. Sentinel-1 dataset shows the interpretation of surface water with a horizontal resolution of up to 10 x 10 m; the modelling results are on coarser grid.

Identification of eligible events

From the measured river discharge data at Pyay, peak discharges from separate 'extreme years' are obtained. The right-most column in *Table 15* shows the estimated return period of these events based on the statistical analysis using the complete timeseries at Pyay (see Appendix B).

Table 15: Peak discharges at Pyay at extreme years and Return Periods (1 in X year) used

Extreme event	Peak discharge at Pyay	Comparable to
1997-09-09	47263 m ³ /s	RP 10
2004-08-01	47697 m ³ /s	RP 10
2007-09-22	44313 m ³ /s	RP 05
2015-08-06	47483 m ³ /s	RP 10

As Sentinel-1 data is available starting from October 2014, only the event in the year 2015 could be used to validate with existing satellite images. This event has a return period of 1 in 10 years. The list of dates used to validate for the extreme month of August 2015 are shown in the table below.

Table 16: Used GEE Satellite maps at those dates

Dates of available satellite images in August 2015 for RWSS area
2015-08-11
2015-08-15
2015-08-23

The peak of the extreme discharge event occurred 6th August in 2015 according to measured data. Interpretations of inundated area from GEE with its available Sentinel data shows 11th August has the most inundated areas. By comparing modelled inundation maps with the satellite images, a comparison per Unit Area is made. Note that the model results are generated specifically at peak flooding. Satellite imagery is a snapshot (fixed moment in time) and not necessarily the correct moment in time. Some unit areas might still be before their peak inundation, some areas might have already drained a bit (this will differ per unit area).

Comparison of calculated and monitored inundation maps

The maps below show the differences between the modelling and satellite results for fluvial flooding baseline assessment for RWSS project area.

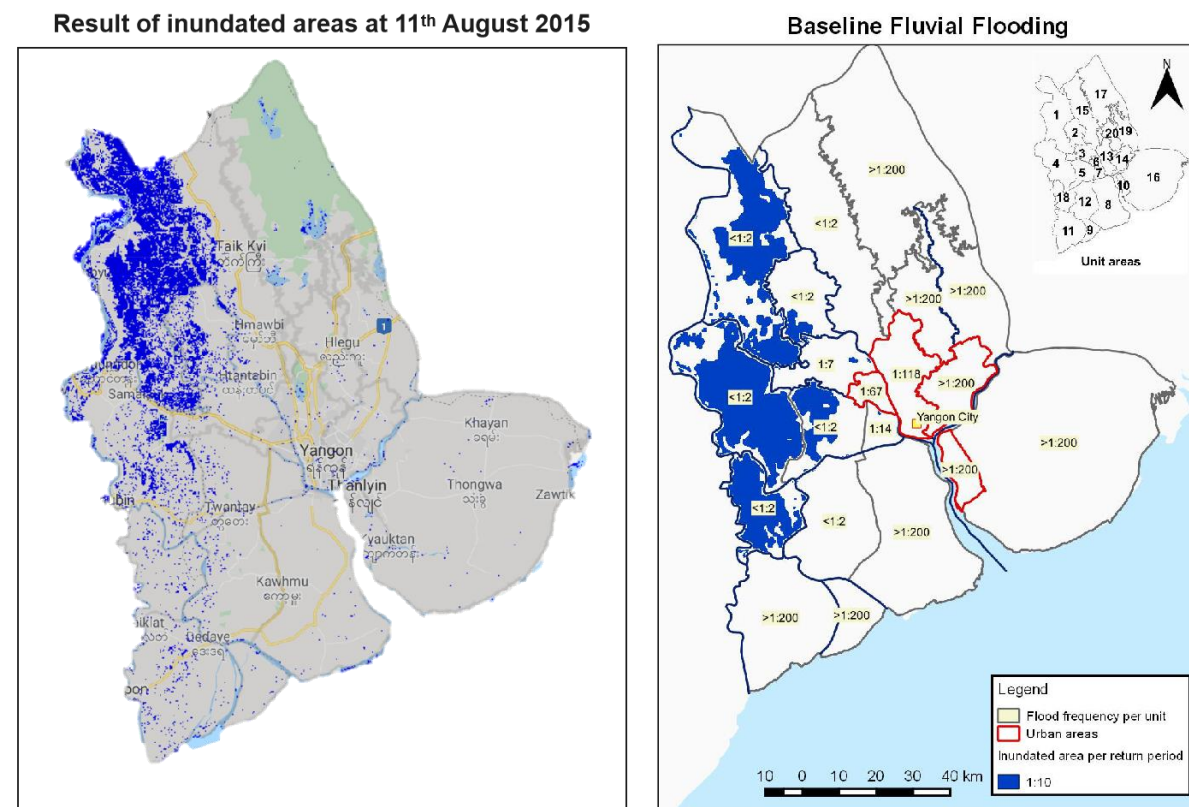


Figure 32: Comparison of modelling results and satellite maps for extreme fluvial flooding events for RWSS project area (1 in 10 year event)

In general, the inundation maps for this 1 in 10 year event show similarities as well as differences. Unit areas 2, 11, and in particular 15 and 18 have the most differences while the other unit areas have much similarities in calculated and observed inundated land surfaces. Differences may be caused by drainage in the five days between peak discharge and satellite image. Generally, the units where differences in flooding are observed the simulated flooding is not very deep.

Yangon South – unit areas 8 and 12

The maps below show the differences between the satellite results (left panel) and the simulated fluvial flooding for a comparable event (right panel) for sub-area Yangon South.

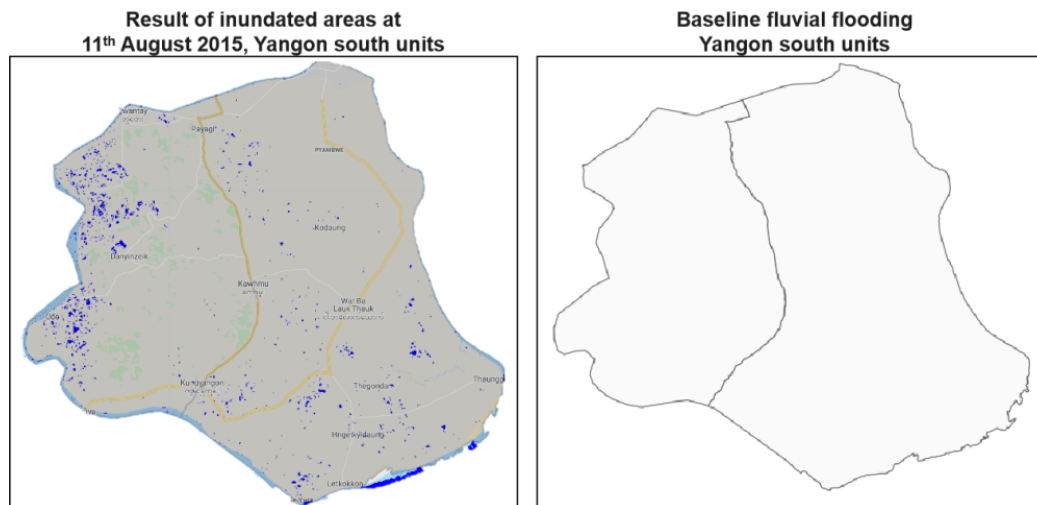


Figure 33: Comparison of modelling results and satellite maps for extreme fluvial flooding events for Yangon South

From both sources it can be observed that fluvial inundation during this simulated 1 in 10 year event is minimal. However, apart from the river profile, the GEE results show sparsely spread spots of inundation in the western half of unit 12 and unit 08. This pattern coincides with low lying areas within these units and its very likely that these small inundations are the result of existing (fish) ponds / paddy fields or additional rainfall accumulation at the time of the considered rainfall event as GEE makes no distinction between the two based on the Sentinel-1 dataset.

Nyaungdon / Pan Hlaing Island – unit areas 3 to 7

The maps below show the differences between the satellite results (left panel) and the simulated fluvial flooding for a comparable event (right panel) for sub-area Nyaungdon / Pan Hlaing Island.

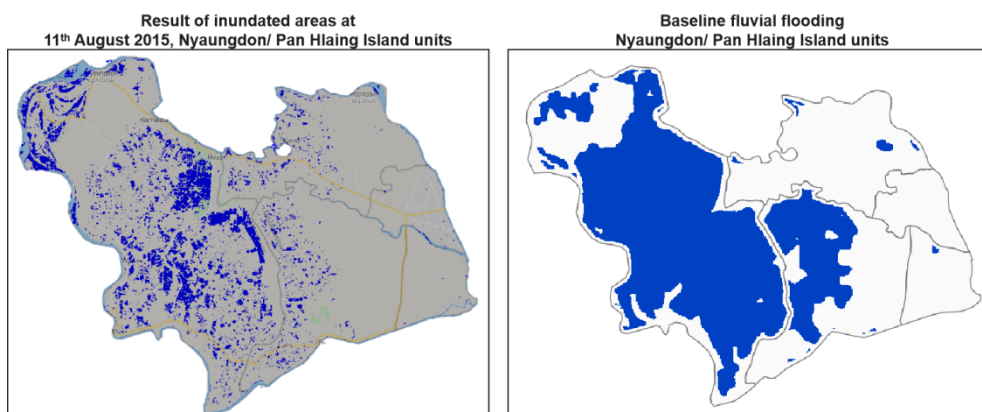


Figure 34: Comparison of modelling results and satellite maps for extreme fluvial flooding events for Nyaungdon / Pan Hlaing Island

Looking at the general inundation pattern, the GEE results and the model results are similar:

- Unit 4 is most impacted by fluvial flooding for most of the unit area, except for a small area in the north.
- Unit 5 is the second most impacted unit, but not necessarily by flooding of its dikes, but by inundation from inland via Unit 4.

- Unit 3 is not impacted as much and shows only minor inundation. According to the model, the source of this inundation is from the Kokkowa River.
- Units 6 and 7 show little to no inundated areas.

The main difference is the detailed spreading of the inundated spots of land. The GEE results show separated inundation areas whereas the model results suggest compact inundated areas. This can be explained as follows:

- The detail of the GEE results is 10 m x 10 m, whereas the modelling result is roughly 1000 x 1000 m. This not only impacts the spatial detail of the results, but also the spatial detail of the underlying topography.
- It is not clear what the minimal water depth and extent is of inundation within the Sentinel-1 dataset before the GEE indicates the surface as being flooded. It could be that the interpretation methodology of the inundation adopted in the RWSS is more sensitive relative to the GEE methodology resulting in larger (compact) areas of inundation.
- The moment of peak inundation and satellite snapshot probably do not coincide exactly. The snapshot is dated 5 days after the peak discharge. It is likely that some flooding has already been drained at the moment of the snapshot.

Unit areas 15 and 18

The maps below show the differences between the satellite results (left panels) and the simulated fluvial flooding for a comparable event (right panels) for unit areas 15 and 18.

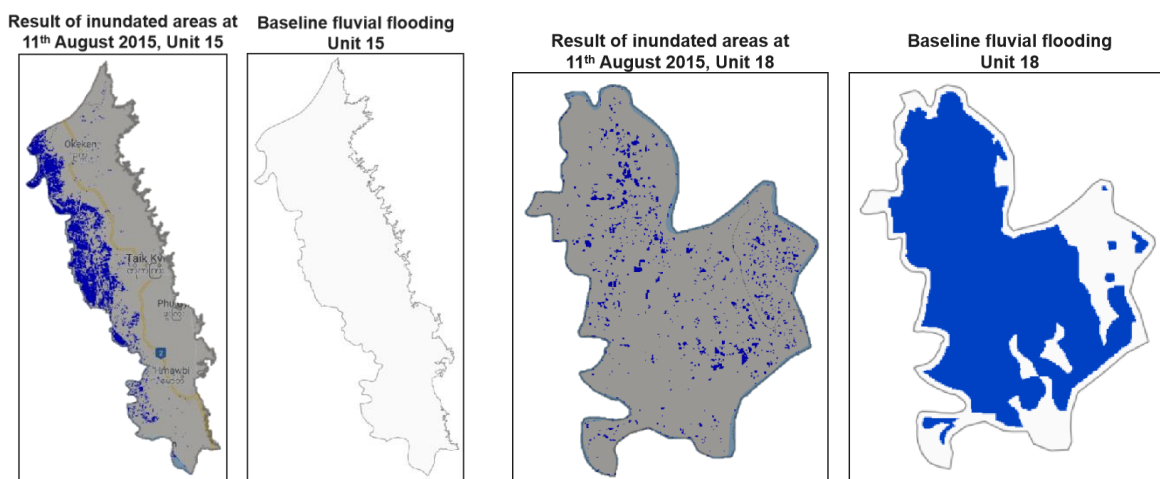


Figure 35: Comparison of modelling results and satellite maps for extreme fluvial flooding events for Unit 15 and 18

Within Unit 15, the RWSS model results show no inundation. However, GEE shows substantial inundation in the northwestern part of the area, adjacent to the Upper Hlaing River. The absence of simulated flooding in this unit is the result of underestimation of discharge in Upper Hlaing River relative to the real-time event (as described in the RWSS (IADS-B) report. Currently, no (additional) rainfall during the simulated event is simulated as the model only considers the fluvial event. It is likely that the actual event in August 2015 had a local pluvial component as well. Upper Hlaing can be pluvial dominated as it is fed directly by part of the upstream catchment area. As a result, the local river discharge and water level is underestimated in the model and no flooding occurs. In case of additional simulated discharge in the river (e.g. by looking at the 1 in 50 year event), the model result does show inundation in the area where the GEE results show this as well.

For Unit 18, the RWSS model results show continuous inundation for the most part of Unit 18. Conversely, the GEE result shows only local inundation areas, likely indicating inundation from a pluvial source instead. When looking at the flooding pattern in time as produced by the RWSS model, this Unit is shown to flood from the west where no detailed data is currently available on the dike heights as it

falls outside of the RWSS focus area. It is likely that the local dike heights in the west are underestimated (based on coarse SRTM data by lack of detailed information). Looking at the computed flooding safety for the section of the dike ring that is considered within the RWSS study area using more detailed data, a fluvial safety level of >return period of 1 in 10 year is computed, which is in agreement with the GEE results.

Conclusion

Looking at the degree of similarity and taking the above remarks into consideration when looking at the differences, the comparison of the inundation patterns gives confidence in the modelled results. However, it also points at some of the shortcomings of the model at this stage.

3.4 Baseline description sub-areas

Although the study analyses the Greater Yangon area, the Terms of Reference of the project defines the project area as the area West and South West of Yangon Municipality and is bordered by the Pan Hlaing River and Kokkowa River in the North, the Hlaing River and Yangon River in the East, the Andaman Sea and Gulf of Martaban in the South, and the Toe River in the West. This area comprising the sub-areas Yangon South (west of Yangon River), Nyaungdon Island and Pan Hlaing Island is further referred to as the focus area.

The below description is based on desk studies, stakeholder workshops and small-scale consultations in some of the townships.

Sub-area Yangon South

Sub-area Yangon South, focusing on the west side of Yangon River, consists of unit area 8 and unit area 12 as indicated on the map below. The townships in unit 8 and 12 are Twante, Dala, Kawhmu and Kungyangon, of which Dala is under management of YCDC as the others are managed by the municipal authority in Yangon Region Government. Unit area 8 is a rainfed agricultural area enclosed between Yangon River and Twante Canal. This unit area is relatively low-lying compared to some higher grounds in unit area 12.

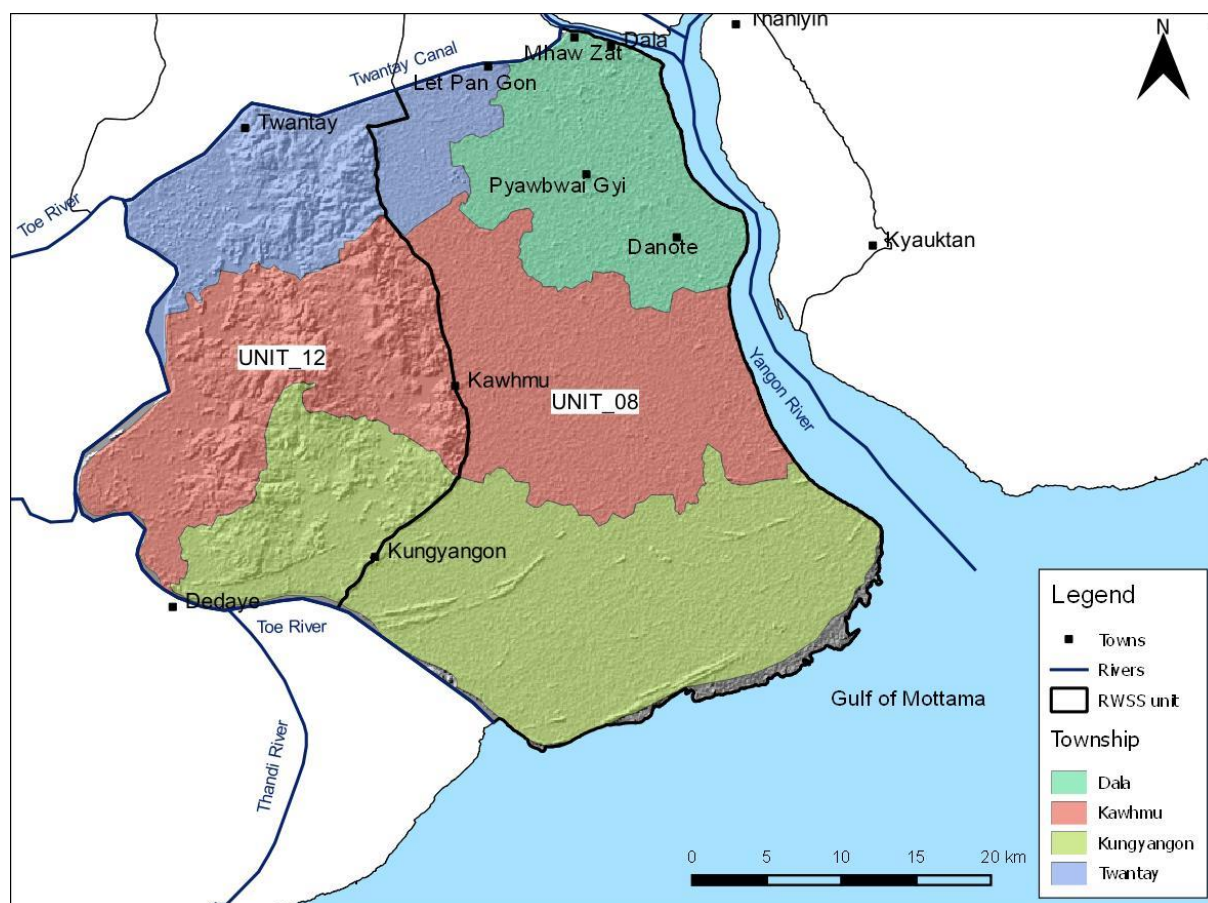


Figure 36: Townships and consulted villages Yangon South

The figure below shows the water infrastructure in Yangon South. Clearly visible are the many canals and outlets that connect the land with the surrounding main rivers. From interviews with local people and field surveys done by the project team, it appears that most of these canals are effectively interconnected. However, it is likely that due to poor maintenance, the interconnectivity and discharge

capacity of some canals have been lost. To be certain about this, a dedicated local field inspection would be needed, which was not included in this project.

There are some open connections with Yangon River found in Dala and paddy fields are mostly spotted near that area. Although salt intrusion may be an issue due to the open connection, the impact of salt or brackish water intrusion is not obvious from field inspections.

The area is protected by embankments and (natural) higher areas. Within the area, a vast system of natural and manmade canals stores freshwater during the dry season and drains the water during the wet season. In unit area 12, the rainfall flows from the elevated areas into the channels. Surface water lakes are used as shared rainwater harvesting system in Dala and Twante, but this rainwater harvesting is often not sufficient for the full dry season.

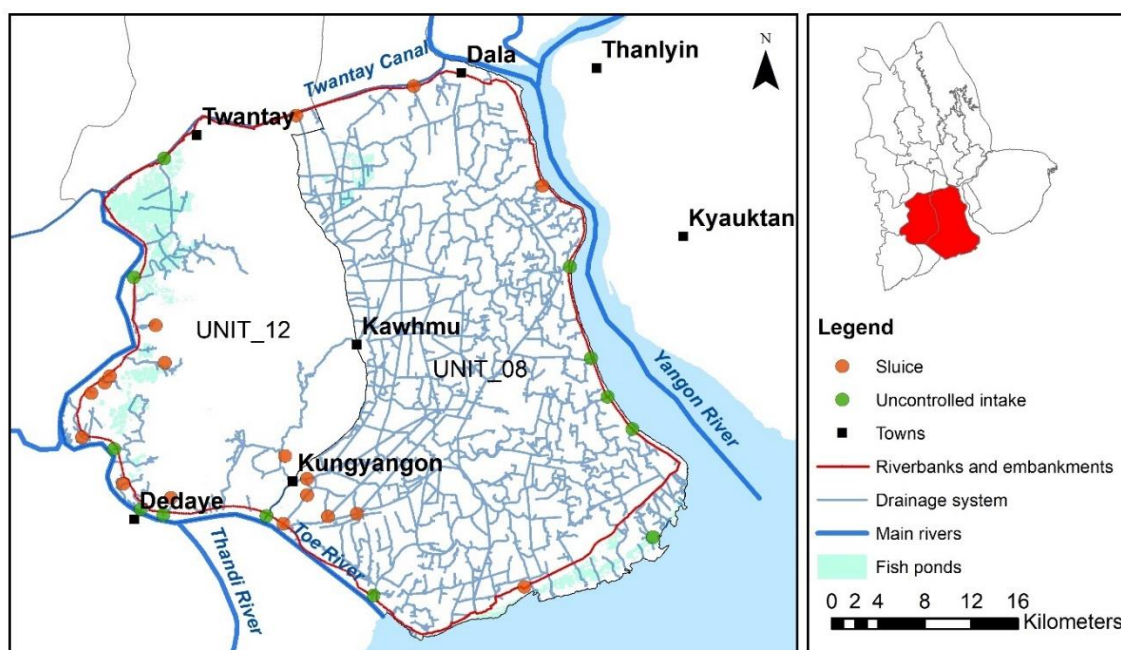


Figure 37: Water infrastructure in Yangon South

Unit 8 is facing pluvial flooding every rainy season (see also Figure 27). The floods result in damages for most of the farmlands in the area. Based on the community sessions (25 July 2019) for RWSS (IADS-B), Danote village is expected to have the highest risk for flooding in Dala Township. Pyawbwal Gyi village and Mhaw Zat quarter in Dala township experienced water scarcity and salinity intrusion. River water cannot be used for domestic and drinking water purposes due to salinity. Unit 12 is an irrigated agricultural area with fishponds enclosed between Toe River and Twante Canal as indicated on the map below (Figure 36). According to community consultations, this unit is facing flooding and saltwater intrusion affecting irrigation.

Also, much aquaculture activities take place in Yangon Region. Fishponds are mainly located around in Twante Township and partly in Kawhmu and Htanbin, while shrimp farms can be found in Kungyangon, using saline water. The estimated number of fishponds and shrimp ponds in each township is shown in Table 17.

Table 17: Aquaculture areas in Townships in Yangon Region in 2018

Township	Fishponds		Shrimp ponds	
	no. of ponds	acre	no. of ponds	acre
Twante	3.692	34.198	136	632
Kungyangon	10	27	192	3.231
Kawhmu	258	3.562	1	1
Dala	0	0	0	0
Htantabin	989	10.740	64	510

The area of Kungyangon and Kawhmu is regulated by several sluice gates along the southern part of Toe river which is affected by saline intrusion. Those sluices close completely mid dry season to prevent saline water flowing into the area. Irrigation takes place by means of pumping water from the canals and creeks. In Dala township, a small amount of irrigation water is being subtracted from the Twante Canal. No aquaculture or irrigation takes places in the south-eastern part of Kungyangon and Kawhmu, as no freshwater inlets are available due to salinity.

The higher ground area in Unit 12 is characterized by lateritic soils and large patches of permanent forest cover as well as occasional rubber plantations. Little to no other agriculture takes place in this part of the sub-area. Water scarcity and salt intrusion are considered serious water security challenges in this area.

A summary of findings from field observations and consultations of local people resulted in the following characteristics per township:

- Dala Township is located in the north of this sub-area. Largely rural area with farmlands, due to its location on the south side of the Yangon River and (yet) lack of a bridge to downtown Yangon. Water related issues such as water scarcity and salt intrusion to the groundwater are common in most parts of Dala Township. There are 332 rainwater collecting surface lakes for domestic use and drinking water. However, the township is still facing water scarcity every year. Groundwater is evidently saline and polluted. While visiting the area, communities mentioned the color and the smell indicating the bad groundwater quality. Some people use groundwater, but most people rely on other sources such as water ponds. Some villages in the township face flooding in the rainy season. Although there are no substantial losses due to flooding and salt intrusion, many minor damages can be observed in private houses and paddy fields.
- Twante Township is located at the waterfront nearby the Twante Canal. This 22-mile (35 km) canal is intensively used as a shortcut waterway to the Ayeyarwady River from Yangon River. The main business in the villages of Twante Township is agriculture (paddies). The dominant soil type in Twante is Nitisol rather than Gleysols that occur in much of the surrounding townships, making them somewhat more suitable for aquaculture. Twante Township has an irrigation system. Some places in the township have suffered water scarcity during dry season. Most of the people in this township are using groundwater for domestic purposes. In the IADS-B report (2019) surface water ponds are used as shared rainwater harvesting systems in Dala, Twante and Hlaing Thar Yar townships but the surface ponds do not meet the demands for sufficient clean water in the dry season.
- Kawhmu Township is in the south and about 40 km from Dala Township. It is one of the townships in Yangon Region that was strongly affected by Cyclone Nargis in 2008 with catastrophic destruction and many people losing their homes and heritages.
- Kungyangon Township is in the southern part near to the coast. Saline water aquaculture and salt evaporation ponds are in this area. According to the consultation in 2019, drainage takes place to the Yangon River or directly into the sea. Consequently, no irrigated agriculture or freshwater aquaculture takes place in this township.

Some socio-economic information for each township is based on Township Profiles (GAD, 2018). In Yangon South (West) Area, the population in the townships varies between 120,000 and 250,000 and the literacy rate for aged 15 and over are 100%. The employment rate is mostly similar for each township, between 95 and 97%, while the GDP per capita in Twante Township is the highest among in region as shown in the figures below.

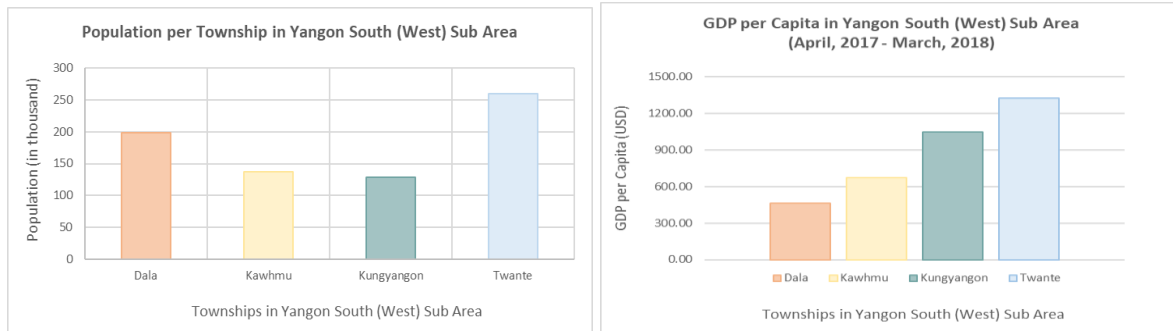


Figure 38: Population per township in Yangon South (West) sub area and Figure 39 GDP per Capita in Yangon South (West) Sub area

Sub-areas Nyaungdon Island and Pan Hlaing Island

Units 3, 4, 5, 6 and 7 are located in the sub-area Nyaungdon Island and Pan Hlaing Island as indicated in the map below.

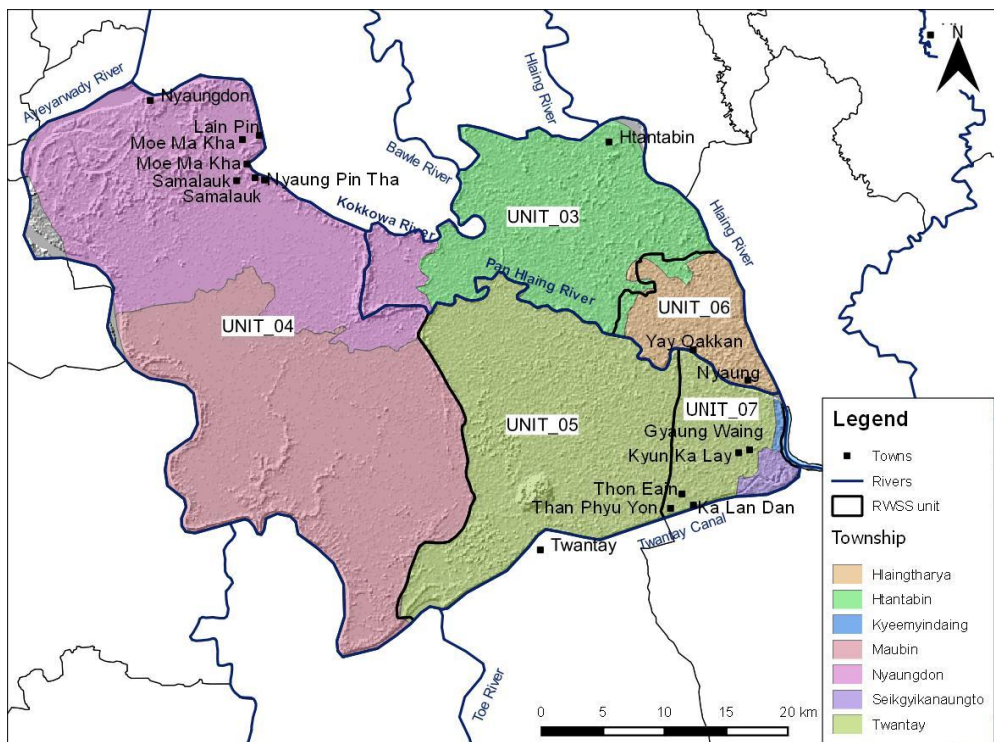


Figure 40: Townships and consulted villages in Nyaungdon and Pan Hlaing Island

Unit 3 is an irrigated agricultural area located between Pan Hlaing and Hlaing rivers. The township in unit 3 is Htantabin which is managed by the municipal authority in Yangon Region Government.

Unit 4 is also an irrigated agricultural area with fishponds where Kokkowa River runs north of the area, Ayeyarwady River is in the west and Toe River is in the south. The townships in unit 4 are Maubin and Nyaungdon which are managed by the municipal authority in Yangon Region Government. Based on consultations in 2019, the people in this unit are not mentioning problems with salinity intrusion. Samalauk village in Nyaungdon township (unit 4) is facing riverbank erosion and limited water supply in the dry season. In Nyaungdon township (Lain Pin, Moe Ma Kha, Samalauk and Nyaung Pin Tha

villages) encounter flooding and Moe Ma Kha fields and Samalauk fields encounter water scarcity (RWSS field visit, 2019).

Unit 5 is an irrigated agricultural area with fishponds situated between Pan Hlaing River and Twante Canal. This unit has some higher grounds. The townships Seikkyi Khanaungto, Kyeemyindaing are under management of YCDC and Twante Township is under control of Yangon Region Government.

Unit 6 is located in Hlaing Thar Yar Township near the bifurcation of Yangon River into Pan Hlaing River and Hlaing River. Hlaing Thar Yar Township is a residential and industrial area which is under management of YCDC. This unit is facing salt intrusion which is also affecting their groundwater sources. The regular water scarcity problems cannot be solved by rainwater harvesting or water donation at this moment according to the people living in the area. Furthermore, pluvial flooding is happening regularly in this unit due to blocked and lack of drainage systems. Kyun Ka Lay village and Gyaung Waing village in Twante Township are encountering water scarcity problems whereas Thon Ein, Ka Lan Dan, Than Phyu Yone and Let Pan Gon have irrigation water also during dry season.

Unit 7 is a rainfed agricultural area enclosing between Yangon River in the east, Pan Hlaing River in the north and Twante Canal in the south. The townships in unit 7 are Seikkyi Khanaungto and Twante, under management of YCDC.

The figure below provides an overview of the water related infrastructure in Nyaungdon and Pan Hlaing Island. In unit areas 4 and 5, aquaculture is mainly taking place on the lower lying lands. Both islands are surrounded by embankments for flood protection. However, in the southern part some open channels are located between the main rivers and the hinterlands (indicated in green). Pan Hlaing River functions as drainage channel during rainy season, but it is also used for irrigation. The system is controlled by the Mezali (2) sluice at the bifurcation with the Kokkowa River. Every three years the channel surrounding Mezali (2) sluices requires dredging to provide sufficient drainage capacity (RWSS field visit, 2020). Pan Daing sluice is used for irrigation in Hlaing Thar Yar and Htanbin townships in unit 3 (reference: Engineering Team Field Trip RWSS report on Mar 10, 2020, A10)

Wadaw sluice has been constructed in unit 4 (south-west) servicing Nyangdonkyun, Maubin township and parts of Ayeyarwady Region (a total of 15,000 acres of land). The sluice prevents Khanaunggyi from flooding during rainy season and will supply water to grow crops in the dry season (RWSS field visit, 2020).

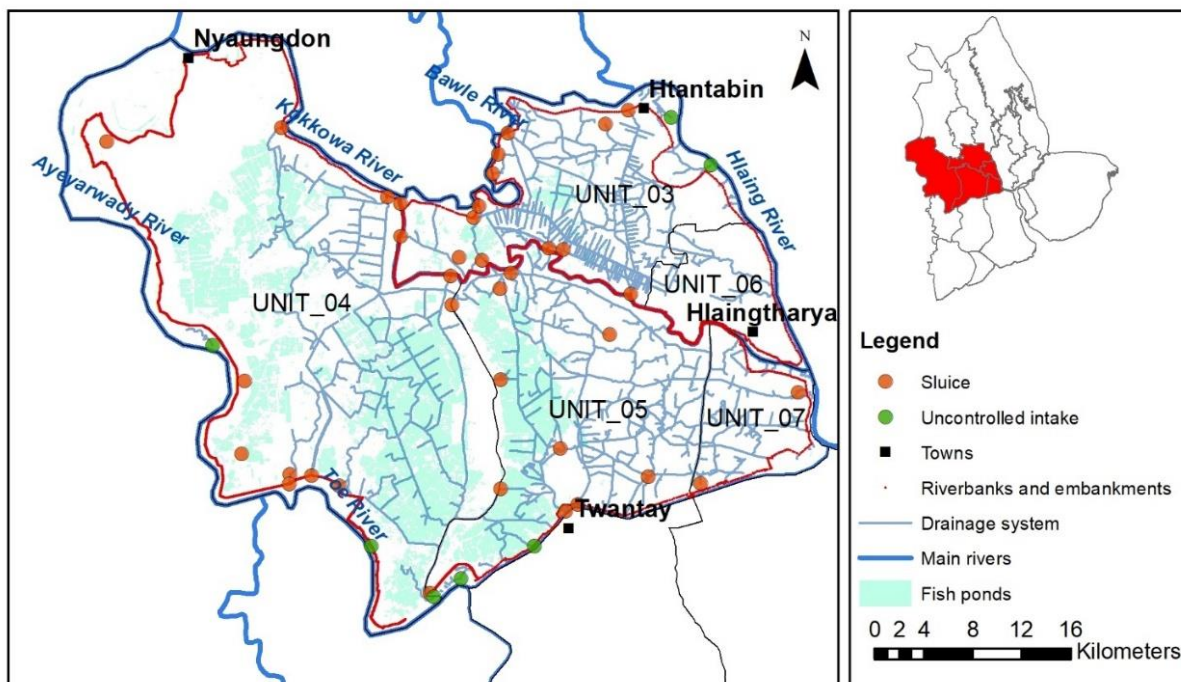


Figure 41: Water infrastructure in Nyaungdon and Pan Hlaing Island

The main source of income in this area is agriculture. In the dry season, irrigation water is pumped from the canals and creeks to the fields. Only in Hlaing Thar Yar Township the main source of income is the industries.

- Hlaing Thar Yar Township is densely populated and nearby central industrial zones with many industrial workers living there. Domestic water use is very large in this area. Water scarcity in Hlaing Thar Yar is challenging because the ground water is saline. Therefore, many people harvest rainwater with ponds for domestic use and they buy water bottles for drinking. Although they have rainwater harvesting ponds, it is not meeting the demands in the dry season. Therefore, the municipality always provides water to some villages at the end of the dry season by using trucks.
- Htantabin Township is a mix of urban and agriculture, the site of the University of West Yangon and a coal fired power plant.
- Seikkyi Kanaungto is largely rural due to its location on the south-west side of the Yangon River and the lack of a connection (e.g. a bridge) to downtown.
- Twante Township is located in both Pan Hlaing/Nyaungdon Island and Yangon South Region. Details about Twante Township could be found under Yangon South (West), as the township is located on the border of both sub-areas.
- Maubin Township has aquaculture as its main practice in large parts of the township. The dominant soil type is Nitosol rather than Gleysols that occur in much of the surrounding regions, making them allegedly more suitable for aquaculture.
- Nyaungdon Township is located in Ayeyarwady Region where agriculture is the main business and aquaculture development such as fishponds are also present. The riverbanks of Nyaungdon are prone to bank erosion.

Since Hlaing Thar Yar is an industrial zone city, the population density there is significantly higher than other townships in Nyaungdon/Pan Hlaing Area. The difference between the employment rate in this area is however marginal. Hlaing Thar Yar leads the amount of Gross Domestic Product (GDP) per capita in the region as shown in the figures below. These official figures, however, do not include the inhabitants of unofficial settlements and slums. The literacy rate of the local people who are above 15 years old in Maubin is around 98% while of the other townships in region is 100% (GAD, 2018).

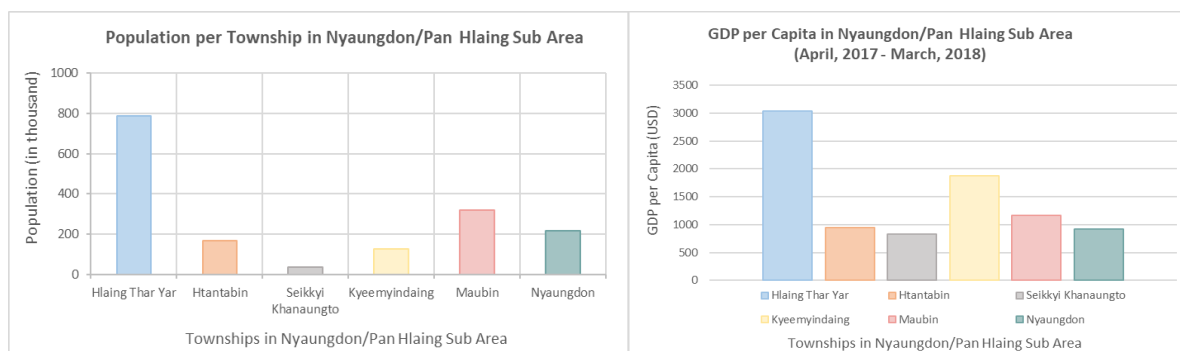


Figure 42: Population per township in Nyaungdon/Pan Hlaing sub area and Figure 43 GDP per Capita in Nyaungdon and Pan Hlaing sub area

3.5 Summary baseline situation

From the assessment of the flood and freshwater security hazards (Figure 44), it becomes clear that many parts of the Yangon Region face multiple risks. Only the hilly unit area 17 is safe from all analyzed hazards.

The calculated inundation induced by an extreme coastal (Nargis, combined with rainfall) and riverine (1 in 10 year event; August 2015) event, have been compared with observed inundation maps. There are good similarities between both, and the differences can be explained, which gives sufficient trust in the validity of the computed flooding patterns.

Due to the relatively low embankments, the western part of the project area is most vulnerable for coastal and fluvial floods. Nyaungdon / Pan Hlaing Island and north of this area (unit area 1, 2, 3, 4, 5, 6, 7) and south of the sub-area (unit 18 west of Yangon City), are most vulnerable to fluvial floods. In the most affected areas along the Ayeyarwady River annual or bi-annual flooding is the norm and very large areas are regularly inundated. Many of these areas have functioned as natural flooding or retention areas during high water levels and are traditionally used to inundation in the wet season. The fluvial flooding becomes less frequent going east and is reduced to less than 1 in 200 year event east of the Hlaing and Yangon Rivers except from isolated pockets that are still flooded more frequently. Also, the coastal units are less prone to fluvial flooding.

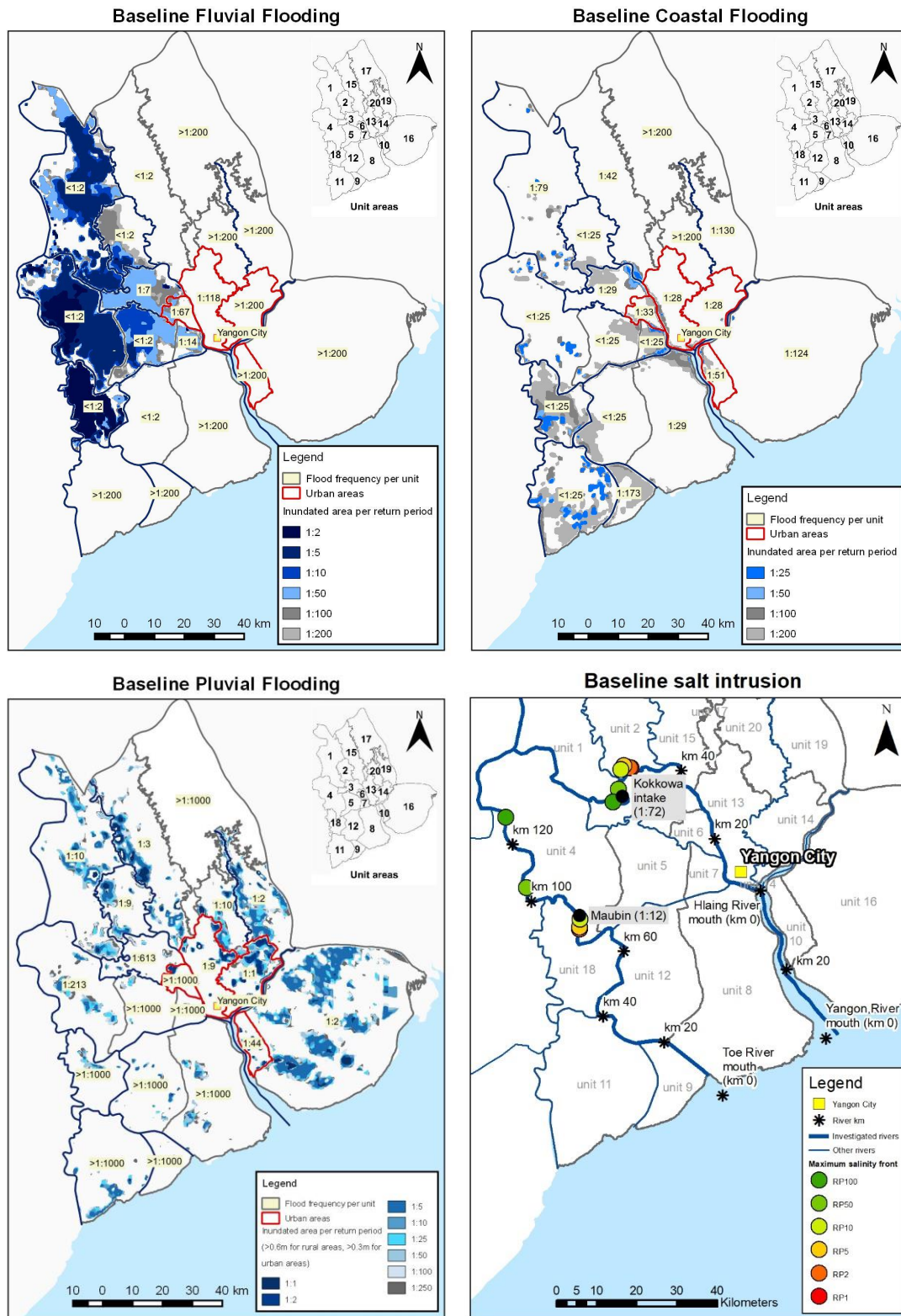


Figure 44: Overview of assessed hazards in Yangon Region

Coastal floods are the main cause of flooding in the area between the Ayeyarwady and Toe Rivers in the west, with probabilities more frequent than 1 in 25 years. The more extreme events are expected to affect larger areas in this part of the study area.

Coastal storm surges are expected to impact areas more inland along the Yangon and Hlaing rivers in the east. The areas affected include the region around Dala, Pan Hlaing Island and even areas along the Hlaing and Kokkowa river further north. Most of these areas also face fluvial flood hazards.

Overall, the probability of river flooding is higher and the extent of flooded areas is higher compared with coastal flooding in most areas because water levels caused by river floods are generally higher than those caused by coastal storms, and because coastal storm surges do not reach the most northern parts of the study area.

As population pressure increases and agricultural needs change, there are indications that farmers try to protect parts of the original retention areas, such as Bawle (unit area 2), from flooding. This will reduce its former natural retention function and will increase water levels elsewhere.

Pluvial flooding is not related to weak points in dikes or levees but is related to the drainage capacity of the region. Sometimes levees may even impede natural drainage. Model results suggest that unit areas 1, 2, 3, 6 and 15 in the north-west are also vulnerable to pluvial flooding. The units east of the Yangon River also face pluvial flood risks, partly due to the lower threshold value for urban areas. In these areas it is the dominant flooding risk.

Overall, it can be concluded that fluvial floods are the main risk in the west and north-west of the region, while rain induced floods are the main risk in the eastern part, and storm surges in the south.

The salinity intrusion in the dry season reaches to the Kokkowa River in the north and the Toe River in the west. The zone in the river with the probability of salt intrusion during low river discharges with return periods ranging between 1 in 1 and 1 in 100 years is a stretch of about 15 kilometers in length. Upstream of this zone the water is very rarely affected by salt and downstream of this zone a yearly intrusion is probable.

4 AUTONOMOUS CHANGES IN WATER SECURITY

4.1 Introduction

The baseline situation described in Chapter 3 is valid for the situation ‘today’. This, however, will change in the future for several reasons:

- The largely agricultural surroundings of Yangon will be further developed and changed into urban and industrial areas (Figure 1),
- Projects may be planned and implemented that may affect the water security in the whole area (system measures), and
- Projects may be planned and implemented that may change the water security demands and as such lead to new projects that affect the water security in the whole area (indirect system measures).

Applying the RWSS framework for analysis (Chapter 2) gives the opportunity to investigate the cumulative and spatial impact of these developments. Such insight is important to avoid situations with conflictive impacts or to adjust existing plans in such a way that the overall impact for the water security situation improves.

A description of the collected measures that may change the behavior of the delta system is given in Section 4.2. Their impact on the water security situation is discussed in Section 4.3.

In addition to these system measures, the baseline situation may also change because of:

- Climate change impact which changes the statistics of the hydraulic boundary conditions (Section 4.4.1), and
- Developments in the upper Ayeyarwady River basin, more specifically the construction of dams that are being considered for hydropower purposes (Section 4.4.2).

Both aspects are difficult to predict beforehand, which is why they are considered possible future *scenarios*. The assumptions and the expected influence are described in Section 4.4.

Section 4.5 presents the conclusions from the flood risk assessment. In this analysis, flood probabilities (or hazards) with different return periods and the consequences of such flood events (damage and casualties) are considered, giving information about the current as well as future (2040) flood risks.

Information about water supply and water demands is provided in Section 4.6. Based on this analysis, the baseline situation is given (now and 2040) with regards to freshwater availability in the project focus areas.

To conclude, Section 4.7 summarizes the main conclusions from this Chapter.

4.2 Planned developments and measures

4.2.1 Inventory

An inventory of future development plans has been made with input from key-stakeholders during workshops and meetings (Appendix A). In addition, information from publicly available websites and reports, such as the “Yangon Project Bank” (Yangon Region, 2019) and the “JICA Yangon masterplan 2040” (JICA, 2018) has been consulted to complement the list. Each plan or project in the list includes information about the project ‘owner’ and the potential funding source. For some projects, such as the Twante Canal Project, additional technical details were collected by one-on-one meetings with the project owners to create a sense of the future adaptability. The complete inventory is shown in *Figure 45* and further described in Appendix D.

Each plan or project from the list has either a direct impact on the regional water system or will enable future developments that changes the water needs and/or safety standards and thresholds. If for example, a river branch or channel is closed off with a sluiceway, then the river and tidal flow distribution

is expected to change, which in turn may change the hydraulic indicators. Another group of plans or projects do not have such direct impact on the hydraulic indicators, but these projects enable economic and population growth in a specific area, such as a bridge towards a remote area. When this is implemented, a larger water supply demand and higher threshold values for flooding may be required.

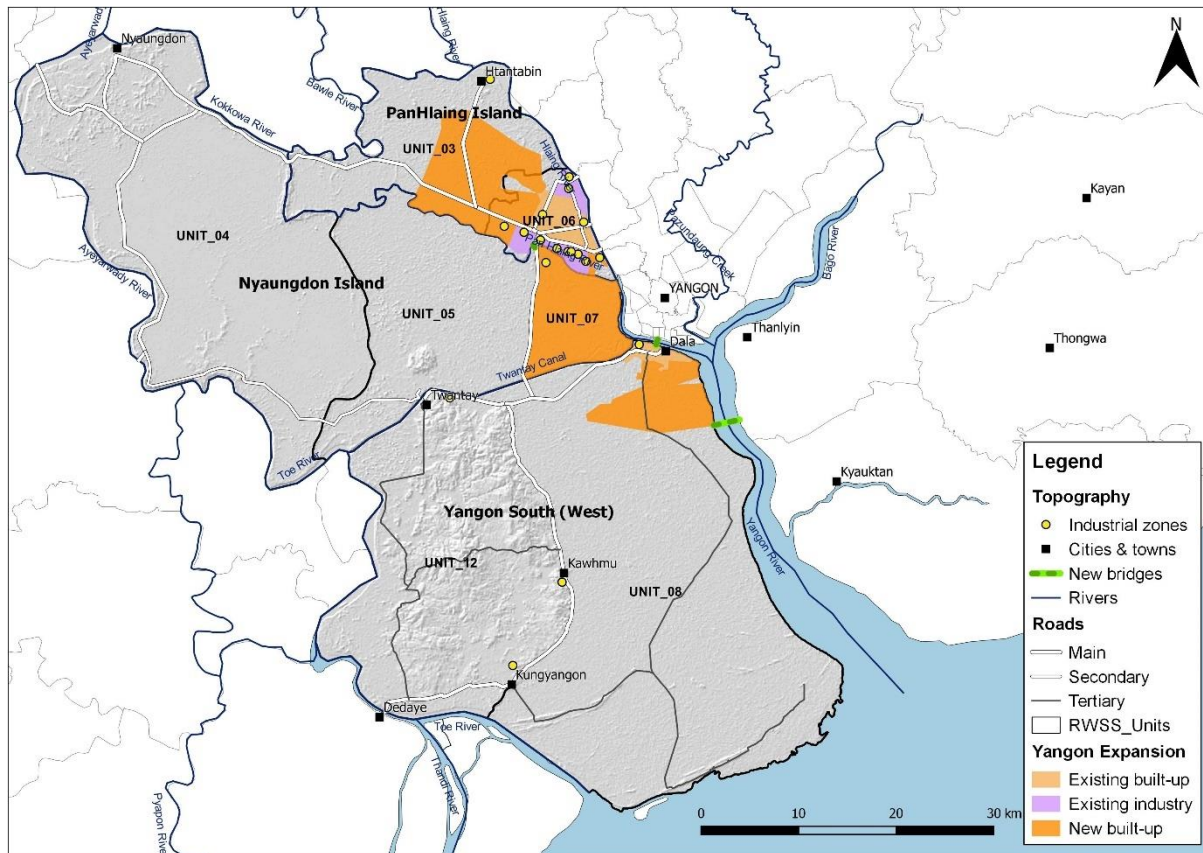


Figure 45: Identified new projects and system measures

Yangon South (West)

In terms of flood and freshwater security flood protection measures are planned along the Twante Canal. The “Improvement of Twante Canal Project” aims to provide a secure waterway, speed up the flow of goods, boost economic development, and minimizes floods. Phase 1 of this project is currently implemented and includes increasing dike height on the first 7 miles on the eastern side along Twante Canal.

The map also indicates other future developments, like the JICA Masterplan supporting water supply improvements to the northern part of Unit 8 at Dala Township (JICA, 2018).

Furthermore, new industrial developments in Dala are planned. Also, a bridge from Yangon downtown to Dala Township will be constructed resulting in a strong transportation connection between Dala Township and downtown, which might increase future socio-economic developments in the area. The bridge will shorten the time taken to travel from Yangon to Ayeyarwady region and lower the transportation costs for people and goods. The project is expected to benefit residents of Dala, Twante, Kungyangon and Kawhmu townships of Yangon Region. The bridge is expected to narrow down the development gap in western areas of Yangon Region. After the construction of the bridge, Dala has ambition to enroll development plans, like Dala-Twante new town, a new airport, a deep seaport and a special economic zone on Dala side, Thilawa side and Kungyangon’s adjacent areas, according to a draft of the Yangon Urban Development Strategic Plan.

Based on the Quicksan report on **saline agriculture** in the Ayeyarwady Delta, the sub area was indicated as potentially suitable for growing salt resistance vegetables (Arcadis et al. 2019). However, more research on soil types, suitable crops, capacity and willingness to change crops by farmers is required.

Longer term ideas for developments could be expected in relation to **New Yangon City** via NYDC. **Phase 2** encompasses development projects from Dala Township to the Gulf of Martaban. The land for NYC phase 2 is flood-prone area. Due to its low-lying elevation, with a maximum elevation of 5 meters (16 ft), the area is vulnerable to cyclonic surges like Cyclone Nargis. The slated areas were previously excluded from development consideration in the 1980s and 1990s by the Ministry of Construction because of this (*RWSS field visit, 2020*).

Pan Hlaing Island and Nyaungdon Island

After the devastation of Cyclone Nargis in 2008, Hlaing Thar Yar experienced an influx of many Internally Displaced Persons who had lost their homes. Most of them are now depending on the local factories for their incomes. Furthermore, agriculture is an importance source of income for many people.

Many new water security measures and future developments are planned. According to the JICA Master Plan 2040, flood protection along Pan Hlaing River and Kokkowa River are considered (JICA, 2018). Also, four water reservoirs are planned as shown on the map. Water intakes from Hlaing River and from Pan Hlaing River, furthermore a drainage channel in unit 6 and water treatment plant in Hlaing Thar Yar are expected.

The target areas of Kokkowa water supply (reservoir, water treatment plant) are the downtown areas of Yangon (unit 13 and 14) and within this sub-area (unit area 7). Overall capacity in the plan of Kokkowa water treatment plant is set to be 140-180 million gallons per day by 2038 (in 3 phases) (*RWSS field visit, 2020*).

The capacity of the planned Toe River water supply plant is 70 million gallons per day and its target areas are the downtown areas of Yangon (unit 13 and 14) and within this sub-area (unit 6 and 7). The project aims to be ready by 2025.

The main objective of the new planned Pan Hlaing sluice is the controlled closure and opening of Pan Hlaing river to contribute to the retention of freshwater and the prevention of salt intrusion and sedimentation processes in the river. The sluice also aims to improve drainage functioning of the river and prevent pluvial and fluvial flooding. The Pan Hlaing Sluice Project area corresponds to the Pan Hlaing River segment between the Mezali Sluice 2 in the West and the mouth of the Pan Hlaing River in the East. This segment encompasses the three townships in this sub-area: Htantabin, Hlaing Thar Yar and Twante. Pan Hlaing Sluice is one of the measures that has been modelled with the RWSS model to assess the impacts.

Another known new development in the area is the New Yangon City (NYC) Project, Phase 1. This development contains major urban planning, proposed by the Yangon Region Government in unit 7. The area designated for this project is approximately 8,830 km² (2,181,941 acres) of land on the west bank of Yangon River, across the water of the existing Yangon city. Phase 1 includes the construction of five villages and townships, two bridges, 26 kilometers of main roads, industrial zones, power plants, power distribution facilities and water and sewage treatment plants. The location of the water treatment plant and associated facilities will be in Twante Township. NYC also takes its own drainage and flood protection measures into account.

4.2.2 Measures that may change the hydraulic indicators

Sluices gates and barriers

The system description in Section 3.2 shows how water flows through the system under different conditions. Closing a hydraulic link of the main river channels is expected to have effect on tidal flows and river discharge distribution over the different river branches and canals. The propagation of the tide into the system as well as the propagation of the storm surge can change if one or more of the branches or canals are disconnected. With changing tidal flows, also saltwater intrusion will be affected.

Improved flood protection

If an area is developed, for example for urban or industrial purposes, then it is important to guarantee a minimum flood safety level. This is generally done through the construction of a dike or increasing the height of the existing embankments. To control pluvial floods, also drainage systems (canals, sluices, pumping stations) are often considered.

The construction of a new flood defense is an intervention that may change water levels and discharges in the system. Overtopping is restricted, taking away the retention capacity of the protected area. This may lead to higher flood water levels locally or even regionally, depending on the scale of the intervention. Upstream flood levels may increase due to the backwater effect. Downstream of the protected area, the higher river discharge will cause higher water levels.

New freshwater extractions

If the water intake volumes are significant, such measures may influence the discharge distribution over the different river branches, if extractions are close to the bifurcation point. The water levels near the intake facility may slightly drop due to the local extraction of the river water. If this lowering is still noticeable at the bifurcation point more water will flow to the branch with the extra extraction. The other branch thus receives less water. Downstream of the water extraction the river discharge will reduce. The salt front may travel more upstream because of the reduced power of the freshwater flow. The effects on saltwater intrusion are expected to become significant when the water extraction is relatively large compared to the river discharge at the intake location.

4.2.3 Selection of measures for modelling

The inventory of plans as presented in Appendix D has been carefully validated with the key stakeholders. Most plans are expected to have a very local impact (such as the construction of bridges or rainfall water collectors), are located outside the project area (for example in Bago Region) or aim to support future developments (such as the construction of roads). From the stakeholder sessions, it followed that some of the mentioned plans are merely ideas, not meant to be implemented on short notice and doubtful if they ever will. Based on the inventory and stakeholder consultations it was concluded that the following four measures could influence the hydraulic indicators on short notice (up to five or ten years):

- Pan Hlaing Sluice including enlarged water extraction near Mezali Sluice (IWUMD);
- Twante Canal improvement project (DWIR);
- Development of New Yangon City, including construction of flood defenses (New Yangon City Development Company);
- New water extraction points in the Kokkowa River and the Toe River (YCDC).

These are the same four measures that were analyzed in the RWSS (IADS-B) project (Arcadis, 2019). The current inventory of plans did not result in any other types of measures that would require a preliminary assessment of their impact on the water security. The results of the re-assessment of the four measures are presented in Section 4.3 by comparing the calculated return periods for the relevant hazards with those obtained for the baseline situation. Note, that the assessment is not done to actually

recommend or advise about these measures, but to illustrate the assessment framework and to provide an understanding about what conditions may prevail in 2040 when these measures are expected to be implemented, so that the project recommendations will be made on the correct initial conditions.

Pan Hlaing Sluice

In the next years and decades, the area on the east side of the Pan Hlaing River (near Yangon City) will be used for new industrial and residential areas. The realization of a new sluice on the east side of the Pan Hlaing River is expected on short term to conclude the Pan Hlaing River Rehabilitation Project which commenced in 2014. With the new Pan Hlaing sluice implemented at the downstream side, and the existing Mezali-2 sluice on its upstream side, it becomes easier to control the water challenges of this part of the Pan Hlaing River basin. As the final design of the Pan Hlaing Sluice is not yet ready, the modeling was based on the available specifications from existing reports. The assessment describes the effect of a closed sluiceway on the Yangon side of the Pan Hlaing River in combination with increased water intake from the river.

Twante Canal improvement project

The Twante Canal is a crucial navigation channel that connects Yangon City with cities in the north of the country along the Ayeyarwady River. The channel links the Yangon River and the Toe River and has a total length of 34 km. Since its completion in 1883, a new shortcut channel from mile 0 to 3.5 on the eastern side was constructed by the British Government in 1917, but it caused critical hydraulic instability. In 1936 Twante Canal was widened, and since then no additional system measures such as sluices have been built. Hence, the strong tidal flows are still present in the current situation but sedimentation in the channel is relatively low compared to the Pan Hlaing River.

DWIR is responsible for navigation on the Twante Canal. Besides the crucial service as navigation channel, the channel also forms a threat to nearby rural communities as floods occur regularly near Dala Township. Yangon South Region, which is located north of the Twante Canal and south of the Pan Hlaing River, is expected to expand significantly with industry and residential areas. Regular flooding will then not be acceptable anymore and therefore DWIR has explored opportunities to increase flood resiliency of the surrounding area of the Twante Canal with the Twante Canal Improvement Project. Another important benefit foreseen is the storage of freshwater in the Twante Canal that can be used in the dry season to supplement the demands for domestic and agricultural use.

The first phase of this project consists of the dredging works and improvements of the embankments along the channel. Regional impact of such works is expected to be limited and are therefore not simulated with the model. On a longer term, DWIR aims to build sluiceways at the Toe River side, the Yangon River side or both. Technical details are not available as this intervention is expected on the long-term. The effects on the water system because of construction of two sluiceways at the western side of the channel (Toe River) and the eastern side (Yangon River) are assessed for this study.

Closing the hydraulic link between the Toe River and the Yangon River is expected to have significant effect on tidal flows in both river branches. As the upstream water input towards the Yangon River is very limited, the closure is expected to have significant tidal effects as the area in which this tidal energy can dissipate becomes smaller. Despite the tidal current along the coast propagating from west to east, the tide in the Twante Canal is dominated by the tide in the Yangon River. Twante Canal therefore contributes to the tidal flows in the Toe River in the west. The tidal flows in the Toe River may reduce to a certain extent after closure.

Flood protection for New Yangon City

Yangon City has expanded in the past decade towards the western side of the city with large industrial and residential zones such as Hlaing Thar Yar. This expansion will continue in the future with new plans already in development, such as the two-phase New Yangon City Development plan. New Yangon City Phase 1 is located south of the Pan Hlaing River and north of the Twante Canal and covers an area of 90 km². Within this area, new industrial zones and residential areas will be built. Phase 2 of the plan covers a much larger area (600 km²) between the southern bank of the Twante Canal and the coastline

in the south. As Phase 2 is only in consideration, the focus on the assessment of this intervention is on the regional impacts on water system caused by Phase 1. The New Yangon City development will include land reclamation and flood protection works. Effectively, this means that there will be less area available for flooding during extreme events. This will impact the flood security level in the surrounding area negatively.

New water extraction point in the Kokkowa River and the Toe River

Yangon City Development Committee (YCDC) is planning to implement Water Treatment Plants (WTP) for water supply to the Yangon City, using different water resources (rainfall and river). Japan International Cooperation Agency (JICA) provided a “Preparatory Survey for Greater Yangon Water Supply Improvement Project” to YCDC. It suggests using water resources of Kokkowa River and Toe River for a potential water supply network. The overall capacity of the Kokkowa water intake (Katwe) will be between 140 and 180 MGD (approximately equal to 7,4 m³/s – 9,5 m³/s) based on the amount of water that can be obtained from Pan Hlaing River for 2040. JICA suggested the project implementation stages as follows:

- Kokkowa Stage 1: 60 MGD (2025), currently in development stage;
- Kokkowa Stage 2: +40 MGD (total 100 MGD);
- Kokkowa Stage 3: +40 MGD (total 140 MGD);
- Kokkowa Stage 4: +40 MGD (total 180 MGD) depending on capacity Pan Hlaing Water Treatment Plant.

For the Toe River WTP, the intake capacity will be 70 MGD (3,7 m³/s) according to the revised JICA report from 2017 (JICA, 2017). Both these extractions will impact the availability of freshwater during low discharge events. This could result in more salt intrusion at an equal upstream discharge. *Table 18* gives an overview of which events are assessed for every intervention.

Table 18: Dominant water security challenges per modelled intervention

Intervention	Fluvial flooding	Coastal flooding	Pluvial flooding	Water scarcity and salt intrusion
Pan Hlaing Sluice (Section 4.3.1)	Yes	Yes	No	No
Twante Canal improvement project (Section 4.3.2)	Yes	Yes	No	Yes
New Yangon City (Section 4.3.3)	No	Yes	No	No
New water extraction Kokkowa River and Toe River (Section 4.3.4)	No	No	No	Yes

4.3 Impact of selected measures on flood and freshwater security

4.3.1 Pan Hlaing sluice

Objective

The realization of a new sluice on the eastern side of the Pan Hlaing River is expected on short term to conclude the Pan Hlaing River Rehabilitation Project, which commenced in 2014. As the final design of the Pan Hlaing Sluice is not yet ready, the modeling has been based on the available specifications

from existing reports. This section describes the effect of a closed sluiceway on the Yangon side of the Pan Hlaing River in combination with increased water intake from the Pan Hlaing River.

Model schematization

The sluice is modeled with a “thin dam” which impedes all flow (*Figure 46* shows parts of the computational grid and the location of the “thin dam”). To assess the maximum effects of the sluice gate on the flows and water levels surrounding the Pan Hlaing River, it is assumed that the gate is closed during high river discharges and storm surges.

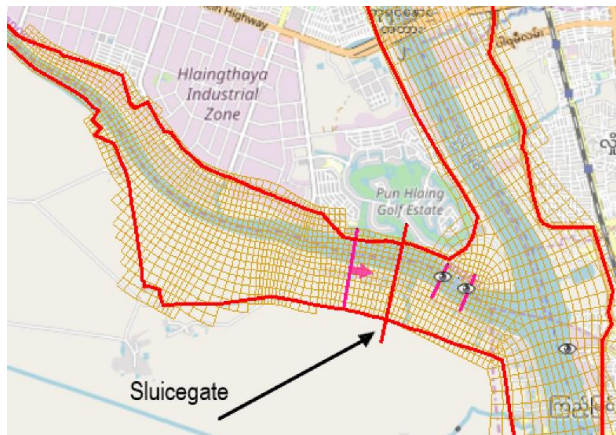


Figure 46: schematization of a “thin dam” in the Delft3D FM model at the proposed location of the Pan Hlaing Sluice

Model results – fluvial flood

The effect of the new sluice on the assessed fluvial flood return periods is shown in *Figure 47*. In general, the impact is low. During the wet season, where fluvial flooding is likely to occur, Mezali sluice is closed and there is no cofferdam present in the Pan Hlaing River for most of the wet season. Pan Hlaing River can then be considered a tidal creek. When Pan Hlaing Sluice is constructed, this is no longer the case, effectively removing the tidal fluctuation from Pan Hlaing River entirely. This results in a minor improvement of the fluvial flood safety of Unit07 (1 in 14 year to 1 in 16 year). However, the tide right in front of the sluice is slightly amplified as a direct result of the blockage, reducing the fluvial flood safety of Unit06 slightly from 1 in 67 year to 1 in 41 year. The flood safety of this unit is however governed by coastal flooding at a level of <1 in 25 year, making this impact less relevant.

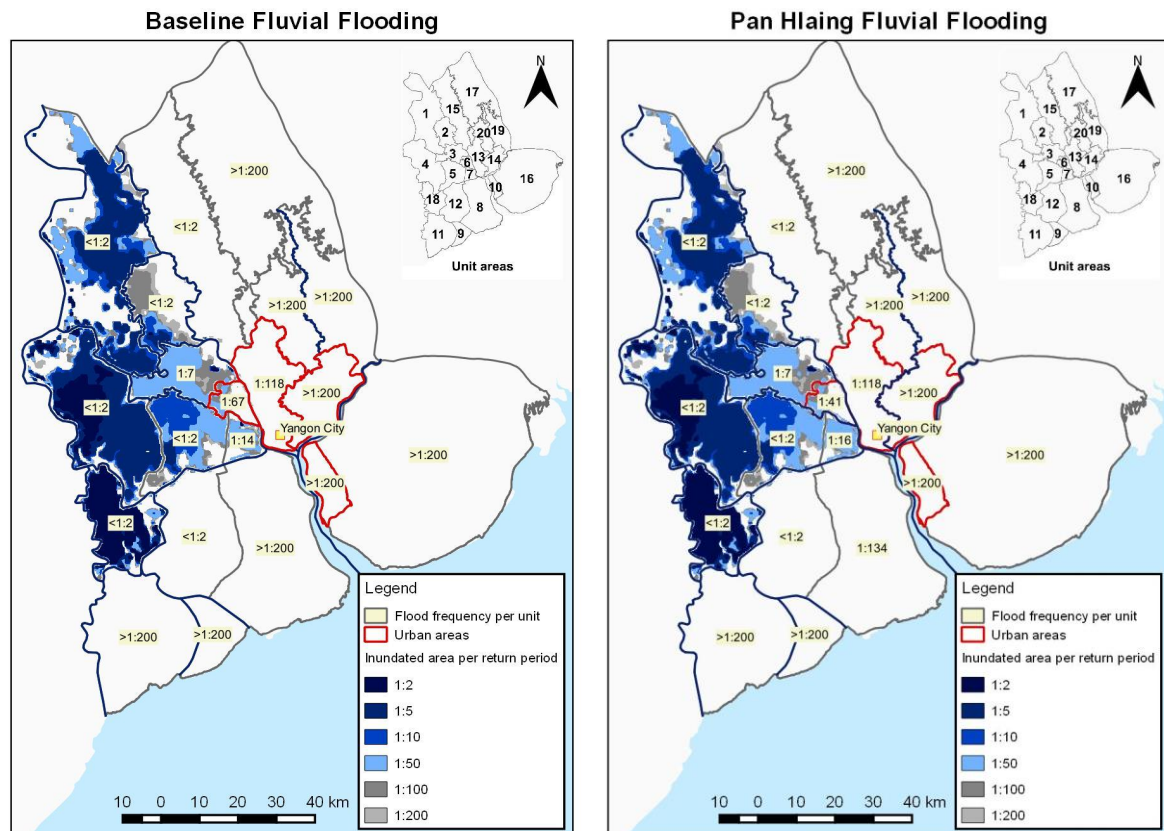


Figure 47: Return period for fluvial inundation per unit, baseline and Pan Hlaing sluice intervention

Model results – coastal flood

The impact on coastal flood hazards as shown in Figure 48 appears to be very small. This is mainly due to the fact that coastal flooding by cyclones is assumed to occur in the dry season when the cofferdam is present in the Pan Hlaing River, basically fulfilling the same function as the sluice from a coastal flooding safety perspective. The cofferdam is erected annually in the dry season a few kilometers upstream (western direction) from the projected sluice. The closure of the Pan Hlaing River by the sluice therefore only blocks a limited extra section of the waterway. The impact on safety level due to coastal flooding is negligible for all units.

Please note that while the assumption that the extreme coastal events considered here only occur when the cofferdam is present is valid, based on the yearly window for cyclone events, less extreme coastal flooding events can also occur during the wet season when the cofferdam is usually not present. The surge can then freely enter Pan Hlaing River, threatening the adjacent units. Coastal flooding statistics outside of the cyclone season are not considered in this study as they are mainly not governing for the flooding levels. However, based on the above, they are likely relevant for Pan Hlaing River. For reference, if the 1 in 200 year coastal event were to occur and the cofferdam was not present, flooding levels of EGM+6.5 m are simulated in Pan Hlaing River just south of Mezali as opposed to less than EGM+3.5 m when the cofferdam is present. Despite coastal surges being less severe outside of the cyclone window, it is strongly recommended to look into coastal surge statistics outside the cyclone season as they are likely relevant for Pan Hlaing River, and not to exclude any impact of climate change on the cyclone season. Furthermore, the associated flooding statistics could serve as an (additional) argument for the construction of Pan Hlaing Sluice, from a coastal flooding perspective.

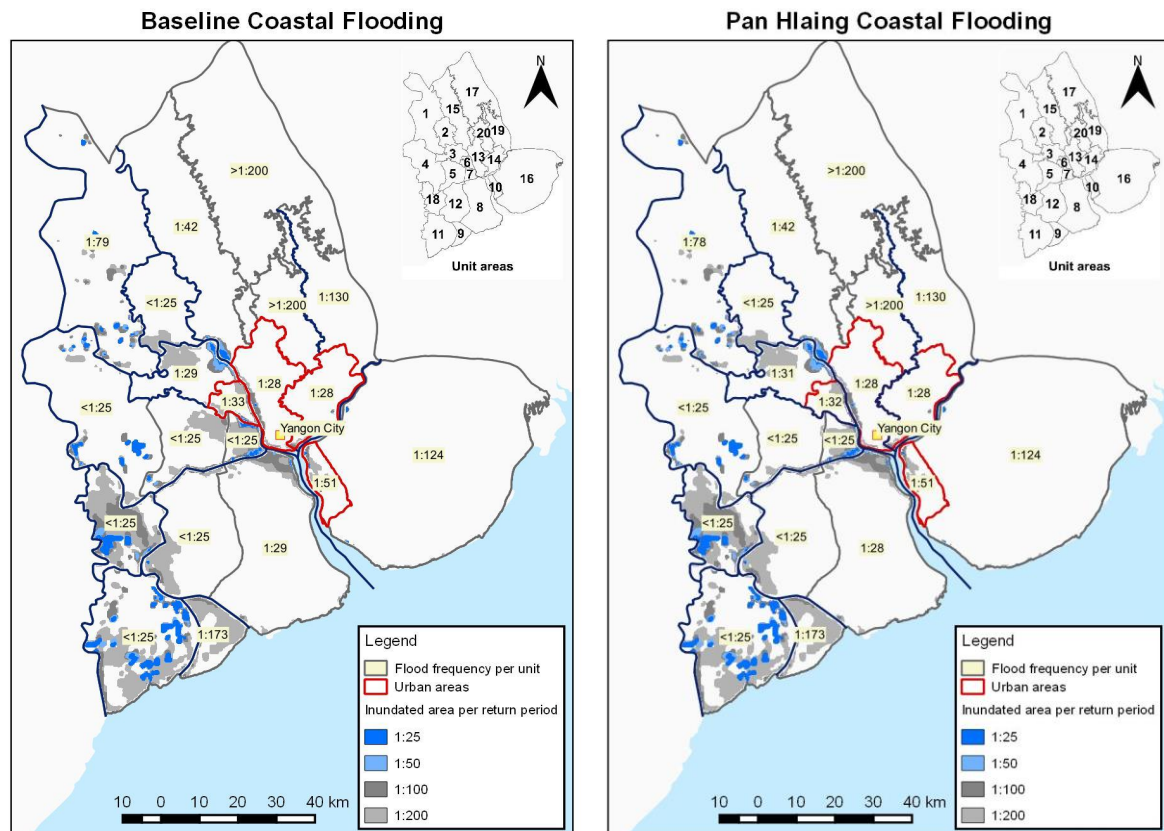


Figure 48: Return period for coastal flooding per unit, baseline and Pan Hlaing sluice scenario

Model results – salinity intrusion

The Pan Hlaing Sluice has hardly any effect on the position of the salt front. Only the computed frequency of salt intrusion at Kokkowa intake (Katwe) changes slightly, from 1 in 72 years in the current situation to 1 in 67 years with the sluice. This small difference is caused by the extra extraction of 3.9 m³/s in the Pan Hlaing River in the new situation, leading to slightly less discharge through the Kokkowa River. This is the same effect as what is found for the intervention with additional water extractions in Kokkowa River and Toe River (Section 4.3.4).

Conclusion impact on hydraulic indicators

The construction of the Pan Hlaing Sluice has a limited impact on the hydraulic indicators for the two - water security hazards considered here. During low discharge events, the system does not physically change as the sluice effectively replaces the cofferdam that is presently deployed, albeit somewhat further upstream. Consequently, the salt intrusion is not impacted either. The fluvial and coastal flood return periods change only marginally.

Qualitative impact on environmental indicators

Below impacts are deducted and summarized based on the ESIA performed for the Pan Hlaing Sluice (Arcadis et. al, 2019b).

- **Biodiversity/Mangroves/Gradient.** The new sluice is expected to impact biodiversity and mangroves due to the change in fresh-/saltwater gradient during the dry season, as the sluice will block saltwater from entering the Pan Hlaing River. As mangroves are present in the Pan Hlaing River, the removal of salinity intrusion in the dry season, means that mangroves will most likely be outcompeted by freshwater vegetation. The Pan Hlaing River was known to host certain migratory fish that can live in fresh, brackish, and saltwater, therefore the change in the gradient is expected to impact these

fish. However, most of the fish in the Pan Hlaing River is known to be freshwater species. This also has to do with the Pan Hlaing River being completely void of saline waters during the wet season, as the freshwater pushes out the saltwater wedge towards the sea. Impacts are hence only expected in the dry season. Considering the impacts on biodiversity and mangroves, the change in gradient can be considered a negative impact, however for the wider water system, the Pan Hlaing sluice is not expected to cause any significant impact in biodiversity mangroves and gradient, as the impacts are rather localized.

- **Sedimentation/Erosion.** Sedimentation will be significantly reduced due to the Pan Hlaing sluice, as the majority of the sediment was entering the river through the tidal influence coming from the sea. From an environmental point of view, reduction in sedimentation could have a positive impact on benthos (bottom dwelling animals) as they are disturbed less frequently, and maintenance dredging will have to be performed less frequently. The reduction in sedimentation could have a potential impact on nutrients being pushed upstream into the Pan Hlaing River, although the impact of this is expected to be minimal. Sedimentation in front of the sluice can increase due to the new build structure, which will have to be maintained at regular intervals. According to the Pan Hlaing ESIA (Arcadis et al., 2019b), erosion is only expected near the Pan Hlaing bridge and near the sluice itself, therefore not having a significant impact on the complete river. The reduction in sedimentation is not expected to increase sedimentation significantly in the rest of the water system, as the Pan Hlaing River is considered small compared to the Hlaing River.
- **Water quality.** The quality of the water in the Pan Hlaing River is expected to degrade in the dry season, because of closure of the sluice and limited inflow from Kokkowa River. This causes untreated wastewater from the Hlaing Thar Yar district to pile up in the Pan Hlaing River, causing severe water quality degradation. In the baseline this is not so much the case as the temporary cofferdam is placed upstream (west) of the industrial zone. Although the water quality is expected to degrade in the new situation, the Pan Hlaing ESIA highlights the implementation of a new Wastewater Treatment Project (WWTP) in the Hlaing Thar Yar district, which is currently in the preparation phases (Arcadis et al., 2019b). The ESIA recommends avoiding closing off the Pan Hlaing River until the WWTP has been completed and polluted wastewater discharge into the river has been minimized. In light of this information, the impact on water quality is expected to be minor. As the water quality due to the WWTP project is not expected to decrease in the Pan Hlaing River, this also means that no impact is expected in the rest of the water system.
- **Invasive species.** Currently the Pan Hlaing area already supports aquaculture in ponds near villages. The Pan Hlaing ESIA does not report on invasive species, but if these species would be hosted in the ponds, these are not expected to have an impact on the biodiversity in the Pan Hlaing River, as ponds are disconnected from this river. The Pan Hlaing Sluice might increase the potential for aquaculture, as more freshwater becomes available throughout the year. If this aquaculture is maintained in ponds the impacts of invasive species should be limited to the ponds. If they are hosted in the river stream, this could mean potential impacts on other species. With the current information it is not expected that the Pan Hlaing sluice has an impact on invasive species, locally or in the rest of the water system.

Qualitative impact on socio-economic indicators

Similar as above, the possible impact of climate change (up to 2040) on the socio-economic indicators are assessed. For the Pan Hlaing sluice a detailed financial and economic impact assessment report is available. This has been used as a basis for the analysis.

- **Employment generation:** Moderate impact, temporary during construction phase. Positive structural due to improved protection of New Yangon City and industrial areas (+/+++).
- **Equity in access:** No major changes expected (0). Only for a few sand/gravel shops next to a dam in case of a more upstream location the accessibility would worsen.
- **Pro-poor/poverty reduction:** Given the scores on water supply (water security), employment generation and equity in access, the Pan Hlaing project is expected to contribute to poverty reduction (+).
- **Navigation:** No real navigation obstacles are present in free flow / base case. Navigation can continue in case of the projected dam/sluice. Impact is zero (0).
- **Recreation:** No impact expected as a result the Pan Hlaing project (0).

- Water supply: in the base case a cofferdam fulfills adequately its role for water supply. Basically, not much impact can be expected, only that a dam/sluis is more structural, so slightly better score on water security (+), especially if a coastal flooding event were to occur in a time period, where the cofferdam would not be present (wet season). A caveat should be made through concerning potential deteriorating of water quality because of closing of the Pan Hlaing river mouth. Refer to the environmental assessment.
- Connectivity: the connectivity of the Pan Hlaing River and the water system in a broader sense is not affected in case of the projected sluice/dam (0). If no sluice were placed, the connectivity would be severely negatively impacted.

The overall score on socioeconomic impacts of the Pan Hlaing sluice is expected to be positive (+) because there are no opposing scores in the underlying effects.

4.3.2 Twante Canal improvement (Phase 2)

Model schematization

To assess the maximum effect of the two sluiceways on the flows in the Toe River and the Yangon River it is assumed that the sluiceways are fully closed. Some minor 'leakage' may occur at both sides caused by drainage and operation of the ship lock. However, this is not considered as a significant effect on the broader system. Therefore, two "thin dams" are included in the model at the potential locations of the sluiceways (Figure 49).

The regional effects of this intervention are assessed for the extreme events: coastal flooding, fluvial flooding and water scarcity, focusing on the salt intrusion.

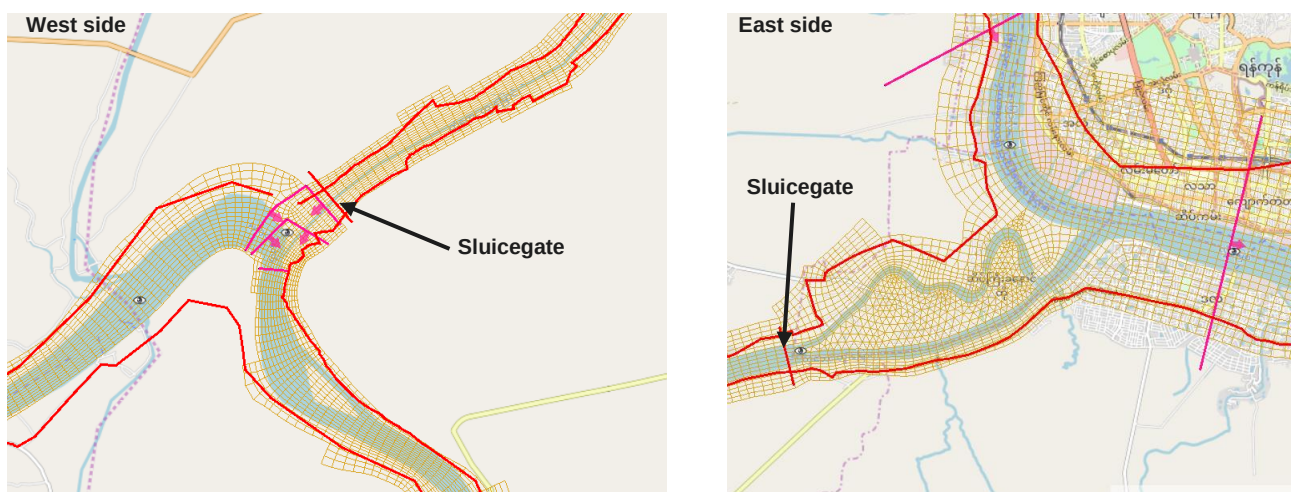


Figure 49: schematization of Twante Canal sluices in the Delft3D FM model

Model results – fluvial flooding

The simulated impact of the closure of the Twante Canal is shown in Figure 50. In general, the water security indicators remain the same or worsen slightly. Especially the flood safety level in unit areas 6, 7 and 8 decrease (unit area 8 from less than 1 in 200 year to 1 in 13 year).

The calculated changes in water levels due to the closure in Toe River, Twante Canal and Yangon River further clarify the impact. Figure 51 shows that water levels in the Toe River increase due to the closure of Twante Canal (up to 65 cm). Overtopping of the dikes along the Toe River will increase, increasing the inundation discharge and water levels inside unit areas 4 and 5. When the flood water levels rise above the level of the dike along the channel, water will enter Twante Canal. Water levels in the canal will increase even above the peak water levels without the intervention, as water cannot flow to Yangon River. This causes inundation of the unit area 8 from its northern boundary, albeit only in very few places (see inundated areas in northern part of unit 8 in Figure 50).

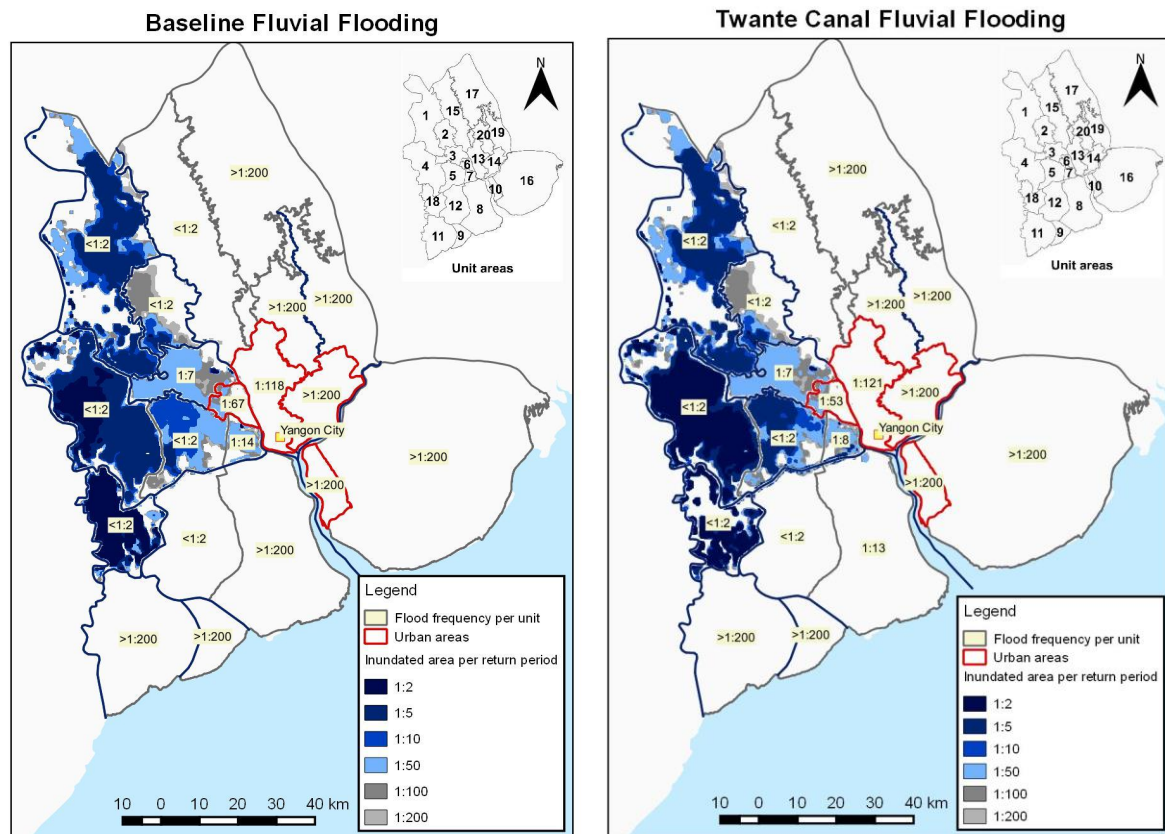


Figure 50: Return period for fluvial inundation per unit, baseline and Twante Canal improvement intervention

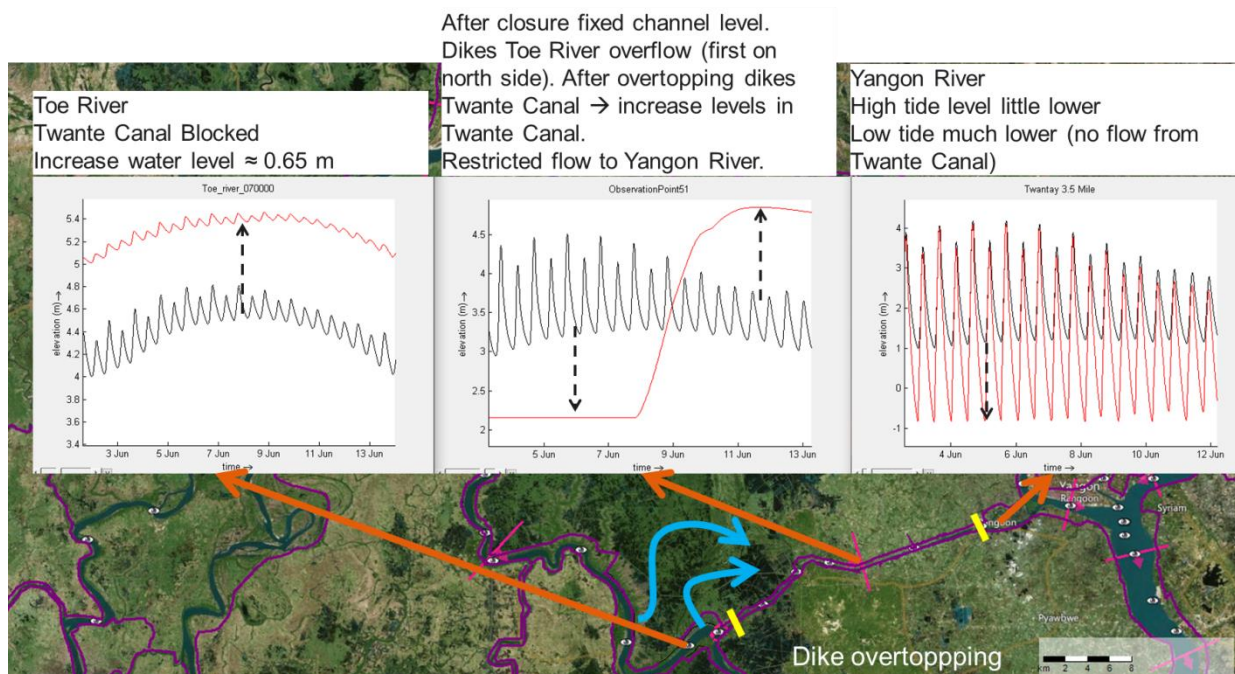


Figure 51: Water levels in Toe River and Twante Canal without (black lines) and with the intervention (red lines)

Model results – coastal flooding

Similarly, a slightly negative impact follows from the calculations on the coastal flood indicators. Comparable to the observed impact for the Pan Hlaing sluice construction, the storm surge is now stronger funneled into the Hlaing River and moves further upstream compared to the baseline. This results in higher peak water levels under storm surge conditions. Consequently, the coastal flood hazard slightly worsens in the adjacent units, including Yangon City (see Figure 52).

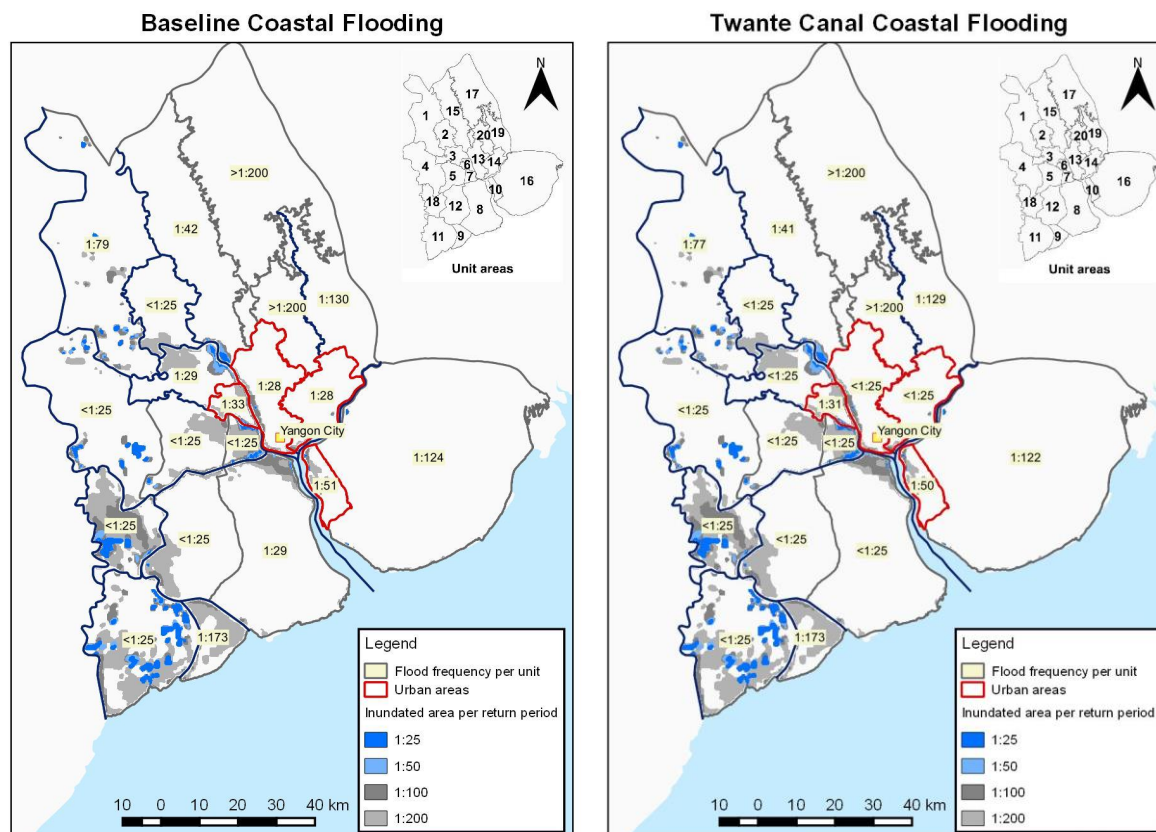


Figure 52: Return period for coastal inundation per unit, baseline and Twante Canal improvement scenario

Model results – salinity intrusion

According to the model, the closure of the Twante Canal results in a larger tidal amplitude into the Hlaing and Upper Hlaing Rivers, due to the increased funneling of the tidal forcing. As a result, the salt wedge moves further inland and with that, the salt intrusion. Consequently, the computed frequency of salt intrusion at Kokkowa intake (Katwe) is increased, going from 1 in 72 year to 1 in 34 year (see Figure 53).

For Maubin, the intervention is less impactful according to the model. The closure of the Twante Canal results in a blockage of saltwater coming from Yangon River through the Twante Canal. The freshwater discharge can now hold back the salt wedge along the Toe River more effectively. However, the discharge distribution is slightly different with a small decrease in the Toe River. Combined, this results in hardly any change in the computed frequency of salt intrusion at this intake location (1 in 12 year).

For the yearly average discharge during dry season, the salt wedge in the Toe River will be located downstream of the sluice to Twante Canal. The salt wedge moves up to km 60 during incoming tide with the bifurcation to Twante Canal being located at ca. km 70. Based on this average position of the salt wedge along Toe River during dry season, it is possible to supply Twante Canal with freshwater from Toe River, for irrigation purposes. However, if the river discharge drops below this average for a

duration of 14 days or more, the salt wedge will move upstream quickly and the freshwater intake into Twante Canal will no longer be possible. Sea level rise will further limit the window where freshwater intake is possible, requiring an increasing minimum river discharge at Pyay with an increasing mean sea level.

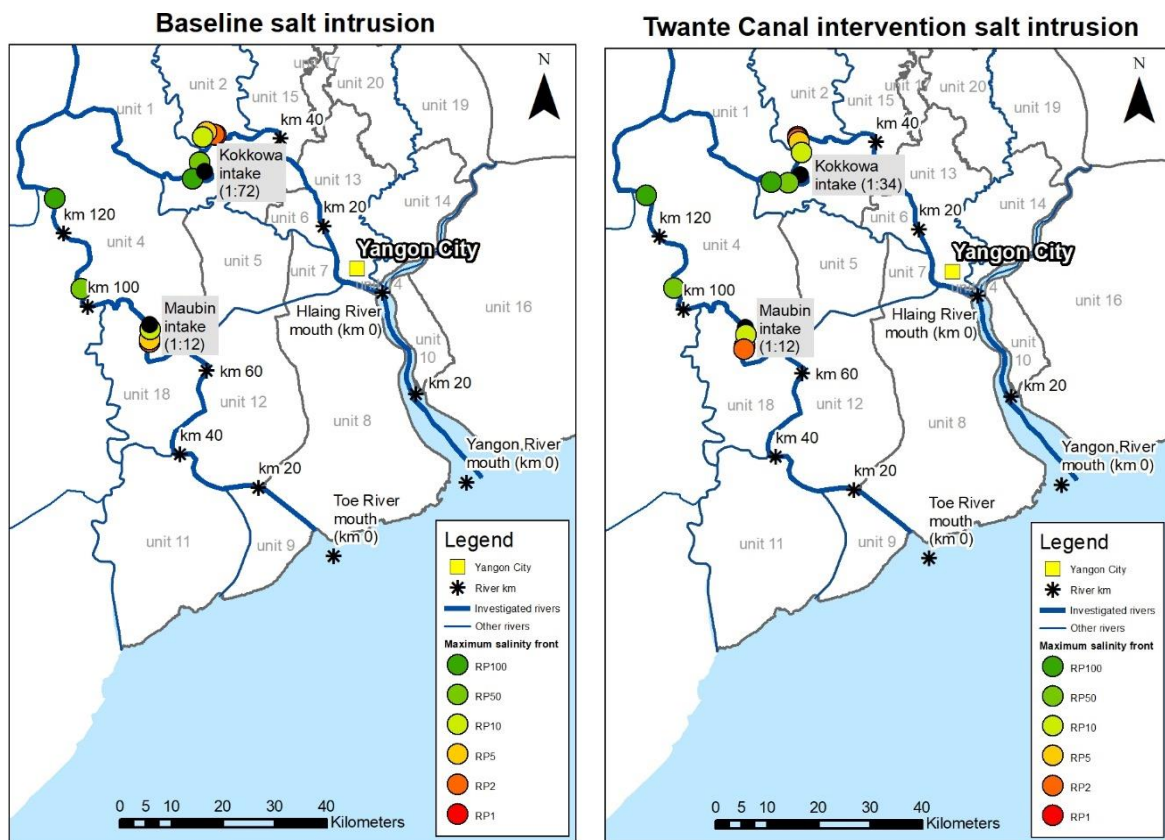


Figure 53: Calculated impact of Twante Canal closure on salt intrusion

Conclusion Impact hydraulic indicators

The changes in discharge distribution during low river discharge are negligible according to the simulations. However, the tidal amplitude in the Hlaing River is amplified, increasing the salt load on the Upper Hlaing and Kokkowa Rivers. The flood probability during high river discharges along the Toe River increases because of a backwater effect of the (western) barrage raising water levels up to 65 cm. The (coastal) flood probability along the Yangon River up to Yangon city also increases because of a stronger tide funneling effect in the Yangon River caused by the presence of the eastern barrage. The salt wedge moves further inland under extreme conditions, even reaching Kokkowa River up to Mezali. A positive effect of the Twante Canal Phase 2 is that the canal itself can serve as a freshwater reservoir that can bring sufficient quantities of water to nearby areas to increase the total surface of irrigated agricultural land.

Qualitative impact on environmental indicators

Although the Twante Canal is a man-made canal mainly used for shipping and the Pan Hlaing River is originally a natural river, impacts on biodiversity, sedimentation, water quality and related aspects are likely quite similar. Therefore, the qualitative assessment of the impact of the system intervention on the environmental indicators is done in comparison to the Pan Hlaing Sluice (no specific ESIA is yet available for phase 2 of the Twante Canal Improvement project).

- **Mangroves:** Compared to the Pan Hlaing the Twante Canal has hardly any mangroves. Therefore, impacts of the sluice development on mangroves in the Twante Canal is expected to be absent.
- **Fresh-/saltwater gradient:** The brackish water zones will shift; however, this is a natural phenomenon to which flora and fauna can easily adjust on a regional scale.
- **Biodiversity:** The ESIA for Phase 1 of the Twante Canal improvements shows that both freshwater and brackish water (including migratory) species are present in the Twante Canal. The closure of the Twante Canal will impact these species if no mitigation measures are included in the sluice development. Thereby the potential change in gradient will impact predominantly salt/brackish water species negatively.
- **Sediment regime/Erosion:** The reduction in flow velocity will reduce erosion at the bottom and along the banks. As with the Pan Hlaing sluice project, erosion around the sluice locations might temporarily increase compared to the current situation, although this is expected to be minor.
- **Water quality:** Although no large industrial areas are known to be present around the Twante Canal which discharge untreated wastewater in the canal as with the Pan Hlaing river, large areas of agricultural land are located around the canal. Given that agricultural runoff of these lands could include excess fertilizer and pesticides, the water quality could be degraded during the dry season, when the sluice gates are anticipated to be closed for the majority of the time, only letting through shipping traffic. This can result in a negative impact on the (local) water quality.
- **Invasive species:** the areas near Twante Canal host fish farms. These farms are struggling with enough water supply during the dry season. If the canal can improve the water availability in the Twante Canal, this means that aquaculture can improve. Dependent on which species are cultured, this could mean an increase in invasive species and a potential negative impact on biodiversity in the river, considering aquaculture might be practiced at the fringes of the canal.

Although the impacts are mixed (positive for salt/brackish water species and negative for freshwater species) the alteration of the baseline situation in environmental assessment would have to be considered slightly negative (0/-).

Qualitative impact on socio-economic indicators

Similar as above, the possible impacts of Twante Canal closure with sluices on the socio-economic indicators are assessed.

- **Flood risk:** Based on the flooding modeling results, the overall impact seems to be negative, both for coastal and fluvial flooding. However, other information points at flood safety improvement as a major objective of the project, also indicating that the majority of benefits are related to flood risk reduction. To achieve this additional dike strengthening along Toe Rover would be required. Hence the suggested score is (-/+).
- **Employment generation:** Moderate impact of sluice construction, temporary during construction phase. If flooding is prevented, this will provide for more secure living environments and sustaining employment opportunities (+).
- **Equity in access:** No major changes expected (0).
- **Pro-poor/poverty reduction:** Given the scores on water supply (water security) and employment, the Twante project is expected to contribute modestly to poverty reduction (+).
- **Navigation:** Constructing sluices with ship locks will not provide a major impact compared to the present, free flow, situation. Combined with the fact that extreme flow velocities (up to 2,5 m/s) are avoided which improves navigational safety, channel training and other fairway improvements however, a slightly positive impact result (0/+).
- **Recreation:** No impact expected as a result of the Twante-project (0).
- **Water supply:** Enhancing water supply is one of the major objectives of the project. given the large need for additional freshwater supply in the immediate surroundings this is considered a positive impact (+).
- **Connectivity:** The project will restore and maintain water system connectivity in a general sense and continue to facilitate shipping (+).

The overall score on socioeconomic impacts of the Twante project is expected to be positive (+), as there are no opposing scores in the individual socio-economic effects.

4.3.3 New Yangon City Development

In the preceding project (RWSS (IADS-B)), it was concluded that the dominant water security issue for New Yangon City is coastal flooding (Arcadis, 2019). This is because the peak water levels are determined by extreme storm surges rather than by high river discharges, which can be seen in *Figure 54*. The upper plot shows the computed water levels along the perimeter of unit area 7 (where NYC is located) for high river discharges and the lower plot shows the same for coastal storm surges. In both images also the location of the weakest section of the embankment is shown.

The extreme fluvial water levels do not differ much per return period (roughly between EGM08 +4 m and +5 m). The extreme water levels for the storm surges on the other hand rise significantly with increasing return periods (above EGM08 +5 m from return periods above 1 in 75 year).

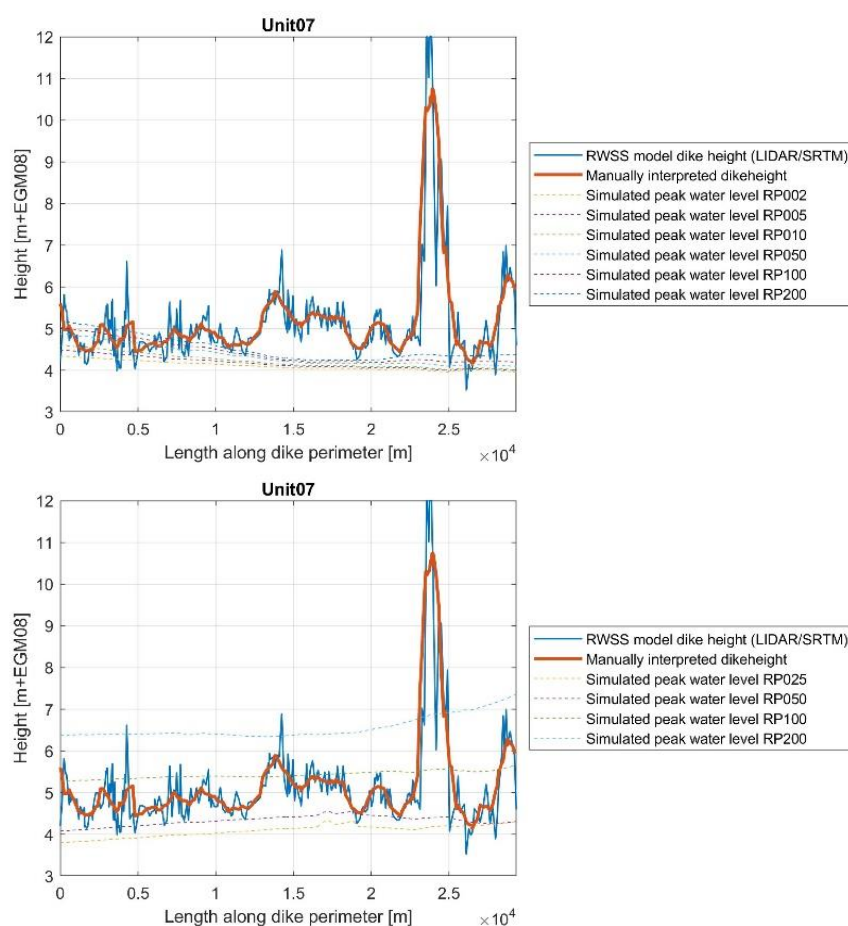


Figure 54: Calculated peak water levels around unit area 7 for fluvial and coastal extremes

New Yangon City Phase 1 is located south of the Pan Hlaing River and north of the Twante Canal and covers an area of 90 km² (NYCD, 2019). Within this area, new industrial zones and residential areas will be build. Phase 2 of the plan covers a much larger area (600 km²) between the southern bank of the Twante Canal and the coastline in the south. As Phase 2 is currently only under consideration, this assessment deals with Phase 1. Figure 55 shows how the intervention is schematized in the model as a “thin dam” that surrounds the entire New Yangon City Phase 1 area. This implicitly assumes that the new dikes will be high enough to resist any storm surge that is simulated and therefore overbank flow will not occur. Furthermore, for this simulation it is assumed that the proposed Pan Hlaing Sluice is not constructed (yet), but it is likely that both measures would be developed and build within the same period. However, as the period of occurrence is assumed to be April – May (cyclone season), the cofferdam is present in the model, which has a similar regional effect as the new Pan Hlaing sluice.

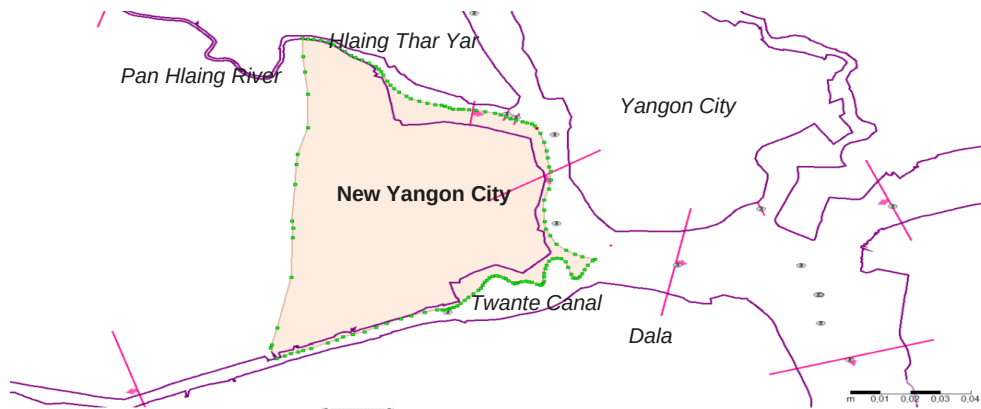


Figure 55: schematization of the flood protection area of New Yangon City

Model results – coastal flood

The impact of flood protection for New Yangon City Development is limited. The effective reduction in flooding area that is available during coastal flooding, leads to a small increase in the peak water level in the Yangon and Hlaing rivers as well as further upstream. However, this effect is spread out over a large area and results in a negligible decrease in the level of flood safety.

Conclusion impact hydraulic indicators

While covering a significant area, unit area 7 is relatively small on the regional scale of the delta. The reduction in 'floodable' area during a coastal flooding event is therefore relatively small. However, an impact in the form of a peak water level increase is still simulated in the surrounding area, with a very small worsening of the coastal flood hazard for surrounding unit areas as a result *Figure 56*.

Qualitative impact on environmental indicators

As highlighted with in the hydraulic analysis, the development of further flood defense around the New Yangon City Development (NYCD) is not anticipated to impact the hydrodynamic situation significantly in the wider water system. Development of flood protection on the borders rivers can have an impact on environmental factors, although these are not related to the water system. These impacts related to the construction of the flood protection, such as water discharges, air quality impacts and clearance of vegetation should be considered in designated impact assessments for these projects.

Qualitative impact on Socioeconomic indicators

- Flood risk: in itself protecting this area is economically sensible, as it is a location of (increasing) economic importance (+). The impact could be more if combined with Phan Hlaing sluice, guaranteeing flood safety also when the cofferdam is not in place.
- Water supply: No impact expected (0).
- Connectivity: No impact expected (0).
- Employment generation: the construction of the projected small dikes will not generate much employment, however the major impact is on enabling the area to economically flourish by protecting it (+).
- Equity in access: No major changes expected (0).
- Pro-poor/poverty reduction: Given the scores on flood protection and employment, the project is expected to contribute modestly to poverty reduction (+).
- Navigation: No impact expected (0).
- Recreation: No impact (0).

The overall score on socioeconomic impacts of flood protection of New Yangon City is expected to be positive (+).

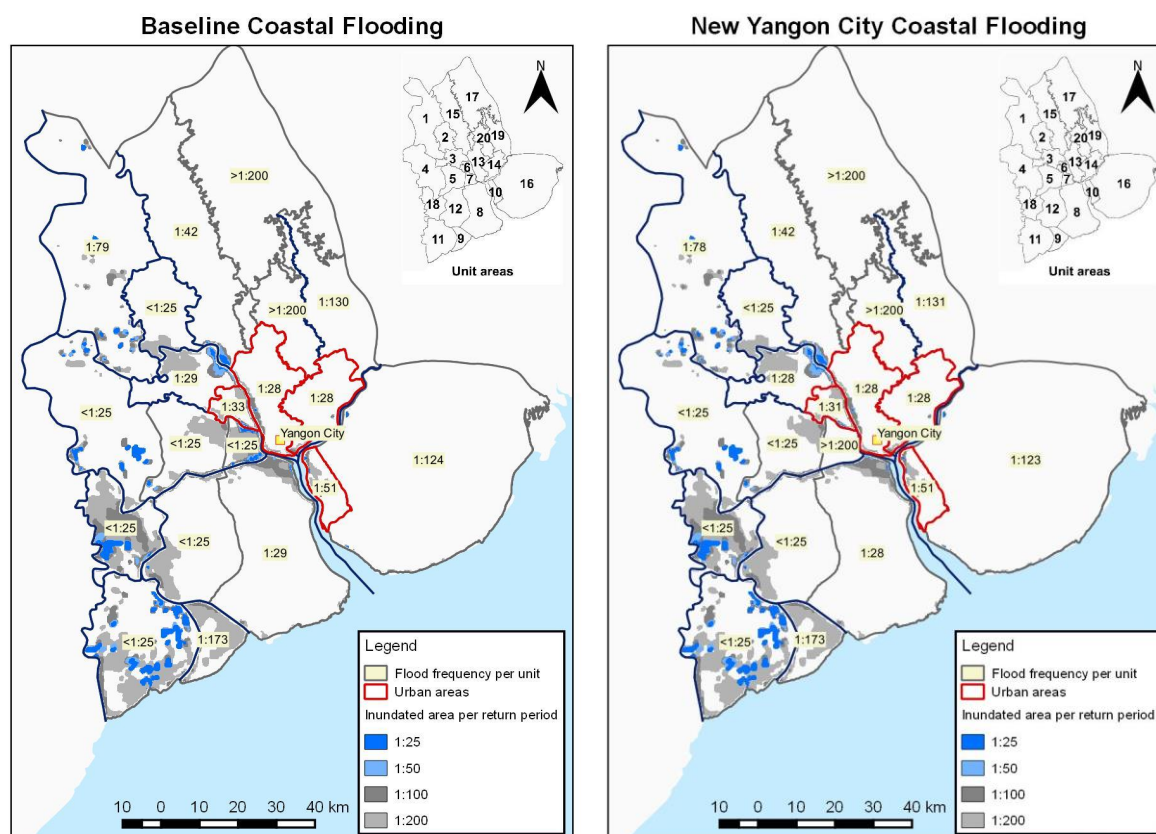


Figure 56: Return period for coastal inundation per unit, baseline and New Yangon City flood protection

4.3.4 New water extraction Kokkowa and Toe Rivers

For the Kokkowa River extraction, the capacity is set to the proposed Stage 1 capacity of 60 MGD (3.2 m³/s). For the Toe River WTP, the intake capacity will be 70 MGD (3.7 m³/s) according to the revised (JICA, 2017).

Model schematization

To model the pumping of water in the model, the “SourceSink” feature is used with $Q = 3.2 \text{ m}^3/\text{s}$ (approximately 60 MGD) to simulate the first stage of the Kokkowa extraction. To simulate the extraction at the Toe River, the same feature is used with $Q = 3.7 \text{ m}^3/\text{s}$ (approximately 70 MGD). Indicative locations of these intake locations are shown in Figure 57.

Model results – water scarcity

The extraction of an additional 3.2 m³/s from the Kokkowa River and an additional 3.7 m³/s from the Toe River effectively leads to slightly less water available to force back salt intrusion. Despite only being small extractions, the model calculates an increase of approximately 10% in frequency of salt intrusion at Kokkowa intake (Katwe) (from 1 in 72 year to 1 in 67 year) and Maubin (from 1 in 12 year to 1 in 11 year - see Table 19).

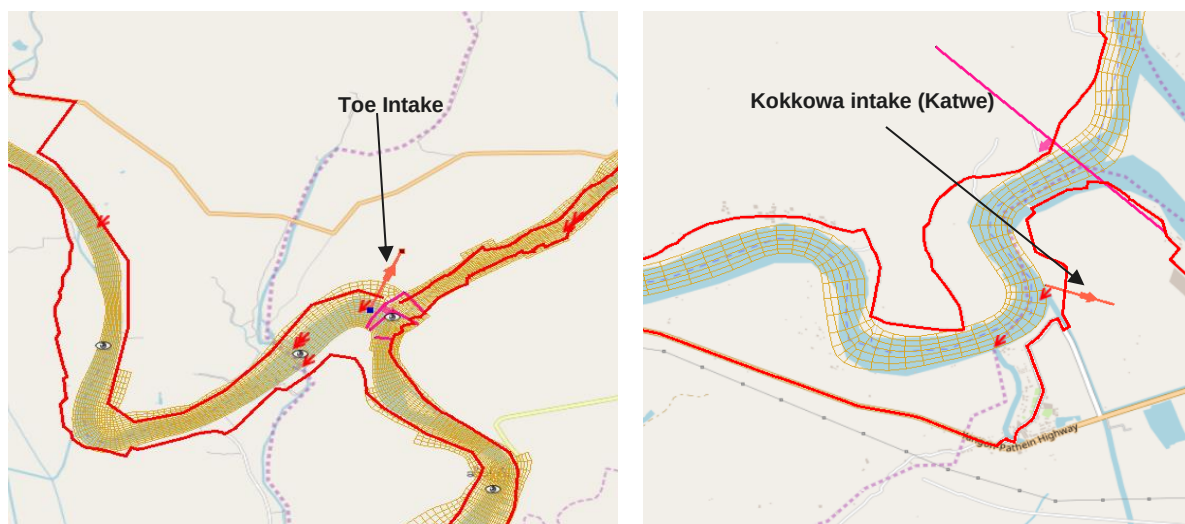


Figure 57: Locations of projected water intakes (e.g. freshwater extractions)

To be able to understand the impact of the new freshwater extractions on the salt intrusion, it is important to look at the discharge distribution through the delta, specifically during low discharge events. For the extraction in the Kokkowa River it is important to consider the river discharge distribution at the bifurcation at Nyaungdon where the discharge distribution is between 85%/15% and 90%/10%, depending on the season (i.e. 15% or 10% enters the Pan Hlaing River).

From the model runs it follows that any freshwater extraction in the Kokkowa River requires a compensation of approximately 10 times this extraction discharge at the upstream location Pyay. This extra upstream river discharge is required to maintain the current push back of the salt front. The same principle applies to freshwater extraction from the Toe River. In that river this multiplier is approximately 5. The simulations show that relatively small freshwater extractions in the delta (e.g. 3 m³/s) can have a significant impact on the salt intrusion.

Table 19: Return period for salt intrusion at key-locations, baseline and new fresh-water extractions intervention

Key Locations	RP [1 in years] (present)	RP [1 in year] (extractions)
Kokkowa intake (Katwe)	72	67
Unit03	<1	<1
NYCD	<1	<1
Maubin	12	11
21Mile	<1	<1
Udo	<1	<1
Dedaye	<1	<1
Pyapon	<1	<1

Qualitative impact on environmental indicators

As discussed in the hydraulic impact of the new intake points at the Kokkowa River, these are anticipated to have a minor impact on the overall hydraulic situation in the water system of the Hlaing and Kokkowa rivers. The increased extraction results in an increase of salinity intrusion by 10% which in its sense has an impact on a small area. As the area is very small, the overall impact on biodiversity is expected to be limited and the wider ecosystem is capable of dealing with such small change. Therefore, the environmental impact of this change is expected to be negligible (0).

Qualitative impact on socio-economic indicators

- Flood risk: no impact is expected (0).
- Water supply: Increasing extraction at Kokkowa/Toe rivers will enhance water supply for the adjacent areas, benefiting all functions (agriculture, households) (+). However, it will depend on the overall balance (availability of freshwater elsewhere) whether the net impact remains positive.
- Connectivity: Increasing the extraction of water at some point may affect the availability of freshwater supply elsewhere in the system. So, there may be negative impact (0/-).
- Employment generation: Compared to the other developments, no major direct employment impact is expected. However induced employment impacts can be expected if e.g. more water is available for agriculture (+).
- Equity in access: With more extraction points, a better access to freshwater supply can be expected (0/+), depending on how the availability of freshwater will change elsewhere.
- Pro-poor/poverty reduction: Enhancing water supply will generate opportunities for employment as well as improve health conditions (+).
- Navigation: No impact expected as the impact on water depths is marginal (0).
- Recreation: No impact (0).

Constructing new water extraction points at Kokkowa and Toe rivers is expected to generate a net positive (+) socioeconomic impact.

4.4 Future scenarios

The future is inherently unpredictable, which is why assumptions of possible changes must be made. Here, it is assumed that these possible changes cannot be influenced. Because, if they could be influenced, or controlled, they can be incorporated in a vision and strategy (Chapter 5).

A distinction is made between climate change scenarios and developments in the upstream Ayeyarwady River basin. It is assumed that for the water management of the delta, the implementation of dams upstream cannot be influenced. This may not be entirely true, as Myanmar national leaders can make such decisions on basin scale, but for this project it is assumed to be out of control and therefore included in the scenario analysis.

River basin projections and scenarios in this study have been developed based on publicly available sources. For the expected next phase of the project (i.e. feasibility studies of selected no-regret priority measures – Chapter 7), it is suggested to use time series to be obtained from the AIRBM Project.

4.4.1 Climate change scenarios

In Horton (2016) projections for climate change in Myanmar have been described related to river flows, sea level and precipitation. The projections show (like most areas world-wide) that extremes become more extreme. *Table 20* summarizes the used climate change scenario for 2040 based on the information in Horton (2016) and MoNREC (2016).

River discharges during wet season

Horton states that mean precipitation rates and thus river discharges will increase with 2-12% in the period until 2040, see *Table 21*. The average estimate for Myanmar (All Regions) is a 7% increase in flood discharges, which is adopted as the 2040 scenario.

Table 20: Summary climate change scenario year 2040

Parameter	Change in 2040
River flood discharge	+7%
River low discharge	-5%
Sea level rise	+20 cm
Cyclones	0% intensity, sea level rise +20 cm
Precipitation	+6% extreme events

Table 21: Changes in precipitation rates (Horton, 2016)

Town/city	Annual		Dry season (March to May)		Wet season (June to October)		Cool Season (November to February)	
	Low estimate	High estimate	Low estimate	High estimate	Low estimate	High estimate	Low estimate	High estimate
Myanmar (all regions)	+1%	+11%	-11%	+12%	+2%	+12%	-23%	+11%
Ayeyarwady delta	-1%	+11%	-13%	+18%	0%	+10%	-27%	+13%
Central dry zone	+2%	+11%	-14%	+13%	+3%	+12%	-32%	+9%
Northern hilly	+2%	+13%	-10%	+14%	+3%	+16%	-19%	+8%
Rakhine coastal	0%	+9%	-17%	+14%	+2%	+10%	-30%	+8%
Eastern Hilly	0%	+10%	-11%	+11%	+2%	+12%	-25%	+9%
Southern Coastal	-1%	+8%	-10%	+8%	-2%	+9%	-11%	+18%
Yangon Deltaic	0%	+12%	-12%	+19%	+1%	+11%	-29%	+14%
Southern Interior	+1%	+11%	-11%	+11%	+1%	+13%	-28%	+14%

River discharges during dry season

On average the change for low flows is around 0% (medium of low and high estimate: -11% and +12%; Horton, 2016). In addition, no indication is given on the duration of low flows. There is, however, consensus on an expected increase in frequency and magnitude of extreme events (floods and droughts) in the future. Therefore, an average of low and high estimates is considered too conservative. For this reason, a 5% reduction of lowest river discharges is used in the year 2040 because of climate change.

Sea level rise

Horton (2016) presents the sea level rise for the 25th and 75th percentile for the middle-range projections (Table 22). Up to 2030, the projected sea level rise varies between 5 cm and 13 cm, and for the period up to 2060, the projected rise is between 20 and 41 cm. Averaging these number gives an approximate 20 cm sea level rise per 2040 which has been taken into account.

Table 22: Projections for sea level rise (Horton, 2016)

Time slice	Middle range of future sea level rise
2020s	5 cm to 13 cm
2050s	20 cm to 41 cm
2080s	37 cm to 83 cm

Note: The middle range refers to the 25th and 75th percentile of model-based outcomes for sea level rise projections

Cyclones

In the Myanmar Climate Change Strategy and Action Plan (MCCSAP) 2016–2030 it is stated that future changes in the frequency, intensity and duration of tropical cyclones as a result of climate change are inconclusive (MoNREC, 2016). For the climate change scenario 2040 in RWSS it is therefore proposed not to alter wind nor pressure boundary conditions, but to incorporate solely a 20 cm increase of sea level.

Precipitation

Horton (2016) shows a range for changes in precipitation during the wet season from +1% to +11% representative for the Yangon Deltaic Region. As an average value an increase of 6% in precipitation intensity is considered for 2040.

4.4.2 Impact of the Climate Change scenario 2040

Impact climate change 2040 - fluvial flooding

The impact of the considered climate change scenario with respect to riverine flooding is summarized in the table below and Figure 58. An increase of 7% in peak river discharge (in combination with a 0.2 m sea level rise associated with this climate change scenario) results in an increase in river levels and frequency of flooding, mainly in the unit areas that were already shown to be prone to fluvial flooding. The increase in water level depends on location and return period, but amounts in general 10 to 30 cm. Especially the units in the center of the project area west of Yangon (units 3, 6, 7, 8 and 13) show a significant decrease in flood security level because of these higher discharges and water levels.

The calculated fluvial flood return period for unit 6 for example changes from a 1 in 67 years event in the baseline to a 1 in 39 year event in 2040. For unit 13 this is even worse: the calculated flood probability changes from a 1 in 118 years event now to a 1 in 35 years event in 2040.

Table 23: computed water levels Fluvial flooding (Baseline)

Fluvial flooding			River high water level [m+EGM] (Baseline)						
Return period [year]	Discharge [m³/s at Pyay]	Tide	Nyaungdon	Mezali	Maubin	KIP	Monkey Point	Twante 3.5M	Elephant Point
2	39481	Average spring	8.31	6.22	5.74	4.07	3.93	4.13	3.71
5	44522	Average spring	8.72	6.51	6.01	4.09	3.96	4.18	3.71
10	47860	Average spring	8.88	6.76	6.17	4.11	3.97	4.20	3.72
50	55206	Average spring	9.11	7.30	6.45	4.22	4.01	4.31	3.77
100	58311	Average spring	9.17	7.47	6.55	4.25	4.01	4.36	3.79
200	61405	Average spring	9.20	7.61	6.63	4.32	4.02	4.48	3.81

Table 24: computed water levels Fluvial flooding (2040)

Fluvial flooding			River high water level [m+EGM] (Baseline)						
Return period [year]	Discharge [m³/s at Pyay]	Tide	Nyaungdon	Mezali	Maubin	KIP	Monkey Point	Twante 3.5M	Elephant Point
2	39481	Average spring	8.56	6.45	5.93	4.23	4.14	4.36	3.93
5	44522	Average spring	8.88	6.76	6.19	4.25	4.16	4.39	3.93
10	47860	Average spring	9.04	7.15	6.34	4.32	4.18	4.46	3.95
50	55206	Average spring	9.18	7.52	6.58	4.45	4.21	4.59	4.00
100	58311	Average spring	9.21	7.65	6.67	4.53	4.22	4.67	4.02
200	61405	Average spring	9.24	7.75	6.75	4.60	4.23	4.79	4.04

Table 25: Water level increase for Fluvial flooding due to climate change (2040)

Fluvial flooding			Flood level increase [m] (2040)						
Return period [year]	Discharge [m ³ /s at Pyay]	Tide	Nyaungdon	Mezali	Maubin	KIP	Monkey Point	Twante 3.5M	Elephant Point
2	42245	Average spring	0.25	0.23	0.19	0.16	0.21	0.23	0.22
5	47639	Average spring	0.16	0.25	0.18	0.16	0.2	0.21	0.22
10	51210	Average spring	0.16	0.39	0.17	0.21	0.21	0.26	0.23
50	59070	Average spring	0.07	0.22	0.13	0.23	0.2	0.28	0.23
100	62393	Average spring	0.04	0.18	0.12	0.28	0.21	0.31	0.23
200	65703	Average spring	0.04	0.14	0.12	0.28	0.21	0.31	0.23

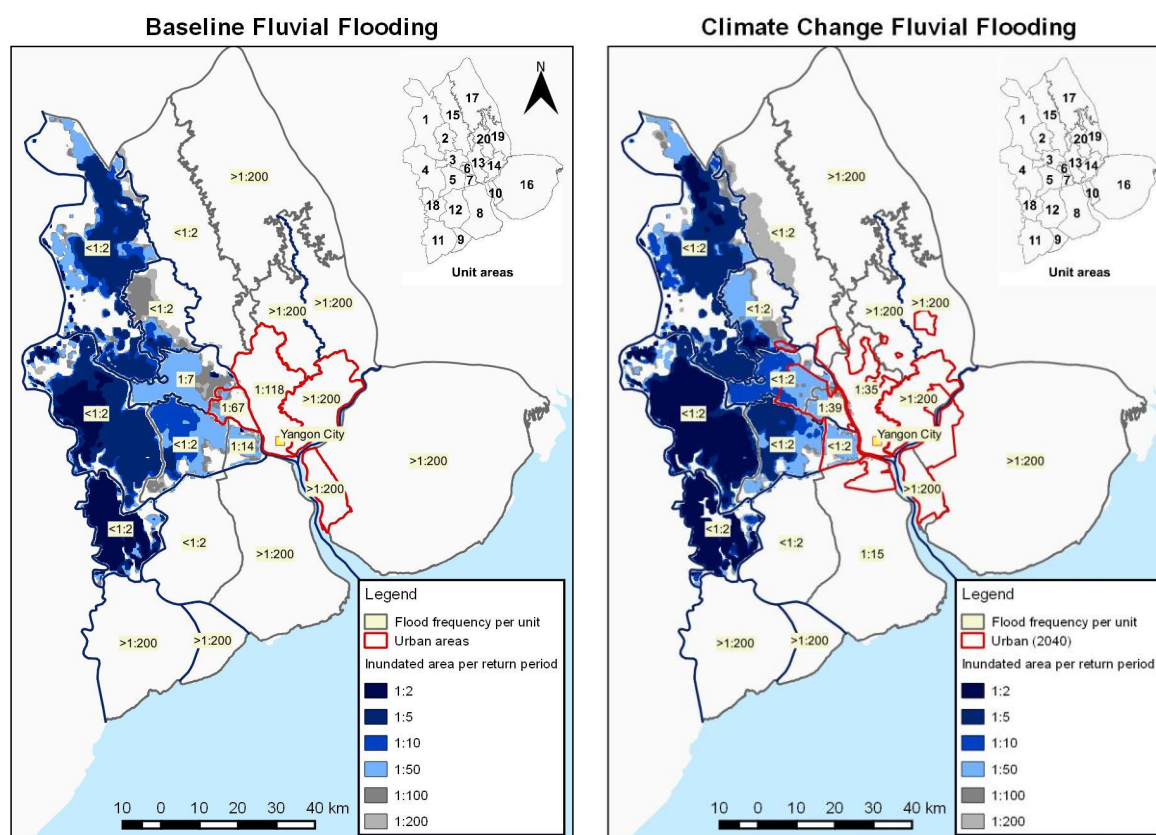


Figure 58: Riverine flooding water security now (left) and after climate change 2040 (right)

Impact climate change 2040 - coastal flooding

For coastal flooding, the impact of 20 cm sea level rise is shown in Table 26 and Figure 59. The water levels also increase by up to 20 cm with the larger increase being observed at the more coastal locations. Without exception, all units show a lowering of coastal flood safety. Most unit areas show an increase in coastal flooding frequency with some 15 to 25%, for example unit area 8 (South Yangon) which worsens from a calculated 1 in 54 years event in the baseline to a calculated 1 in 41 years event in 2040. The calculated coastal flood safety levels reduce most along the Hlaing River to the north. This is caused by the so-called funneling effect of the storm surge, which goes further inland with higher sea levels. The discharge at Pyay in these simulations corresponds to the average discharge at Pyay during the cyclone period.

Table 26: Flood table Coastal flooding (Baseline)

Coastal flooding			River water level [m+EGM] (Baseline)						
Return period [year]	Discharge [m³/s at Pyay]	Tide	Nyaung don	Mezali	Maubin	KIP	Monkey Point	Twante 3.5M	Elephant Point
25	4500	Average spring	7.74	4.49	4.51	4.07	4.05	3.95	3.69
50	4500	Average spring	7.74	4.49	4.51	4.32	4.29	4.19	3.90
100	4500	Average spring	7.74	5.00	4.82	5.28	5.11	5.15	4.54
200	4500	Average spring	7.74	6.00	5.43	6.13	5.78	5.88	5.09

Table 27: Flood table Coastal flooding (2040)

Coastal flooding			River water level [m+EGM] (Baseline)						
Return period [year]	Discharge [m³/s at Pyay]	Tide	Nyaung don	Mezali	Maubin	KIP	Monkey Point	Twante 3.5M	Elephant Point
25	4500	Average spring	7.74	4.60	4.58	4.23	4.23	4.11	3.88
50	4500	Average spring	7.74	4.60	4.58	4.5	4.47	4.40	4.08
100	4500	Average spring	7.74	5.13	4.91	5.4	5.27	5.32	4.71
200	4500	Average spring	7.74	6.08	5.47	6.2	5.93	5.99	5.24

Table 28: Water level increase for Coastal Flooding due to climate change (2040)

Coastal flooding			Flood level increase [m] (2040)						
Return period [year]	Discharge [m³/s at Pyay]	Tide	Nyaung don	Mezali	Maubin	KIP	Monkey Point	Twante 3.5M	Elephant Point
25	4500	Average spring	0	0.11	0.07	0.16	0.18	0.16	0.19
50	4500	Average spring	0	0.11	0.07	0.19	0.18	0.21	0.18
100	4500	Average spring	0	0.13	0.09	0.14	0.16	0.17	0.17
200	4500	Average spring	0	0.08	0.04	0.14	0.15	0.11	0.15

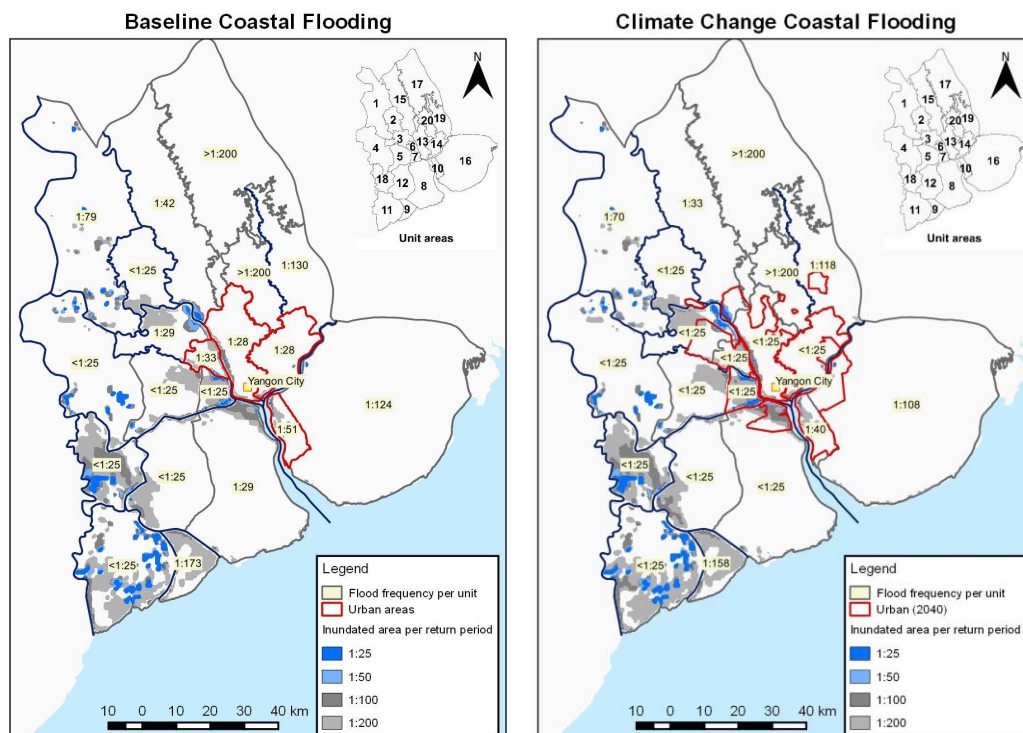


Figure 59: Coastal flooding water security now (left) and after climate change 2040 (right)

Impact climate change 2040 - combined river and coastal flooding

For 1 in 100 year fluvial and coastal flood events the increase in peak water levels due to climate change is shown in *Figure 60*. The two courses from Pyay to the Gulf of Martaban and the locations along these courses are shown in the map of *Figure 9*. The charts show that the increase in flood levels for fluvial flood events can be more than the 20 cm of sea level rise. This increase is due to the increase in flood discharge (in the reach Pyay – Nyaungdon) or due to the combination of increased discharges and sea level rise (Kokkawa-Hlaing River). In *Figure 60* the transition points from fluvial dominated to coastal dominated were shown to be situated near 21 Mile and Htantabin. Simulations with climate change have shown, that these transition points do not shift due to higher discharges and sea level rise.

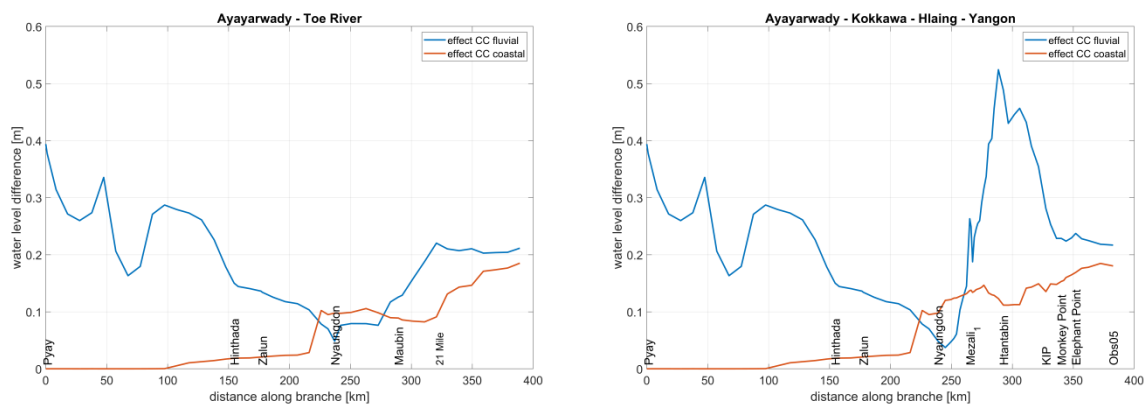


Figure 60: Increase in peak water levels due to climate change in 2040 for 1 in 100 year fluvial (blue) and coastal (orange) event

As fluvial and coastal flooding can be considered non-interrelated events, the flooding probabilities can be added giving the combined flood probability. These combined probabilities for the baseline and the projected climate situation in 2040 are shown in *Figure 61*. The maps show that due to climate change the combined fluvial and coastal flooding probability increases in areas already prone to flooding, especially in the central and southern parts of the project area. The spatial scale of the flooding is not expected to increase much.

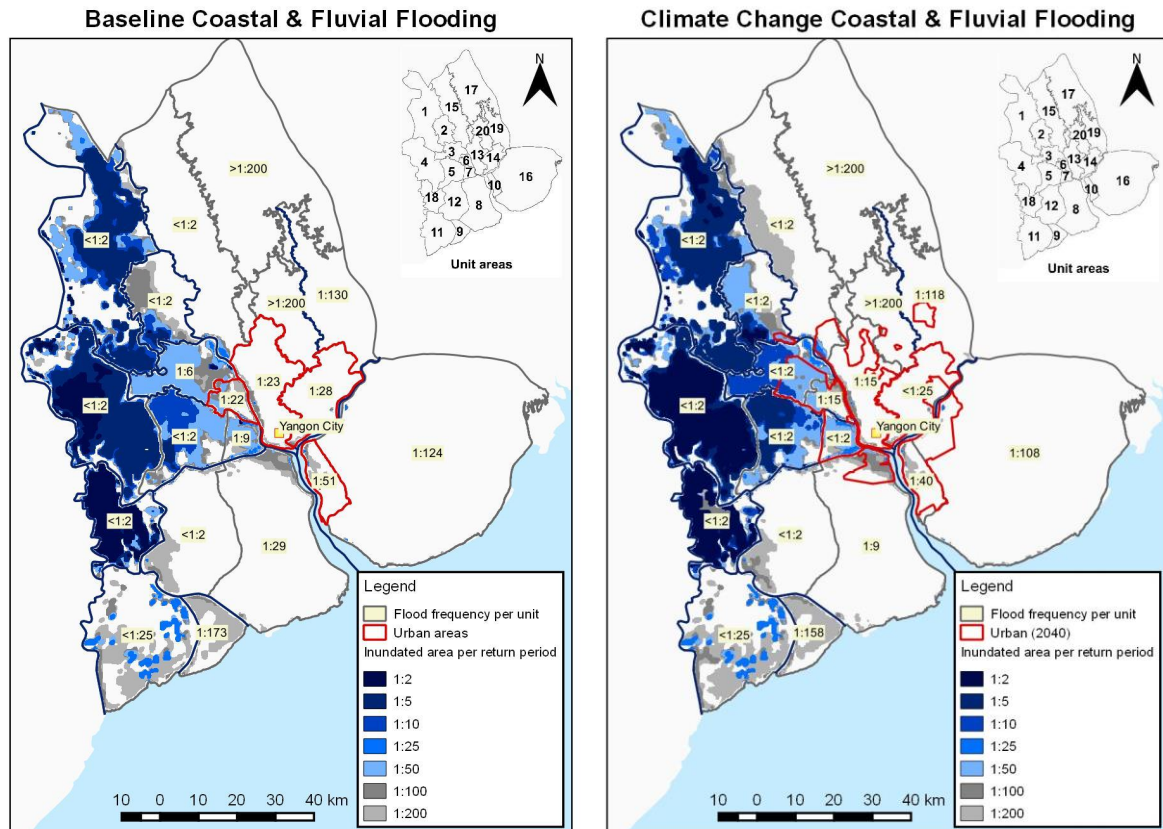


Figure 61: Water security combined flooding now (left) and after climate change 2040 (right)

Impact climate change 2040 - pluvial flooding

An increase in precipitation of 6% during extreme events, with equal drainage capabilities, results in an increase in pluvial inundation for all units. Based on the simulation results it can be concluded that the return periods of critical pluvial flooding events reduce with nearly a factor two, which means that such events will occur twice as often in 2040. Unit areas 6 and 10 are impacted more severely. Unit areas 5, 7, 8, 9, 12 and 17, however, maintain a pluvial flood safety of 1 in 1000 year or better.

Impact climate change 2040 - salinity intrusion

The effect of climate change on salt intrusion is quite significant (Figure 62). According to the model simulations, the critical level for salt intrusion in the Kokkowa intake at Katwe is expected to occur three times more frequently in 2040 than today (the return period decreases from 1 in 72 year to 1 in 21 year). The intrusion at Maubin (Toe River) is expected to occur yearly in 2040 (from 1 in 12 year to 1 in 1 year). Apart from an increase in the frequency of occurrence of reaching the threshold for freshwater intake at these locations, the combination of 20 cm Sea level Rise and a 5% reduction of extreme low river discharge allows the salt wedge to move further upstream in the river.

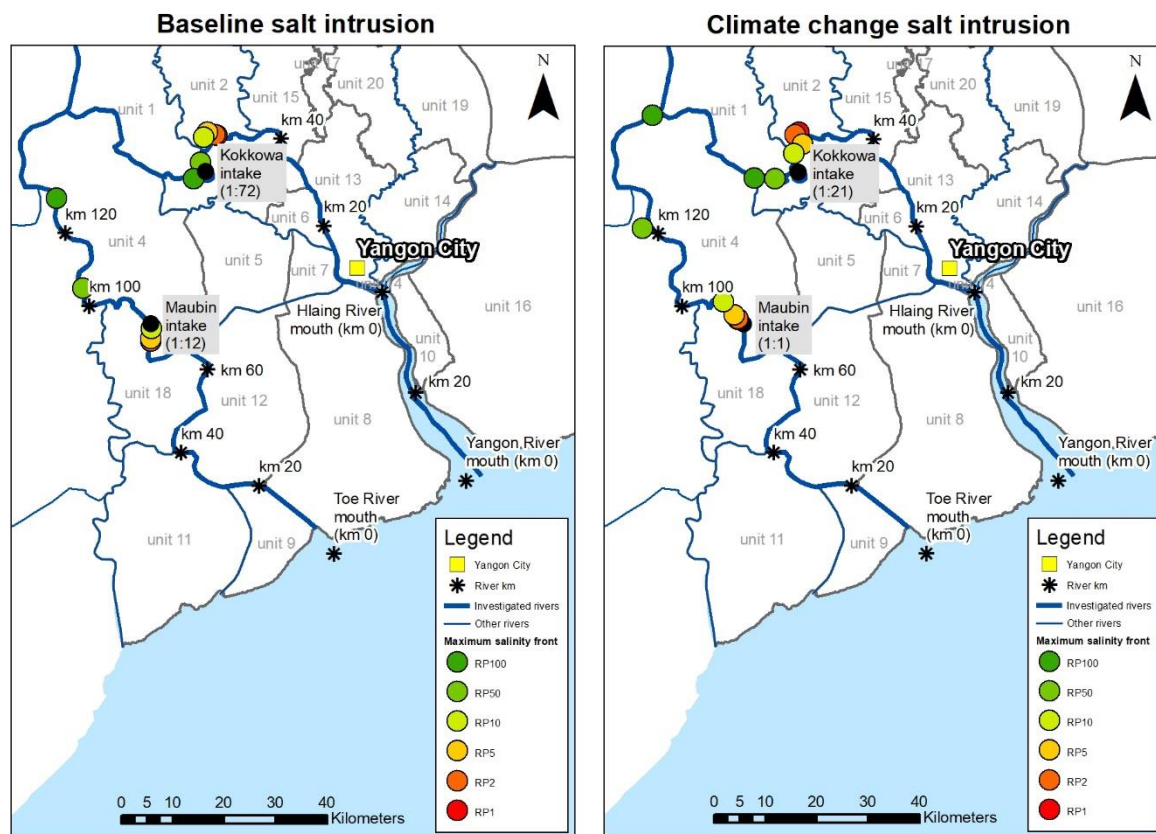


Figure 62: Return period for salt intrusion at key-locations - baseline and impact climate change

Qualitative impact of climate change on environmental indicators

Although climate change has a myriad of impacts on biodiversity and other environmental factors, only the impacts related to changes in the hydraulic system are considered below. In summary the impact revolves around:

- Increase in fluvial flood frequency,
- Pluvial flooding twice as frequently, and
- Salinity intrusion 2 – 3 times more frequently in certain areas.

The above changes have an impact on environmental factors as follows:

Biodiversity/Mangroves/Fresh-Saltwater gradient

As the increase in salinity intrusion affects the fresh-saltwater gradient and this mainly affects biodiversity and mangroves, these factors are considered together. The hydraulic assessment shows that salinity intrusion becomes 2-3 times more frequent in Maubin and Kokkowa intake (Katwe) respectively. This means that these areas are affected by increased salinity intrusion, which potentially affects the ecosystem. Although fish species can migrate between locations, freshwater species can change to more upstream locations where water remains fresh. Brackish/Saltwater fish that migrate can migrate with the saltwater wedge, which can increase potential spawning locations for them to reach.

Plants like mangroves are not mobile, therefore having to deal with local factors of the environment. The increasing salinity in some areas more upstream can prove to be beneficial for mangroves if they are given the chance to grow, since mangroves are able to cope with high salinity concentrations (Parida & Jha, 2010) compared to freshwater vegetation (Nielsen et. al., 2003).

Although the salinity intrusion will most likely cause changes in the distribution of fish species, these are expected to cope with the changes, as they are mobile. Freshwater vegetation might be impacted negatively by the change in salinity in more upstream areas, which in turn could prove to be beneficial for mangroves.

One aspect that should not be forgotten is that increased dry periods can affect both biodiversity and vegetation with less rainfall and lower water levels. Currently it is unsure how climate change will affect precipitation near Yangon in the dry season, as a WWF (2017) report on climate change impacts for Myanmar states that precipitation could differ between -11% or +12% annually for the hot season, although the tendency goes towards an increase. Nevertheless, even small increases in drought periods and recurrent longer droughts in summer or hot seasons could alter biodiversity in a region, resulting of certain plant species outcompeting others and fauna species either being severely reduced or outcompeted by others (Archaux & Wolters, 2006). Even though precipitation might increase in the hot season, the maximum temperatures or “extreme temperatures” are expected to increase, which most likely affect range-restricted species, slow-moving species, low-dispersal species and species already facing high threats (WWF, 2017).

Sedimentation/Erosion

Increased pluvial and fluvial flooding can also increase erosion due to the overflowing and subsequent draining of flooded areas (Wolanski & Elliot, 2016). This is known to cause erosion of especially barren, less vegetated areas and riverbanks. Thereby, the reduced freshwater pressure and increased tidal influence will cause sedimentation to reach further up the basin, increasing sedimentation in more upstream areas. This can negatively affect previously undisturbed ecosystems and reduce water depth due to increased sedimentation.

Climate change is therefore expected to negatively impact (-) sedimentation and erosion due to increased flooding and sediment inflow in upstream areas due to the tides.

Water quality

Linked to the increased erosion due to more frequent flooding, flooded areas can transport polluted stormwater and surface pollution (including more sediment) to the river systems (USGS, 2020). Although it is hard to quantify substantially at this stage, this could negatively impact water quality, although the dilution and discharge to sea is most likely reducing this impact. Until further research is available this impact should be considered negative (-).

Increased salinity from a purely environmental perspective cannot be considered as a negative impact to water quality, as it is the use of the water which either creates a negative or positive impact to species, amongst which social impacts relate to humans.

Invasive species

Climate change might impact invasive species, considering further salinity intrusion in the dry season might impact the ability to extract freshwater from the neighboring rivers. As this is only applicable to the dry season and therefore temporarily the effect can be considered negligible (0).

The overall conclusion is that climate change will not have a noticeable impact on the environmental indicators. This is largely because the delta system does not change that fast that environmental processes would not be able to catch up.

Qualitative impact of climate change on socio-economic indicators

- Flood risk: An increase of coastal, pluvial and fluvial flooding events is expected (--).
- Water supply: A probability that water scarcity may occur (mismatch demand and supply) as well as water quality issues due to salinity intrusion (-/-).
- Connectivity: Due to a greater chance of erosion and siltation, the connectivity of the water system may be negatively impacted (-).

- Employment generation: No direct impact expected as result of climate change itself. However, in case of an increase of flooding events and water scarcity, severe negative impacts are expected (--).
- Equity in access: With increasing freshwater scarcity and flooding events, the equal access of people will be negatively affected (-).
- Pro-poor/poverty reduction: Given the other impacts, poverty reduction will be negatively impacted (--).
- Navigation: Due to more flooding and siltation, obstacles for navigation can be expected (-).
- Recreation: No direct impact is expected on recreation, but some long-term impact may occur in case of an increase of flood events (0/-).

Climate change is expected to generate an overall negative socioeconomic impact.

4.4.3 Upstream basin developments

Upstream dam development in the Ayeyarwady catchment may alter high and low flow conditions in the delta. The Basin Exploratory Scoping Study (BESS) of the Future Ayeyarwady basin explored storylines to offer plausible and (moderately) provocative images of alternative long-term futures in the Ayeyarwady Catchment (Foran et al., 2019). It compares a baseline (2016) with a future (2055) scenario. In BESS a scenario of 21 hydropower dams, additional to 13 operational dams in 2016 (baseline), has been analyzed in a future dam-only scenario. This scenario comprised 27 billion m³ of storage volume. As the operation rules of the dams are not known, and based on information in IFC (2018), BESS assumed that each reservoir is operated as storage-backed dams. These fill during the wet season. During the dry season consequently, they operate with a uniform daily water release, to reach a specified drawdown level. These assumed operating rules maximize the impact of hydropower operations on the seasonal hydrograph.

BESS applied a hydrological model originally developed to support the SOBA surface water resources baseline assessment to assess the impact of dam development (Foran et al, 2019; eWater, 2018). The model was run with 36 years of historic climate data (1981–2016). The choice of model baseline was determined by the availability of inputs and observed calibration data sets.

Figure 63 shows modelled and observed monthly discharges, and the associated percentage deviations from the baseline scenario. Average monthly discharge in the lower Ayeyarwady showing flow at Pyay for each month comparing modelled scenarios and observations (left) and the percentage difference in monthly flows from the Baseline scenario (right) (Foran et al., 2019). During low flow periods, the difference between observed data and the baseline model scenario ranges from -20 to -40%. The results show that the model may not be suitable to predict absolute low flows values. However, comparing modelled scenarios with each other and relative to the Baseline scenario is informative. This is further described in the next paragraph.

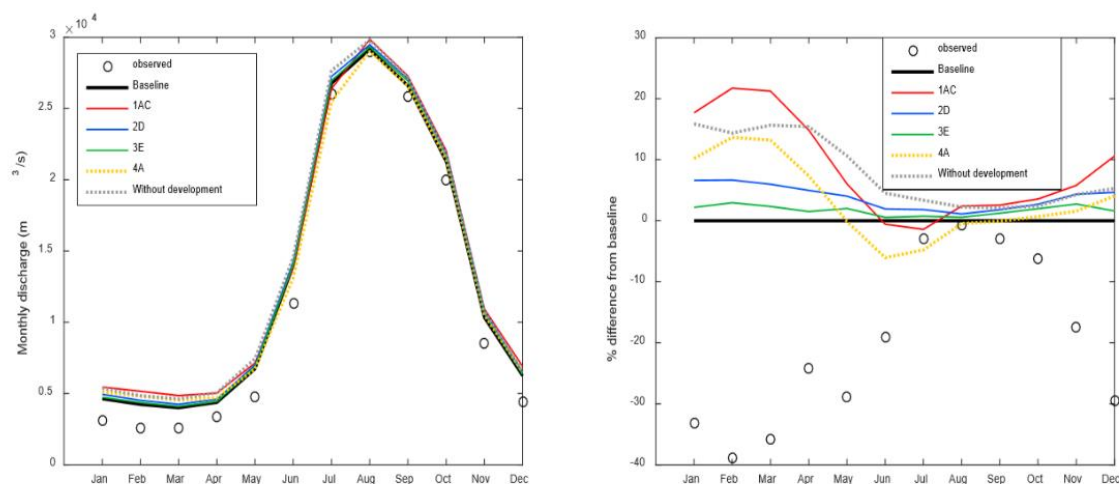


Figure 63: Seasonal discharge in the lower Ayeyarwady: modelled scenarios vs. observations.

Quantification of assumed impact

The comparison between the Baseline scenario and 'maximum' hydropower development (Scenario 4A) is given in Figure 63 (yellow dashed line). It shows an increase in the low flow period January-April of about +10% in discharge. During the wet season (August-September) the impact on flood discharges is negligible. These results are as expected based on the operation rules for hydro-power generation. In the wet season the reservoirs are expected to be totally filled. This leaves no additional flood storage in these months, while in the dry season the water is released from reservoirs in addition to the normal flow resulting in a slightly increased dry season flow. The impact of these expected changes on the water security in the project area is neutral for flooding and slightly positive for the salt intrusion indicator (see Appendix B).

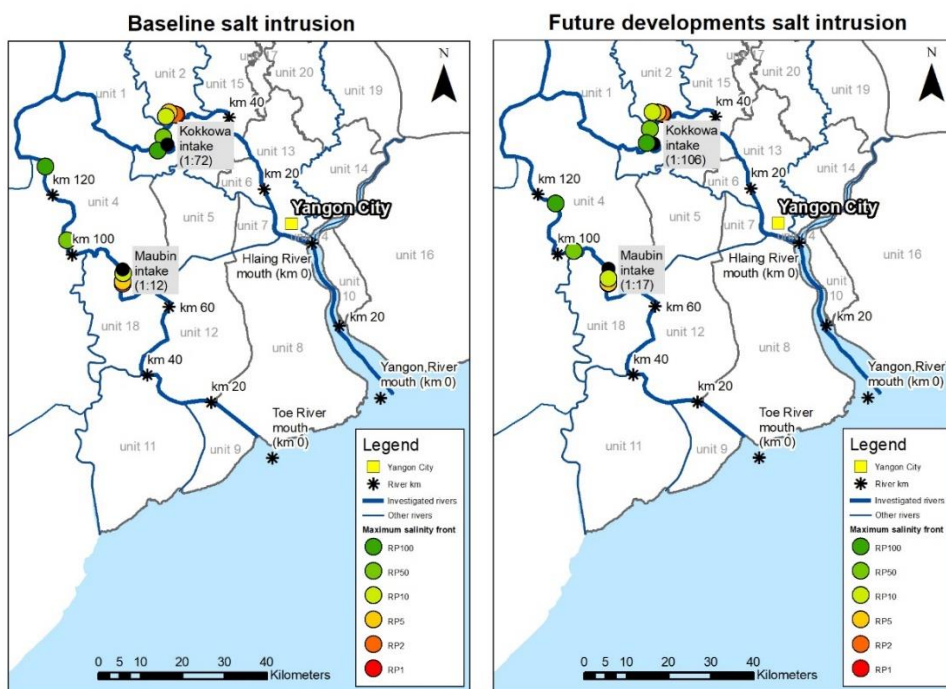


Figure 64: Return period for salt intrusion at key-locations – baseline and impact upstream basin developments

Model results – water scarcity

The expected impact on the water quality for the different intake stations is given in Figure 64. For the intakes at Kokkowa intake (Katwe) and Maubin, salt intrusion is expected to occur some 40% less frequently in 2040 as a result of the changed retention capacity upstream (Kokkowa intake (Katwe): from once per 72 y to once per 106 y, for Maubin: from once per 12 years to once per 17 years). However, the location of the salt wedge remains located upstream of the other key-locations, which means that the frequency of salt intrusion at these intakes stay once per year or more frequent.

Qualitative impact on environmental indicators

Basin development for storage of water and hydropower generation is known to have significant environmental impacts. These impacts are rather complex, and any hydropower/basin development will require a detailed ESIA to be developed upfront to assess potential impacts.

- Fresh/saltwater gradient. As changes in the salinity intrusion is limited, this is not anticipated to significantly alter the fresh/saltwater gradient and can therefore be considered to have a negligible (0) impact.
- Sedimentation/Erosion. Nutrient rich sediments coming from upstream rivers are blocked by dams, therefore having potential impacts on downstream rivers in the sense of “sediment starvation”. This

can impact both floral and faunal species. On the other hand, sediment clearing that happens as part of dam maintenance can temporarily increase sediment loads in the downstream river areas, which can have impacts on fish species, as water becomes more turbid and on bird species that are hunting based on sight. For the above reasons, sedimentation is negatively (-) impacted. Erosion can become more severe near the dam areas and the borders of the storage basin, therefore potentially requiring embankment reinforcing. In case these reinforcements are not included in the project plans, erosion can be negatively (-) impacted.

- Water quality. Dam maintenance can increase the sediment load of the water temporarily, reducing water quality. As this is a temporary effect over the entire water system, the water quality impact might be diluted more, the impact can be considered negligible (0). Localized effects should however not be underestimated, especially directly downstream of the dams.
- Biodiversity. The development of a basin can result in the inundation of previously dry areas, therefore impacting terrestrial species. Although the basin can be seen as a freshwater habitat for fish species, fish species that were dependent on migration between downstream areas will no longer be able to do so without the proper mitigation measures in place. It is hard to detail these impacts in a more granular way at this stage, but without proper mitigation measures (which are currently unknown) impacts on biodiversity are considered negative (-).
- Invasive species. Basin development could lead to the increase in aquaculture as people see potential with the increased water availability in their region. If this is the case, chances of negative impacts of invasive species could come up. Again, this is related on how aquaculture is implemented. Closed-off ponds will have a smaller potential for negative impact than netted areas inside the basins and river areas. Without further research and understanding of aquaculture in the upstream areas, this factor is scored negative (-).

Qualitative impact on socio-economic indicators

- Flood risk: No impact if the basins cannot cater for additional flood storage. If there is additional storage capacity, then this would be beneficial (0/+).
- Water supply: No impact if the basins are only meant for power generation. In case of combination with water supply, then this would be beneficial (0/+)
- Connectivity: Building dams and reservoirs upstream may negatively impact the connectivity of the water system in Myanmar, triggering problems further downstream concerning water supply, siltation, erosion (-).
- Employment generation: Availability of (hydro)power is essential to any economic development. In the case of additional capacity for flood management or freshwater supply, this would further enhance employment opportunities (+/+++).
- Equity in access: Increasing power supply will be beneficial for creating more equal access to job opportunities, education for people. However, building reservoirs and dams may also involve resettlement issues. Furthermore, the impact should be considered in relation to the connectivity issue, mentioned above. Taking all of this into account, the overall score is assessed as (0/+).
- Pro-poor/poverty reduction: Given the other impacts, a net positive impact on poverty reduction can be expected (0/+).
- Navigation: No impact on navigation is expected if there is no impact on flood discharges. Maybe also too far upstream to really impact navigation. The increased dry season flow may give slight positive impact, but it is doubtful whether this will happen in the more extreme prolonged droughts (0).
- Recreation: No impact expected on recreation (0).

Upstream basin development is expected to generate an overall positive (+) socioeconomic impact with some caveats, relating to issues of resettlement and connectivity.

4.5 Flood risk assessment

The flood frequency values of the unit areas for coastal- and fluvial flooding (Section 3.3) give an indication on how often the maximum water level – which has been calculated with the RWSS hydrodynamic model – is higher than the crest level of the embankments and riverbanks along each unit area. The result is inundation of the hinterlands, of which the extent (which areas flood) is given as output of the model. During the baseline assessment it has been observed that extent of the inundation and the flood frequency are not directly intertwined and vary largely per unit area and flood event.

To make the effects of flood events more quantifiable, with a better indication of the locations where measures are needed the most, the economic and social impacts of flood inundation have been calculated for fluvial- and coastal flooding events. This section describes the approach and the results of the flood risk assessment that is carried out to deliver input for the selection of potential measures.

4.5.1 Approach of flood damage analysis

The following steps have been followed to determine the economic impacts on a spatial scale, which is described as the expected annual damage (EAD);

1. Preparation of inundation maps from the RWSS hydrological model;
2. Inventory of flood damage curves for specific land use types;
3. Development of land use maps for the current situation and for the situation in 2040;
4. Calculation of damage from single flood events; and
5. Calculation of expected annual damage for coastal and fluvial flooding.

Step 1: preparation of inundation maps from the RWSS hydrodynamical model

Flood damage is related to the depth of the inundated areas of a flood event. The RWSS hydrodynamical model delivers spatial outputs of inundated areas, which have been interpolated to a grid of 100x100 meter for the entire flood extent of each simulation. With this, the maximum flood depth has been determined to deliver input for the flood risk assessment. The model simulations that are used as input for the flood risk assessment are presented in *Table 29*.

Table 29: Used model simulations for the flood risk assessment

Extreme event	Return periods of single flood events
Coastal flooding (baseline situation and climate change situation)	1 in 25, 1 in 50, 1 in 100 and 1 in 200 years
Fluvial flooding (baseline situation and climate change situation)	1 in 2, 1 in 5, 1 in 10, 1 in 50, 1 in 100 and 1 in 200 years

Step 2: inventory of flood damage curves

Huizinga investigated and formulated flood damage curves and maximum damage values for various land use types under the Yangon Flood Model project. For various sets of land use types, the maximum potential damage including the relation to the water depth have been formulated and are shown in *Figure 65*. Based on the available information and land use maps of the area, seven land use classes have been formulated (*Table 30*) (Huizinga, 2019).

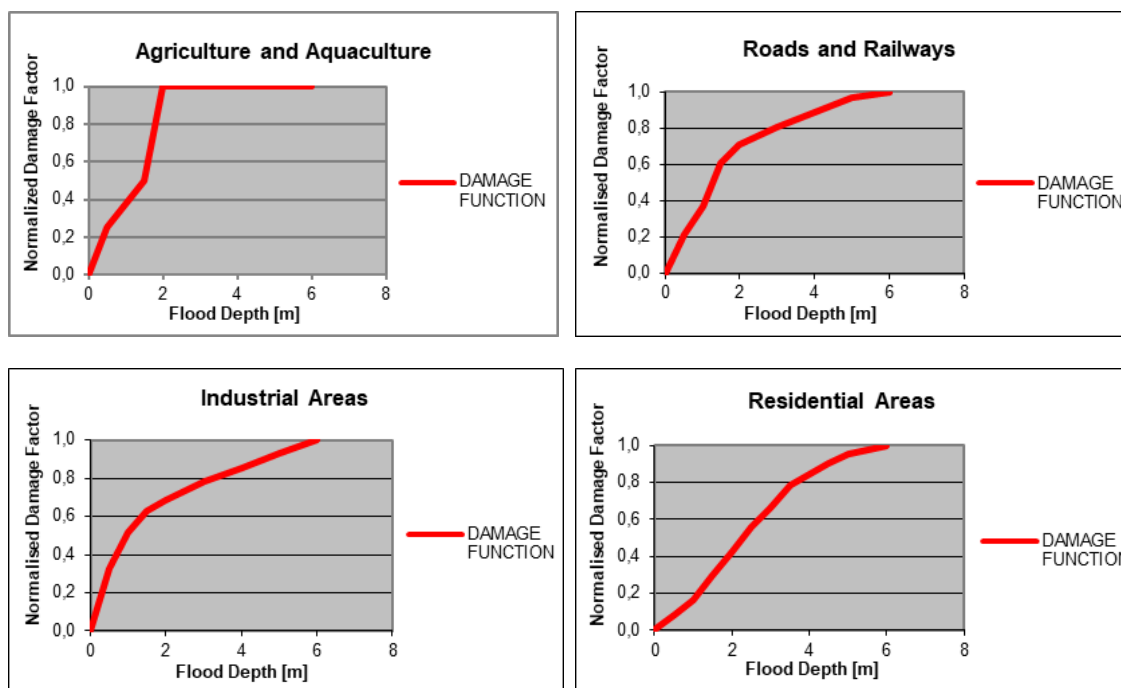


Figure 65: flood damage curves for agriculture, aquaculture, domestic buildings, industrial buildings, roads and railways.

Table 30: maximum damage per land use class

Land use class	Maximum damage (MMK/m ²)	Remark
Agriculture	101	
Aquaculture	303	3x larger damages per m ² than paddy
Built-up Yangon	175,395	36% of the urban area is covered by buildings
Built-up Industrial	102,657	29% of the industrial area is covered by buildings
Built-up rural	136,886	33% of the town area is covered by buildings
Roads	6,000	
Railways	600,000	

Built-up areas

The maximum damages for buildings are given in the order of MMK/m² for different types of buildings. To connect this to the land use maps, the maximum damage is reduced to the percentage of surface area that is built-up. A distinction is made between built-up areas in Yangon, rural communities outside Yangon and industrial areas. With Open Street Map data (source: <http://download.geofabrik.de>) the typical percentage of buildings per surface area is determined by calculating the percentage of footprint of buildings for representative locations. The types of buildings are different between the areas inside Yangon and rural built-up areas. For built-up areas inside Yangon, higher damages can be expected as the buildings are built to more modernized standards compared to rural buildings. The resulting percentages of built-up surface area and the maximum damages are shown in Table 30.

Step 3: development of land use maps for current situation and 2040

Existing land use maps have been collected and analyzed to select the most suitable land use map that can function as base for the flood risk assessment. The resolution of the data and the date of the source were considered as important criteria for this selection. This resulted in using the land use map SERVIR Mekong from 2018 as a basis ((USAID, NASA, ADPC and ICIMOD, 2018). The map classifies the land use with a resolution of roughly 40 by 40 meters. To make this data useful for the flood risk assessment, the classes have been re-categorized to the classes that are considered by the damage curves. The adjustments of the land use maps are described in *Table 31* and the text below.

Table 31: land use classes used for the flood risk assessment

Original land use classes	Land use classes for damage calculations	Remark
Cropland and Rice	Agriculture	The “rice” land use class covers in most of the flood prone areas . However, a minor part of these areas is in the land use map indicated as “cropland” and is limited prone to flooding based on the inundation maps of the hydrodynamical model. Based on local field knowledge, paddy fields are expected in these areas. Due to the limited contribution to the total damage it is decided to give these “cropland” areas the same damage contribution per areas as paddy fields.
Aquaculture	Aquaculture	
Built-up	Built-up Yangon	
Built-up	Built-up Yangon Industrial	
Built-up	Built-up Rural	
Not included	Roads	Data from MIMU added to the land use map
Not included	Railways	Data from MIMU added to the land use map
Surface water, mangroves, forests, orchard or plantation forest, evergreen broadleaf, mixed forest, wetlands and shrubland.	Other	Insignificant damages

The table shows three different land use classes for built-up areas, in agreement with the difference in maximum damages between built-up and industrial areas in Yangon City and rural built-up areas.

Roads and railways are not included in the land use map of SERVIR Mekong (SERVIR Mekong, 2020). Therefore, these land use types are manually included by using datasets derived from MIMU (MIMU, 2020). The roads and railways have a typical width of 10 m and 5 m respectively. Smaller (dirt) roads are not considered.

The category “other” considers all land use classes that are less prone to flooding, such as wetlands, or classes that are not very common. The contribution of the land use classes to the total damage is relatively scarce and is therefore neglected in the damage calculations. Another reason for not including some land use classes is because they occur mainly at higher elevations and are not prone to flooding.

For the situation in 2040, the land use map of the current situation has been adjusted for the simulations that consider a potential future expansion of Yangon City. How the city will expand is rather uncertain. Therefore, the land use map from the JICA Yangon Masterplan 2040 (JICA, 2018) has been used as a basis, with some additional developing areas that have been identified throughout the RWSS project (*Figure 66*). First, the land use map of the JICA Masterplan has been digitized with GIS software, including satellite imagery to identify the expansion’s boundaries, which are mainly existing roads.

Furthermore, a difference has been made between areas that will be mainly industrial in the future, and areas that will be mainly built up by housing.

Besides the JICA Yangon Masterplan, other urban development projects have been included such as the New Yangon City project (**A** in Figure 66) and the Htantabin Industrial Zone project along the northern bank of the Kokkwa River and north-west of Yangon City (**B** in Figure 66).

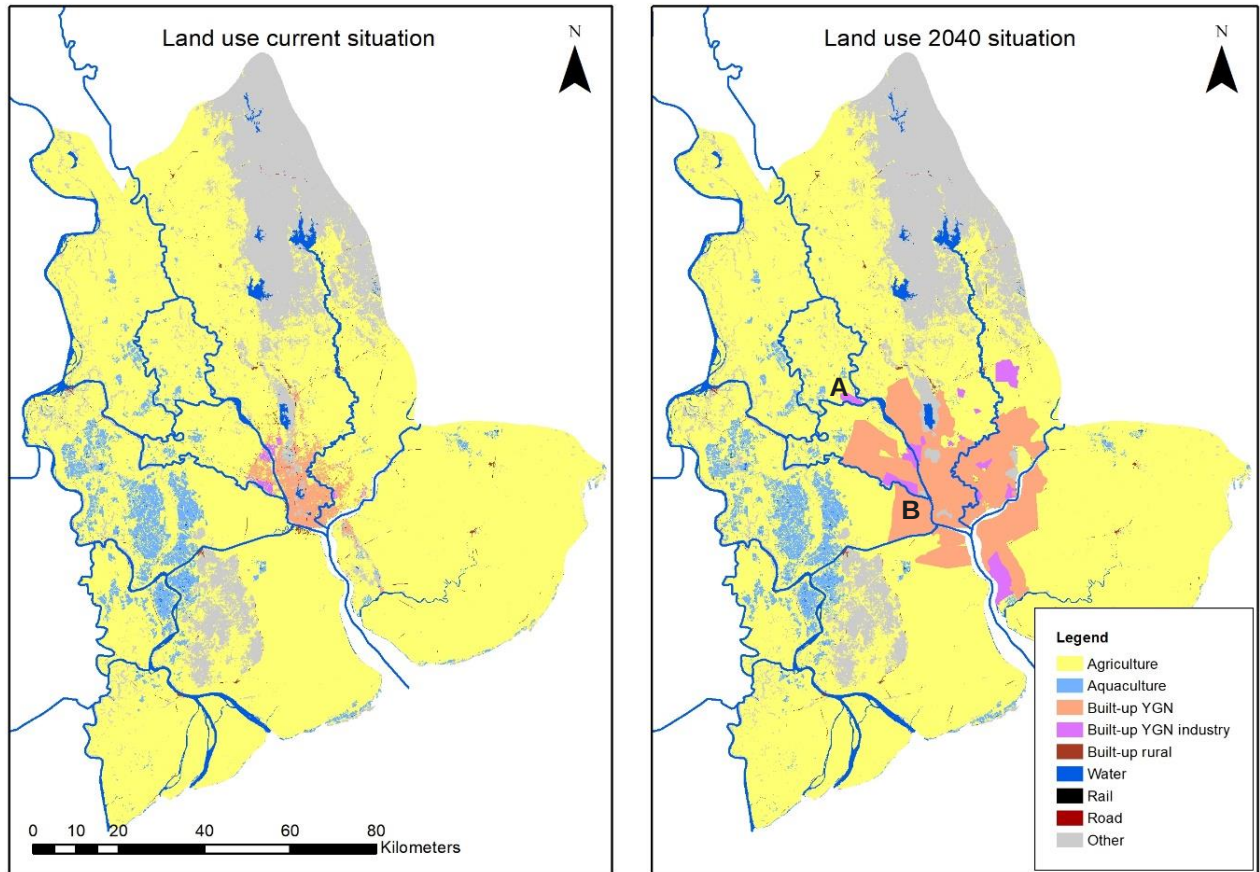


Figure 66: land use maps for the current situation and 2040 reclassified and adjusted for the flood risk assessment

Step 4: determination of damage from single flood events

With the land use maps and the flood damage curves for each land use class, the flood damage is calculated for all coastal- and fluvial flooding events. For every individual location, the inundation depth is used to determine the damage factor (Figure 65). This factor describes the percentage of the maximum damage and is therefore multiplied with the maximum damage to determine the actual damage for each location. The result of this analysis is a raster dataset that shows the geographical distribution of flood damage for each individual return period.

The sum of the spatial distributed flood damage is input for the annual expected damage (AED) - calculation. The distributed flood damage was summed per land use type. For agricultural land use, fluvial flooding with return periods lower than 10 years are assumed to be beneficial. The positive effect cannot be monetarized in the damage calculation. However, the negative effect (damage to agriculture for RP less than 10 year) is left out of the calculation of the AED.

Step 5: determination of expected annual damage

The expected annual damage for every location is calculated using the results of the expected damage for each return period. The equation used to determine the expected annual damage is:

The annual expected damage is calculated as:

$$AED = \frac{1}{RP_n} \cdot D(RP_n) + \dots + \left(\frac{1}{RP_2} - \frac{1}{RP_1} \right) \cdot \frac{D(RP_2) + D(RP_1)}{2}$$

In this equation:

AED = Annual Expected Damage

$RP_{1:n}$ = Return Period from 1 (smallest) to n (largest)

$D(RP_n)$ = Damage for flood event with return period RP_n

4.5.2 Approach to determine flood affected people

Additional to the expected damage of flood events, the number of affected people is calculated. For this study, "affected" is used with the meaning that water depth exceeded the threshold of 0,6 meter for rural unit areas and 0,3 meter for urban unit areas (Section 2.2.1). The lives of the people are affected in a way that transport and their occupation cannot proceed as usual. The following steps are followed to determine the number of floods affected people per year for coastal- and fluvial flooding.

1. Spatial distribution of the population in the project area;
2. Threshold values for inundation depth;
3. Calculation of flood affected people per simulation; and
4. Calculation of annual flood affected people.

Step 1: spatial distribution of the population in the project area

A common source for population data is the Myanmar National Census from 2014. This information describes the number of people for each township, but the distribution of the population within each township is unknown. Therefore, the spatial population maps from (*Worldpop, 2018*) are used instead, which shows the estimated number of people per pixel (90x90 meter). The dataset from 2018 (adjusted to UN national estimates) is used as a basis for determining the number of flood affected people. Within the RWSS project area, the population per ~90x90 meter varies between 0 people per pixel in remote rural areas and 700 people per pixel in Yangon City.

Step 2: threshold values for inundation depth

Together with stakeholders from various governmental departments, the maximum acceptable flood depth is set to 0,3 meters (~1 foot) for urban areas and 0,6 meter (~2 feet) for rural areas. For every unit area, a single threshold value has been set based on the dominant land use. Unit areas 06, 10, 13 and 14 are set as urban areas which cover Yangon City and its major suburbs. The other unit areas are set as rural.

Step 3: calculation of flood affected people per simulation

The same inundation maps as used for the flood damage analyzes have been used as basis to determine the number of flood affected people for each simulation. First, the dataset is adjusted to filter out all inundation depths that are lower than the threshold value. The remaining inundated areas are used to select grid cells of the Worldpop data (*Worldpop, 2018*). This results for the number of affected people for each grid cell, which is either 0 or the total number of the population. The results are maps indicating where people are affected, and how many.

Step 4: calculation of annual flood affected people

To calculate the estimated affected people per year, the results the total number (n) of simulations with a different probability are included. The equation below is used. This analysis is done for every single pixel to create a spatial distribution of affected people. Note that this parameter is an average (between

the different numbers of people affected in frequent and extreme events) used for comparison, it does not imply that every year this number of people will be affected.

$$\text{Annual flood affected people} = \frac{1}{2} \sum_{i=1}^n \left(\frac{1}{T_i} - \frac{1}{T_{i+1}} \right) * (D_i + D_{i+1})$$

In this formula:

N = number of simulations
 T = return period of a specific simulation
 D = number of affected people

4.5.3 Results

Expected annual damage

Figure 67 shows the expected annual damage for the baseline situation of coastal- and fluvial flooding. It distinguishes more vulnerable areas which are exposed to flooding. The annual damage for Yangon City is singularly caused by coastal flooding, whilst other areas such as the north-western unit areas, are mainly at risk for fluvial flooding. The rural areas on the western side of the Yangon River such as Dala, are to a larger extent prone to flooding. As the city will expand towards these more flood prone areas, the annual expected damage is expected to become larger. This has been investigated by including the future expansion of Yangon City in 2040 into the land use map, but not accounting for potential growth of populations. The annual expansion of this specific situation is given in Figure 68. Additional flood protection measures are not considered into the model simulations. As sea level rise is included in these simulations for 2040 land use, the extent of inundation is larger. Because of the change in land use from rural (mainly agriculture) to urban housing and industries, the annual damage increases significantly. The results of this assessment are used to develop the flood protection program described in Chapter 5.

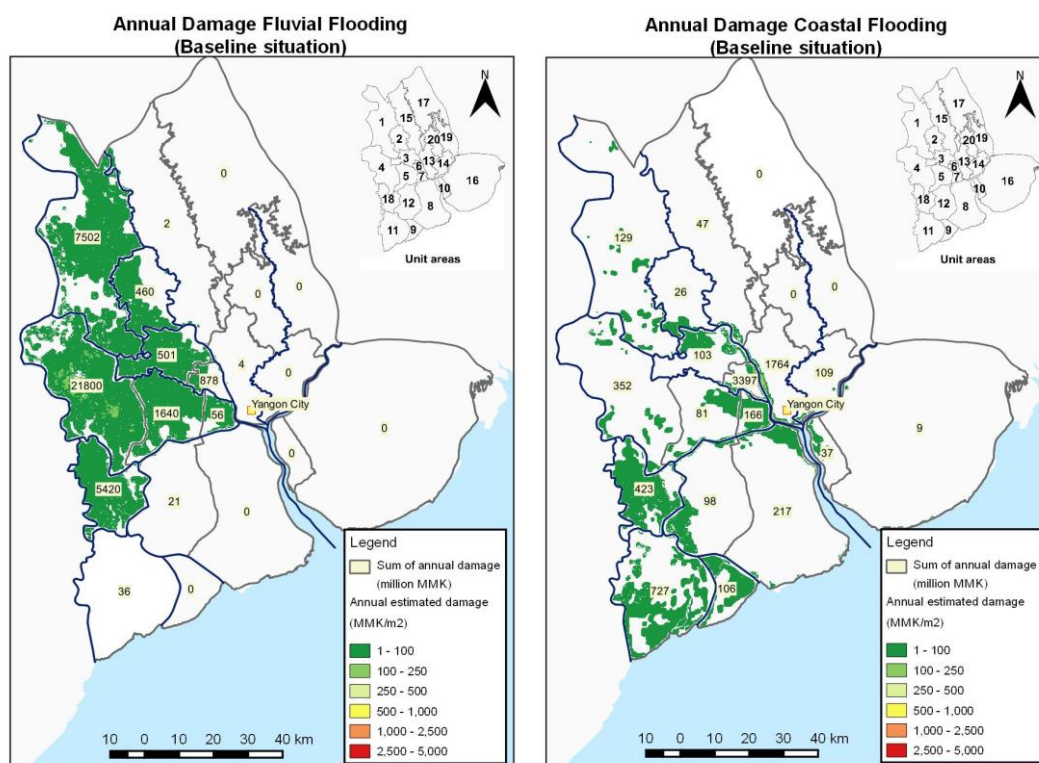


Figure 67: the expected annual damage for fluvial flooding (left) and coastal flooding (right) for the baseline

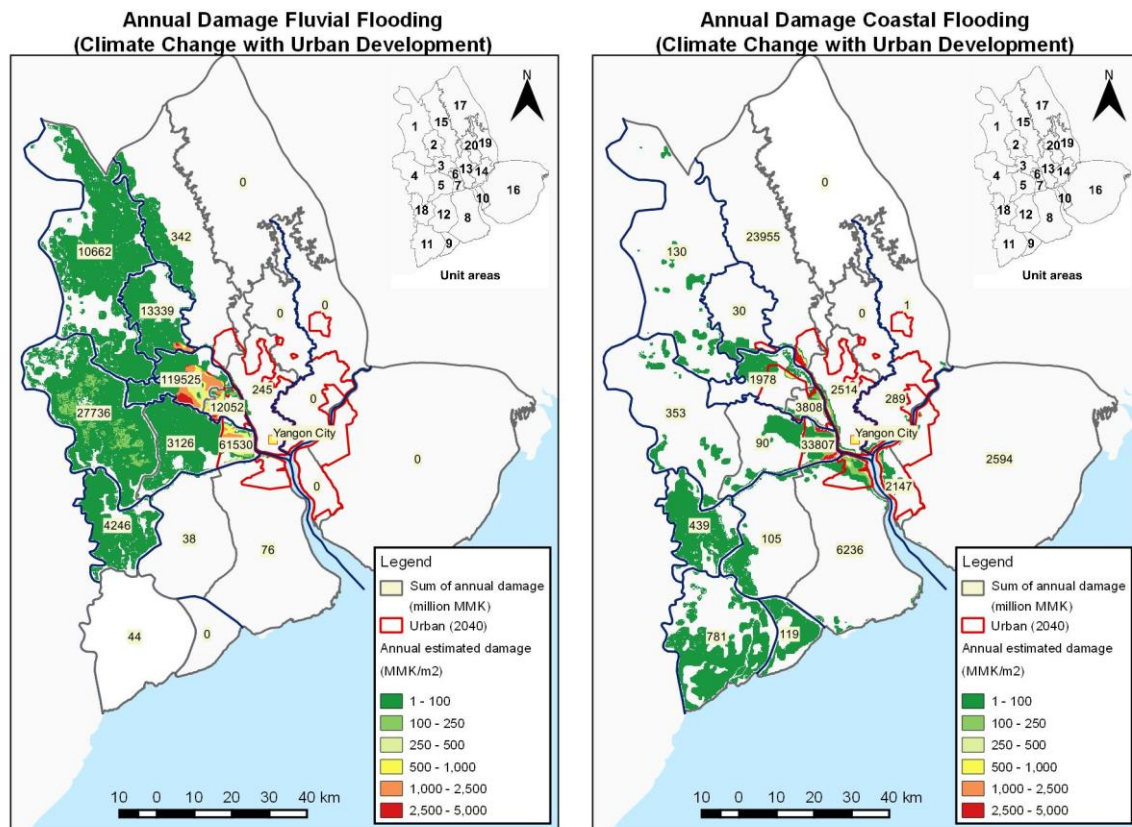


Figure 68: the expected annual damage for fluvial flooding (left) and coastal flooding (right) for the climate change scenario plus urban expansion of Yangon City

Annual flood affected people

The annual affected people by fluvial flooding and coastal flooding are shown in Figure 69 for the baseline situation and in Figure 70 for the future situation with climate change but without considering the population growth. In general, more people are potentially affected by fluvial flooding than by coastal flooding. This is because larger areas are being flooded with greater inundation depths.

For the fluvial flood hazards, the largest number of affected people is predicted in Nyaungdon Island and Pan Hlaing Island and in particular along the riverbanks of the Kokkwa River. For coastal flooding, the low-lying areas at the eastern bank of the Yangon River have the largest number of affected people due to a relatively high population density. The impact of climate change is noticeable in many areas and only caused by the greater extent of flooded areas for a specific return period. In reality these numbers will be likely much higher if population growth is accounted for. Due to lack of any demographic prediction, however, such an estimate is not possible in the current study.

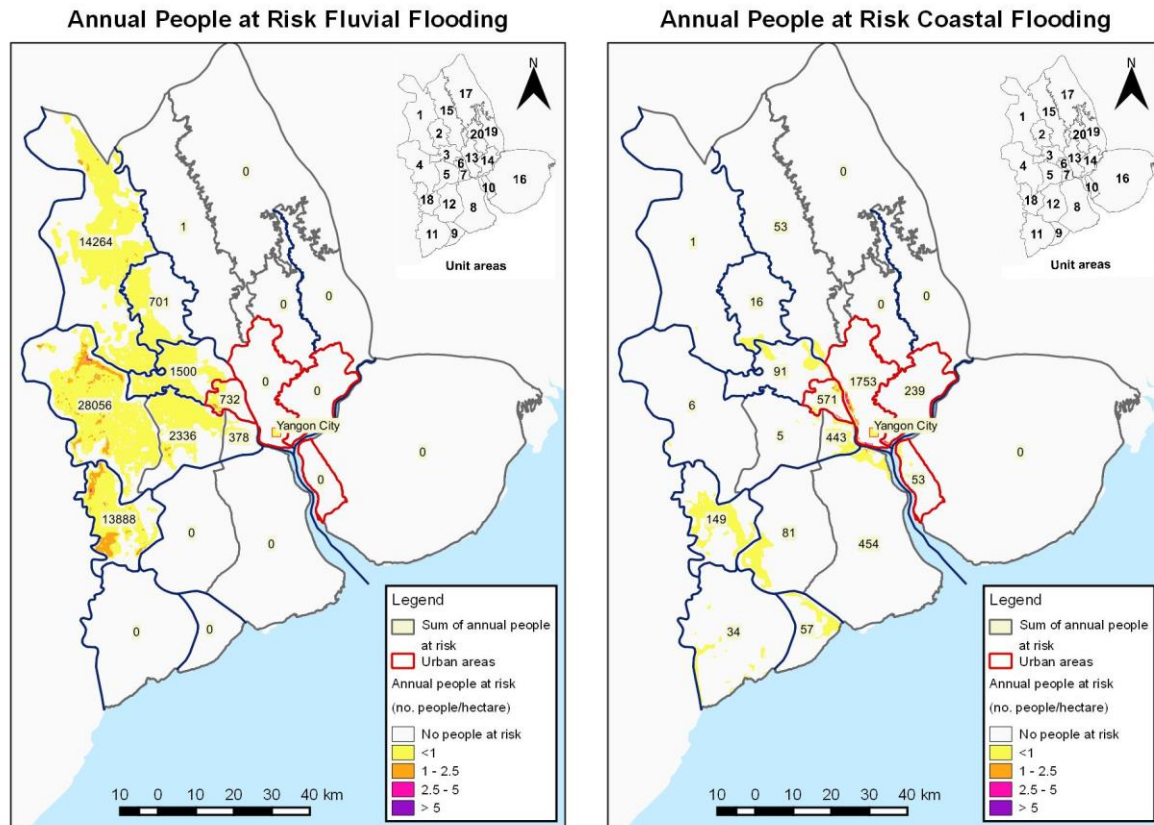


Figure 69: annual affected people for fluvial flooding (left) and coastal flooding (right) baseline situation

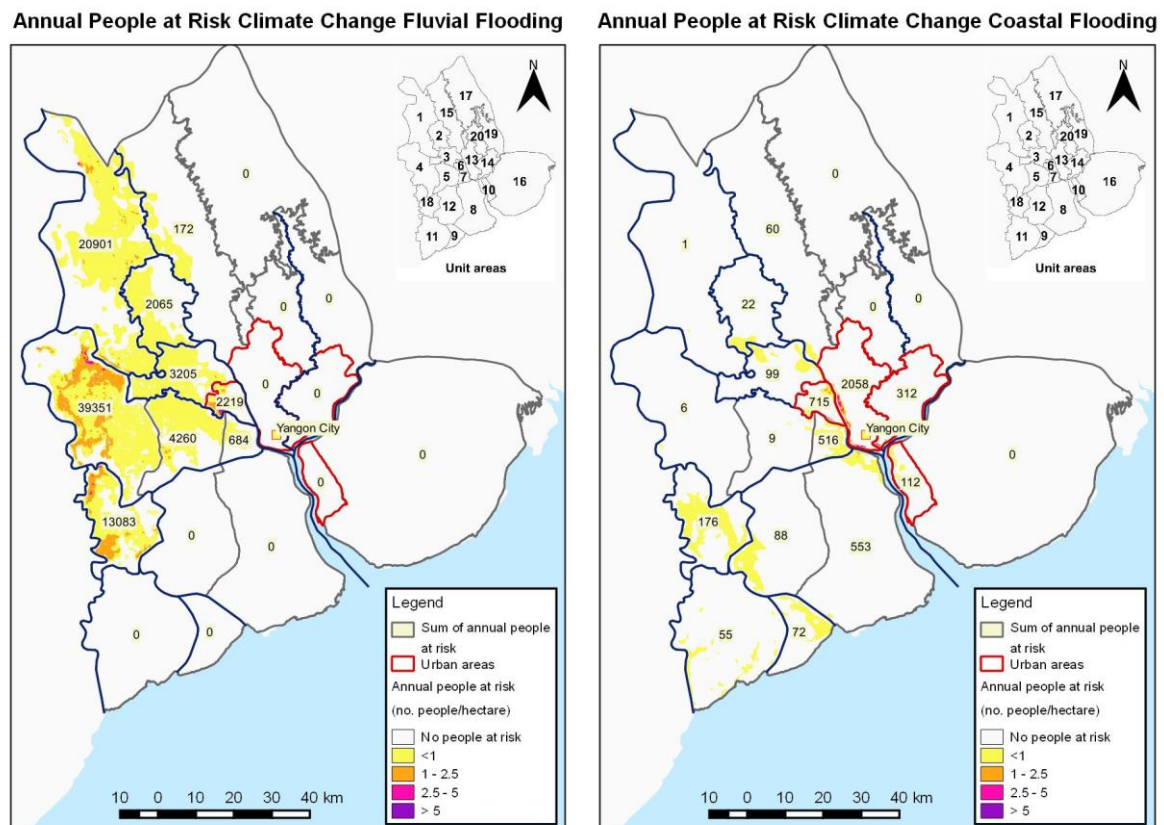


Figure 70: annual affected people for fluvial flooding (left) and coastal flooding (right) with climate change 2040

4.5.4 Sanity check flood risk assessment

A sanity check is done to compare the calculated results from the flood impact calculations, with experiences from flood events in the past. The most severe (recorded) event was Nargis in 2008. This event has been simulated with the flood model as a combination of a storm surge plus extreme rainfall. It was found that the calculated and observed inundated areas look much alike.

To do the sanity check, the same approach for determining the 'economic damage' and 'number of affected people' from flooding has been used as described in this chapter. The results are compared below with observed impacts published by United Nations:

- 2.5 million people were seriously affected, and
- total economic damage estimated at 12.9 billion USD for the four affected regions: Ayeyarwady Region, Yangon Region, Bago Region and Mon State (Reuters, 2008).

The spatial distribution of the calculated 'number of affected people' and 'economic damage' for the project area are shown in *Figure 71*. Comparing these results with the above observations cannot be done straightforwardly because:

- The RWSS project area is roughly 3 times smaller than the totally affected area by Nargis.
- The calculated number of affected people was assessed by the number of people living within the simulated inundation contours of the Nargis (plus rainfall) event, while the reported number of affected people didn't necessarily have to be affected directly by the inundation itself (it is unknown how this was assessed in the Reuters report).
- Economic damages by for example extreme wind speeds are not included in the calculations, but these events have caused serious damage in reality.
- Reuters mentions that most damage occurred in the western part of the Ayeyarwady Delta because cyclone Nargis made landfall here with maximum wind speeds. This most-affected part of the delta is not part of the RWSS project area.

The calculated economic damages are circa 3 billion USD (circa 1 billion USD for the RWSS project area times 3 to compensate for area differences) and the reported economic damages during Nargis were 12.9 billion USD. The difference in calculated and reported damages are significant, a factor 4, which may give some doubts about the accuracy of the calculations. However, in the calculation no damage is included that is caused by extreme strong winds, and no data is available about where the reported damage really occurred compared to the areas in the calculations. So, to make a better comparison, it is necessary to collect local information about where damage occurred and what caused it. Given these considerations, the calculated damages appear to be in a same order of magnitude which gives some trust in the way potential economic damage is calculated in this project.

The calculated 'number of affected people' is circa 2.3 million people for the RWSS project area times 3 to compensate the area different (6.9 million people) and the reported 'number of affected people' is circa 2.5 million after Nargis. Reuters (2008), however, refers to a much larger area than just the RWSS project area and considers only "severely affected" people who were in urgent need for aid and relief during and shortly after the disaster.

To calculate the 'number of affected people' in the project area, a flood depth threshold is used without the inclusion of secondary effects of the storm nor the adapting capabilities of people to escape to higher ground or the like. Given all these differences and uncertainties, it can be concluded that the calculated 'number of affected people, agrees well with the observed figures, giving some trust in the way this is calculated in the project.

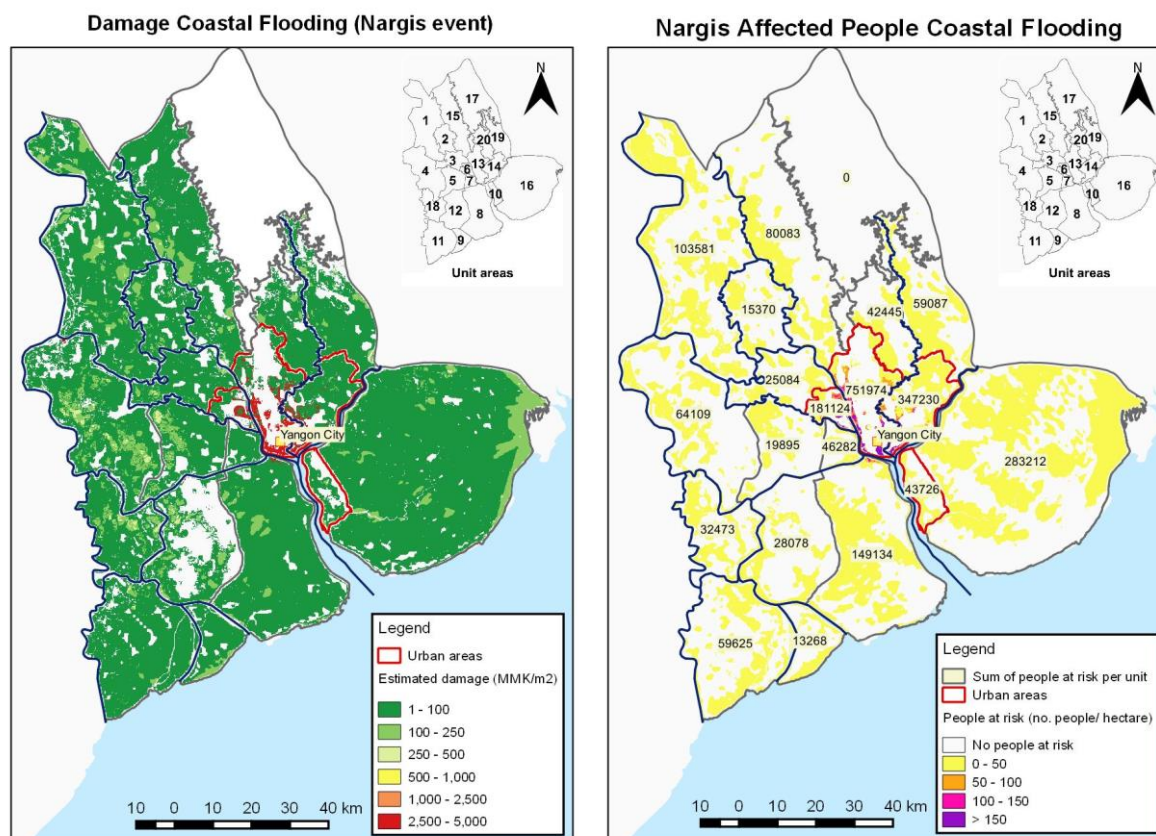


Figure 71: Calculated damage and affected people for the Nargis event

4.6 Freshwater demands

To understand the freshwater demands in the current and future situation, the needs, scarcity and potential scarcity have been analyzed for rural communities. Based on the assessment of planned developments and measures it was concluded that the urban areas of Yangon are already planning many new water storage, supply and treatment projects. These projects are described in the JICA Water Masterplan financed by JICA and the World Bank program, all managed by YCDC (JICA, 2014).

4.6.1 Rural community water demands

A significant part of the population in the Yangon and Ayeyarwady regions live in rural communities. Current population per township is determined by the Myanmar Government Census and estimated for 2040 (YCDC, 2019), shown in Table 32. The minimal domestic water need per person is estimated by YCDC to be 25 (imperial) gallons or about 114 liters per person per day. This is high compared to the global average minimal domestic water use of 15 liters/person/day. An explanation for this relatively high estimate could be that this number was estimated in a high-density urban area in Yangon City and projected as an average in absence of more specific township data. This number could result in overestimation of the domestic water use for less densely populated areas in the focus areas.

YCDC data show domestic water use in Kawhmu Town of 191,000 liters/day in the urbanized areas of Kawhmu with a population of 10467 people, indicating average domestic water use is less than 20 liters/person/day. A UNICEF census was carried out on a household level and specified whether a household was in the rural or urbanized part of the township and specified whether the household has access to basic domestic water supply. Based on this household data the average household size was determined to be 4 people per household. Based on the estimation for the per capita domestic water use of both the YCDC and the UNICEF census, the domestic water use per household was determined

to be 100 liters/household/day. In the table below the total water demand per township is shown, based on this number.

Table 32: Total population and total water need per township 2020 [m³/day]

Township	Region	Population (Current)	Urban population [%]	Rural population [%]	Water demand based on: 100 liters/household/day [m ³ /day]
Htantabin	Yangon	167,317	06.0%	94.0%	4183
Twante	Yangon	260,077	17.8%	82.2%	6502
Kawhmu	Yangon	136,842	07.5%	92.5%	3421
Kungyangon	Yangon	128,605	14.0%	86.0%	3215
Dala	Yangon	198,415	66.8%	33.2%	4960
Maubin	Ayeyarwady	318,502	12.7%	87.3%	7963
Nyaungdon	Ayeyarwady	218,837	11.5%	88.5%	5471

Rural communities' current unmet demands

For the Demographic and Health Survey (Unicef, 2014) a census was carried out where three categories for domestic water availability to households were assessed: basic, unimproved, and no service.

Table 33 classifies the water availability for the households under each of these three categories. For each household, the water source was determined, and the household categorized. Piped water is classified as an improved source though often, there is no treatment when it is taken from lakes and reservoirs directly. Also, quality control on bottled water varies and sometimes contamination can be found in bottled water sources. Because the survey was carried out before the official categorization of the Joint Monitoring Program under the Sustainable Development Goals (SDGs), it is unclear whether a distinction was made between unprotected ponds and for instance covered cisterns from rooftops when regarding rainwater.

The census data was used to determine the volume of improved water needed per township. The combined ratio of households that are categorized as 'unimproved' and 'no service' serves as an indication for this unmet need for improved water.

Table 33 shows that households that are classified as having access to an improved source (basic) have access to water from a source that is subjected to at least some sort of control either through a designated agency or company. This includes tap/piped water, tube well boreholes, protected wells and spring, bottled water and water from tanks or trucks. Households that are classified as not having access to improved water (unimproved & no service) get water from sources that do not necessarily subject to control of any kind. This includes unprotected wells, springs, pools, ponds, lakes as well as rivers, streams, canals and rainwater. For the households classified as using unimproved sources, it is often difficult to determine the exact source of their domestic water. To ensure water supply and water quality in the future, households that have access to improved water sources are categorized as having their domestic water demand met, whilst households using unimproved sources are categorized as not having their domestic water demand met.

Table 33: Classification of water availability for households (UNICEF, 2014)

Improved (met demand)	Basic	Tap water/Piped, Tube well borehole, Protected well/Spring Bottled water/Water from vending machine, Tanker/Truck
	Unimproved	Unprotected well/Spring Other
Unimproved (unmet demand)	No Service	Pool/Pond/Lake River/Stream/Canal Waterfall/Rainwater

Towns like Kawhmu, Kungyangon and Twante experience periods where there is a significant lack of domestic water during April and May. Most of the domestic water for towns in these areas originates from groundwater pumping or wells. The Town of Kawhmu is 100% relying on municipal groundwater pumping whereas Htantabin relies 100% on groundwater wells. Kawhmu experiences groundwater quality problems in terms of salinity. The towns of Kungyangon and Twante are partly (about 30%) serviced by surface water. Rainwater harvesting is not implemented in any of the Towns of Kawhmu, Kungyangon, Twante and Htantabin.

To determine the unmet demand for improved domestic water, the ratio of households that does not have access to an improved source (i.e. unimproved and no service classes) is multiplied by the population and the minimal daily domestic water need per capita. This is done for both towns and remote areas. The resulting current (2020) total need for improved domestic water is shown in the table below. It is important to note that these numbers for unmet domestic water demand are based on the ratio of households that use unimproved sources for their domestic water needs. As mentioned before, quality control can vary or even be missing for piped surface or ground water and even bottled water. In reality the unmet water demand can be more severe than based on the unimproved sources.

Table 34: Total population, population without access to basic domestic water, and total unmet water need per township

Township	Region	Population (Current)	Households without improved source: Urban [%]	Households without improved source: Rural [%]	Unmet water demand based on: 100 liters/household/day [m ³ /day]	Unmet domestic demand Total [%]
Htantabin	Yangon	167,317	18.3%	68.0%	2720	65%
Twante	Yangon	260,077	10.2%	71.1%	3920	60,3 %
Kawhmu	Yangon	136,842	88.4%	56.2%	2006	58,6 %
Kung yangon	Yangon	128,605	96.0%	62.1%	2148	66,8%
Dala	Yangon	198,415	87.7%	99.2%	4538	91,5%
Maubin	Ayeyarwady	318,502	6.4%	79.1%	5563	69,9%
Nyaung don	Ayeyarwady	218,837	60.6%	68.2%	3684	67,3%

Rural community water scarcity now and in 2040

YCDC has made estimations for the population in 2040. The estimated population per township for 2040 is shown in the table below. Based on these estimated populations the estimated total water demand per township for 2040 is calculated based on an assumed water need of 100 liters/household/day. Since the problem with water supply in these regions is not the availability of water, but merely poor household connection to the water supply, it was assumed that the ratio of households

that have access to basic water supply remains constant till 2040. If none of the new households have access to basic water supply, the unmet water demand can rise even higher. A growth in both population and water demand can be observed from below table.

Table 35: Estimated population per township in 2040 and estimated unmet water demand per township [m^3/day]

Township	Region	Population (2040)	Unmet water demand for 2040 based on: 100 liters/household/day [m^3/day]
Htantabin	Yangon	219,308	3565
Twante	Yangon	341,777	5151
Kawhmu	Yangon	181,580	2661
Kungyangon	Yangon	171,110	2858
Dala	Yangon	259,733	5941
Maubin	Ayeyarwady	325,202	5680
Nyaungdon	Ayeyarwady	224,710	3783

The above results show the unmet domestic water demand for several of the townships in the area. To determine where measures can be implemented efficiently, it is important to find the spatial distribution of the domestic water demand.

To obtain a spatial distribution map of the unmet water demand, the following steps were taken:

- Towns were differentiated from remote areas using a population threshold. To be classified as a town, population density must exceed 10 people/hectare.
- It was assumed that average household size in towns and remote areas are 4 persons.
- Areas identified as towns were calculated using the ratio of households with unmet demand for towns and those identified as remote using the ratio of households with unmet demand for remote areas.
- The minimal domestic water need for a household was assumed to be 100 liters/household/day.

Based on the spatial distribution of the unmet domestic water, locations can be identified where measures can be implemented efficiently.

Figure 72 shows the unmet demand for improved water, based on data from the UNICEF survey of 2014, measuring household access to domestic water (UNICEF, 2014). Darker red areas show areas that have a larger unmet demand for domestic water. The unmet domestic water demand is based on the population of the area and the ratio of households that do not have access to basic domestic water supply. Important to note is that the darkest areas resemble an unmet domestic water demand of more than 100 liters/day/hectare. For towns, this can go up to several $\text{m}^3/\text{day}/\text{hectare}$. The high unmet domestic water demand can be because the area is densely populated, has a high percentage of households in the area with no basic access to drinking water, or both.

Notably the densely populated areas around Yangon have a high unmet domestic water demand. Also, the densely populated areas of Twante Town, Kawhmu Town, Kungyangon Town and the less densely populated areas in between have a high unmet domestic water demand.

The orange text boxes in the map indicate the total expected unmet domestic water demand for the respective whole township for 2040. This includes both the towns as well as the surrounding areas that are inside of the township borders.

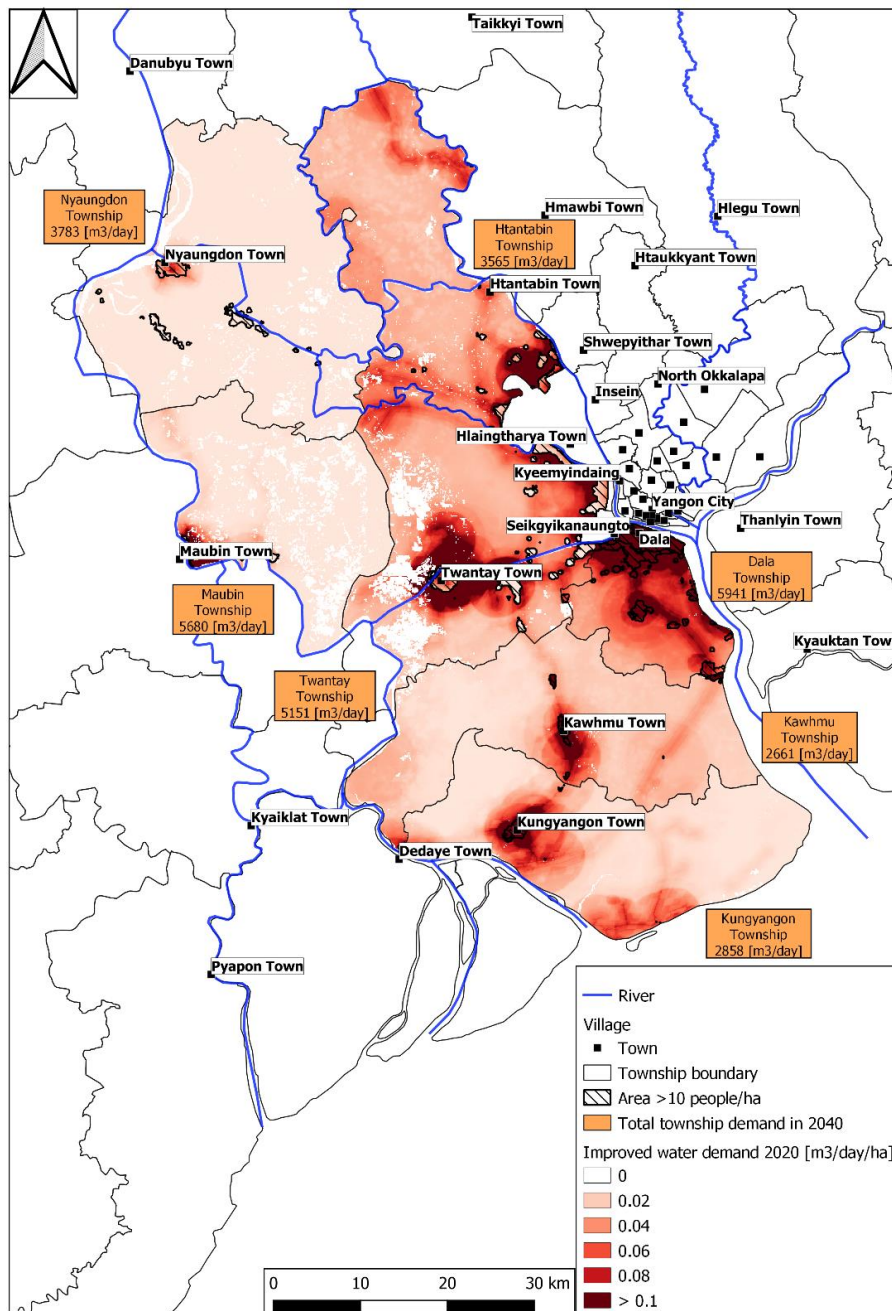


Figure 72: Unmet water demands for improved water in focus areas (100L/day/household) in 2040

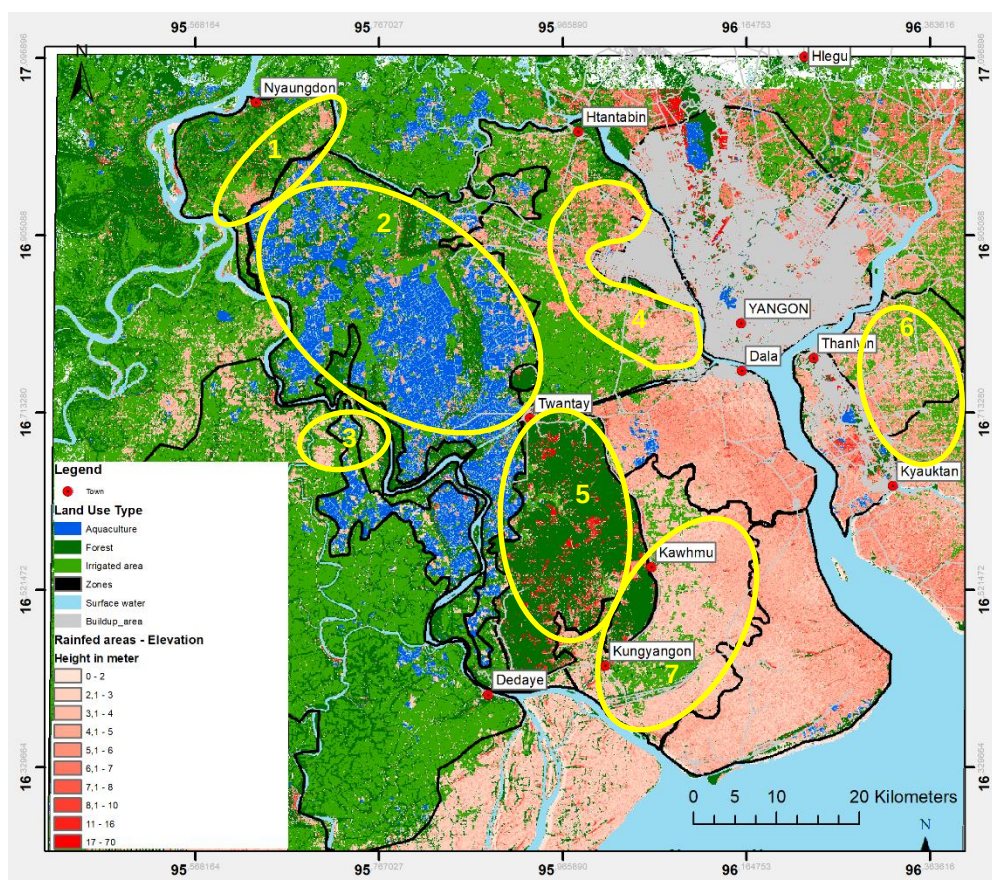
4.6.2 Agriculture water demands

In the Ayeyarwady delta there are two types of agriculture: rainfed agriculture and irrigated agriculture. Rainfed agriculture occurs on most agricultural land during the wet season. During the dry season, however, only irrigated lands can receive sufficient water to grow crops. This means that land that is not irrigated, is only able to grow one rice crop per year.

Limitations for irrigation

Although there is an autonomous increase in demand for agricultural products, due of the direct link between agricultural development and water security measures, there is no autonomous development of the agricultural water demands. Contrary to domestic demands that exist whether they are met or not, agricultural demands only materialize when crops are actually planted. In this paragraph, therefore, the potential rather than development is described. The most obvious limitation for irrigation is the salinity of the surface water in certain areas. Other limiting factors are elevation and the presence or lack of irrigation infrastructure. Figure 73 shows the rainfed areas with, in a red scale, the land heights. Inside the project's focus areas seven sub-areas are identified that could potentially be turned into irrigated agricultural land.

Figure 73: Land use map indicating the elevation of the rainfed agricultural areas .(RHDHV, 2019)



Potential areas analysis

The area characteristics and main obstacles are analyzed, and suggestions are given about how to overcome them for the following high potential areas.

Area 1 – South of Nyaungdon

Located just south of Nyaungdon city, two areas are identified that appear to be relying on rainfed agriculture. These areas are located at a higher land elevation of circa 1m higher than their surrounding areas where irrigation is available in the dry season. The surrounding irrigated areas pump water using small portable fuel pumps that can only be used for agricultural land in close proximity to the canals of the drainage system. Therefore, since the two areas are located on elevated lands far away from the drainage and irrigation canals, irrigation water cannot reach these locations or pumping may be too costly for the farmers. These areas may be considered potentially interesting for irrigation to boost the income of the local farmers and to increase food production. For this, pumping systems and increased water storage can be considered.

Area 2 – East of Maubin

The second area is located to the east of Maubin and according to the remote sensing data largely focusing on aquaculture practices. However, in between the aquaculture fields there are indications following from the Normalized Difference Vegetation Index (NDVI) analysis that rainfed areas are present (RHDHV, 2019). Most of the areas are purely fishponds constructed on the 1m and higher lowland. Some combinations of paddy and fish are located below 0.5 m to 0 m MSL.

The area located above 2m and 3m from MSL seems to be rainfed agriculture and irrigation is not a common practice in the higher areas, because small pump systems are unable to reach these higher lands. Investing in improved pumping might be an option for some of the larger rainfed-only areas.

Area 3 South east of Maubin

Southeast of Maubin there are two locations between the Pyapon and Thande river that are identified as rainfed areas which are surrounded by irrigated areas. Based on consultations and expert judgement, it seems that the two areas are developing fishponds and therefore, the area becomes less attractive to consider additional irrigation.

Area 4 Pan Hlaing Island and Nyaungdon Island

This area appears to have an abundance of land that is currently practicing rainfed agriculture. Some parts will be urbanized by the New Yangon City project which will also support modernized irrigation agriculture to the North West adjacent to the new city.

The Pan Hlaing River from its confluence with Hlaing river can function as a water source for urban, industrial and agriculture areas based on ongoing studies and plans in terms of wastewater treatment and the new Pan Hlaing Sluice. Based on this information and taking into account the predicted available water from Pan Hlaing River in a few years from now, the potential for future irrigation in the area is expected to increase. The Pan Hlaing Vision project estimated an increase in irrigated land of around 8000ha with water available from the Pan Hlaing river through pumping and lowering the existing irrigation sluices (Arcadis, 2019).

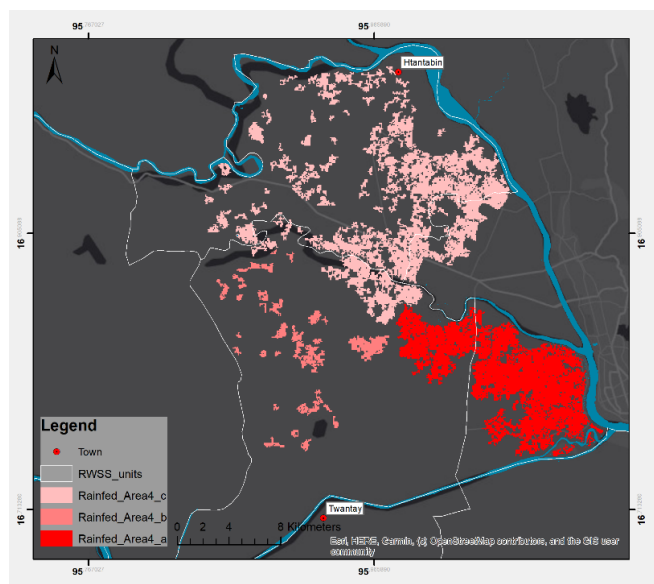


Figure 74: Rainfed areas in sub area Nyaungdon / Pan Hlaing island

Area 5 East of Twante river

The forest area in area 5, located on the East of the Thande river, has a higher elevation (above 3 to 4 meter above MSL) compared to the surrounding areas and has hardly any irrigated agriculture. However, the land use image indicates that some rainfed areas are present in forest that looks like rainfed agriculture. Small parts of this area are feasible for additional irrigation but that requires costly pumping and distribution network systems.

For some part of the area, the soil is less suitable for agriculture. The area consists of Lateritic soils which have poor fertility, are acidic in nature, have low water retaining capacity and lack nutrients. Local experts suggest that a (pre)feasibility study could be done based on the baseline data from IWUMD, DWIR, DOA and DALMS. The land plots that are currently practicing only rainfed agriculture are spread out and potentially hard to reach with canals or pumping due to the topography.

Area 6 East of Thanlyin

This area is located to the east of Thanlyin and practices both irrigated and rainfed agriculture. It seems to be difficult to irrigate in this area because most of the area is turning into industrial zones and urban area soon. Looking at the future the area might not be suitable to initiate additional irrigated agriculture.

Area 7 Yangon South (West)

Much of the land that is currently used only for rainfed agriculture could potentially be developed to irrigated agricultural lands. The main limiting factor is freshwater availability in the area. The area is serviced by multiple sluice gates. Due to salinity intrusion these sluices are closed to stop saline water from flowing into the area around the middle of the dry season. Irrigation therefore only happens along the canals. Increased water storage and/or increased freshwater supply in the dry season would allow for the development of irrigation agriculture for many of those areas. Due to the large size of the area it is considered of high interest.

The analysis (further detailed in Appendix E) results in the following table. The table shows the total area of each identified area location, that was deemed of interest during the analysis in combination with the total irrigation requirements. The last column in the table includes the total potential increase in production value (based on current prices) in those areas in case the areas are upgraded to irrigation agriculture growing Sin Thu Kha rice during the dry season. Note that water requirements of high value crops may be less than for rice.

Table 36: additional irrigation requirement and total potential increase in production value in case potential is developed

Area location	Area size (m ²)	Total irr. Req. (m ³)	Total increase in production value/year (€)
South of Nyaungdon	12,571,604	12,902,250	1,087,371
East of Maubin	15,893,097	16,310,004	1,374,569
Pan Hlaing Island and Nyaungdon Island	A 73,784,892	75,730,153	6,382,360
	B 15,267,877	15,673,617	1,320,936
	C 93,741,490	96,217,736	8,109,005
East of Twante river	56,092,230	57,572,571	4,852,081
Yangon South (West)	280,897,019	288,324,749	24,299,334

A detailed elaboration of the options for improved irrigation in RWSS focus area Yangon South (Unit area 8) is provided in Appendix E.

4.7 Synthesis

The climate change scenario for 2040 as simulated in this study, has negative effects on all aspects of the flood and freshwater security. On average, the areas with pluvial inundation will double in size, while the areas already affected in the baseline will experience deeper inundation levels due to the increased rainfall. Especially units 06 and 10 in the middle of the study area are sensitive to increased rainfall, indicated by an increased probability that 10% of the surface area exceeds the threshold from 1 in more than 1000 years to 1 in 34 years for unit 6, and from 1 in 44 to 1 in 16 years for unit 10.

Without exception, all unit areas show an increase in flood hazard level related to coastal flooding with water levels rising by an additional 20 cm near the coast and gradually lower going upstream. Especially the units along the Hlaing River show an increased risk due to the funneling effect of the storm surge.

Especially the units in the center of the project area west of Yangon (units 03, 06, 07, 08 and 13) show a significant increase in fluvial flood probability because of the expected higher river discharges and related river water levels. The total flooded land surfaces do not change significantly.

During (extreme) dry conditions, both the decrease of freshwater discharge and the increased sea water level allow the salt front to move 5-10 km more upstream.

Most of the collected planned measures do not have a big impact on the behavior of the delta system. The expected upstream Ayeyarwady River basin development with hydropower dams and reservoirs will have limited positive effects on salinity intrusion in the dry season (i.e. slightly less salt intrusion).

Proposed new freshwater intake facilities at Toe River and Kokkowa River will have even smaller negative impacts (i.e. slightly more salt intrusion). The impact of flood protection of New Yangon City Development is negligible outside the protected area, and only results in a minor decrease in the level of flood security upstream due to backwater effects. The closure of the Pan Hlaing canal only blocks a relatively small waterway with a relatively small increase of the funneling of the storm surge as a result.

The closure of the Twante Canal, however, leads to a significant physical change of the hydraulics in the delta. The tidal amplitude in the Hlaing River is further amplified, increasing the salt load on the Upper Hlaing and Kokkowa rivers. Despite being closed off on both ends, flooding of the units adjacent to the Twante Canal still occurs for fluvial events with return periods more frequent than 5 years originating from the Toe River. Regarding coastal flood risk, the funneling effect is increased in the Yangon and Hlaing rivers with a peak water level increase as a result.

The overall score of the individual projects considered here on their socioeconomic impacts has been assessed as 0/+ or +. Although some of these projects might have limited impact on the regional water system as a single project, the combined set of projects might influence the water system more prominently, depending on where the projects are situated and the scope of their respective impacts.

The main issues are how the connectivity of the water system will be affected and/or what the combined impact would be on flood safety levels. Another, probably even more important question is to what extent these projects will be able to counterbalance the overall negative impact (--) of climate change. Without a more detailed system approach analysis however, it is very difficult to assess the cumulative water system and induced socioeconomic impacts.

5 VISION AND STRATEGIES

5.1 Introduction

Not only today, but also Yangon's future requires water security and therefore a regional vision for 2040 has been developed. The vision is a common view on what water security in Yangon Region ideally looks like. It describes the desired long-term situation, considering different uncertain future developments that are initiated by climate change or socio-economic developments. Aspects of Integrated Water Resources Management (IWRM) have been included, like safety against floods, sufficient availability of freshwater and a participative approach to balance potentially conflicting demands and needs. The balance between the characteristics of the natural water system and the long-term societal demands, both subject to much uncertainty, are crucial to consider.



A vision has value when it is translated into clear management objectives with (measurable) targets which are based on an inclusive process in Myanmar.

This Chapter describes the Region Water Security Vision with its targets for 2040 and the strategies to reach the targets. Reference is made to stakeholder meetings and workshops, and existing visions, policies and planning documents of the government of Myanmar.

After specifying the future water security targets, a logical set of measures has been developed on conceptual level (Section 5.5).

5.2 Review of existing and exemplary visions

The National Water Policy (NWP) of Myanmar is the first integrated water policy for the watersheds, rivers, lakes and reservoirs, groundwater aquifers and coastal and marine waters of entire Myanmar (NWRC, 2014). The National Water Resources Committee Expert Group prepared the NWP, and it has been approved by the National Water Resources Committee on 13 March 2014. The NWP was formalized by the approval of the Vice-President. As a consequence, the NWP can be used as an umbrella and as guidance for:

- All further policy development on water resources or subjects that relate to or have an impact on Myanmar's water resources;
- Further development of legal instruments such as the Water Framework Directive and a system of institutions and laws to protect and manage Myanmar's water resources;
- Strategies, master plans, development plans and projects that relate to or have an impact on Myanmar's water resources.

The National Water Resources Committee has formulated an Integrated Water Resources Management (IWRM) vision for Myanmar in the National Water Policy (NWRC, 2014):

"In 2040 the country is sufficiently protected against damaging flooding and can rely on sufficient water supply of good quality. This provides the social, and economic and natural environment where all people can live safely, prosperously and pleasantly, while maintaining a healthy economy and valuable nature."

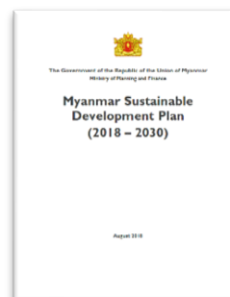
An updated and published vision for IWRM in Myanmar emphasizes the importance of IWRM, sustainable water management, water security and good water quality for Myanmar people by 2030. National campaigns on rainwater harvesting and flood mapping are mentioned to support the vision (NWRC, 2015).

On a regional scale many stakeholder consultations and workshops on delta vision and objectives were held, for example for the Integrated Ayeyarwady Delta Strategy (IADS, 2017). As part of IADS, a quick

scan on Myanmar's sectoral policies, plans and strategies took place to collect sectoral targets for the Ayeyarwady Delta. The IADS assessment of policy documents have been finetuned and updated as part of the RWSS. The most relevant plans are summarized below.

1. Myanmar Sustainable Development Plan (2018-2030)

The Ministry of Planning and Finance presents MSDP 2018-2030 to address the demands resulting from rising urbanization, the need for investment and added economic activity by proactively building institutional capacity to support a sustainable infrastructure development program and ensure effective pipeline management. The plan provides an overall framework for coordination and cooperation across all ministries, states and regions for development across Myanmar. This development plan is structured around 3 pillars, 5 goals, 28 strategies and 251 action plans. Serving Goal 5 (Natural Resources and the Environment for Posterity of the Nation) strategy 5.3 was developed, summarized:



“Enable safe and equitable access to water and sanitation in ways that ensure environmental sustainability: Much of Myanmar receives abundant rainfall; however, water shortages can still be found. Geographical disparities between urban and rural areas also exist. The result of geographic variation, degradation of important ecosystems and underinvestment in water related infrastructure (for household, private sector and agricultural usage) has meant that too many of the Myanmar people remain without access to improved sanitation facilities. Recognizing the important role that ecosystems play in providing clean water during the dry season and that degradation of these ecosystems ultimately affects water quality and quantity, Myanmar will enhance investments in conservation and in water-related infrastructure. The Government of Myanmar will also promote township-level water use planning and encourage healthy water use practices.”

Relevant action plans in the document related to water security are:

- Enhance irrigation and drainage services, and support more efficient and sustainable water management systems resulting in increased Productivity and Farmers' Income
- Conserve and protect terrestrial and inland water areas, coastal and marine areas, and national sanctuaries through integrated resources planning and effective and equitable management
- Introduce catchment-based integrated water resources planning and management to ensure that water resources are used equitably and sustainably and are responsive to gender-specific needs.
- Develop national and subnational inventories of existing water supply services, repair and/or upgrade existing water supply services, and prepare plans for the development of new water supply services.
- Develop township and village water safety plans, including ensuring the provision of clean and safe water to all people.
- Increase people's use of safe practices for the handling and use of water for domestic and drinking purposes.
- Ensure that quality of life considerations such as water management (retention and reticulation) and expansion of public spaces (centers of learning/libraries, parks, playgrounds and green areas) are fully integrated into urban planning frameworks and decision making.
- Water management of rivers and canals serving other economic purposes, such as inland transport, is adjusted to maintain the required quantity and quality as required for that function.

Union Project Bank is a national initiative to support the development of the most effective and public beneficial projects from all regions and states that aligned with MSDP. The **Yangon Project Bank** is a similar parallel initiative that focuses on the Yangon region and complements the Union Project Bank.

2. National Adaptation Programs of Action (NAPA) to Climate Change (2012)

The Myanmar National Adaptation Program of Action (NAPA) Report was prepared within the framework of the project "Preparation of National Adaptation Programs of Action" implemented by United Nations Environment Program (UNEP) and executed by the Department of Meteorology and Hydrology, Ministry of Transport and Communications. NAPA serves as simplified, rapid and direct channels to identify and communicate priority activities to address Myanmar's urgent and immediate adaptation needs.

NAPA emerged from the multilateral discussions on adaptation measures within the UN Framework Convention on Climate Change (UNFCCC). Myanmar's NAPA specifies 32 priority activities for effective climate change adaptation for eight main sectors: i) Agriculture; ii) Early Warning Systems; iii) Forest; iv) Public Health; v) Water Resources; vi) Coastal Zone; vii) Energy, and Industry; and viii) Biodiversity. The plan provides detailed project profiles, budgets, financing agencies and prioritizes sectors and projects with regards to implementation. The climate change projections and vulnerability for Myanmar (2001-2100) are provided under Myanmar's framework for climate change adaptation.

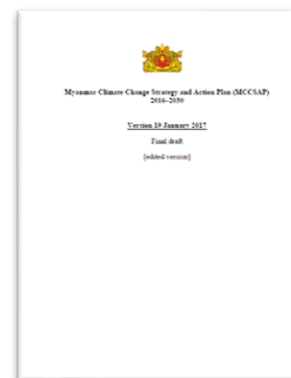


One of the priority sectors is 'water resources'. Considerable investments have been made to ensure water security across Myanmar. The Government initiated several irrigation schemes from 1988 to 2010 to maintain agriculture productivity during dry periods. Additional measures to assist water security in Myanmar, related to Yangon at the time (2012): The Yangon City Development Committee (YCDC) has been implementing tube-wells to supplement piped water supply from reservoirs. The document also mentions a priority which is in line with the RWSS, namely: 'Assessing the status of dams for providing sustainable water supplies and withstanding flood risks under future climate change.' This includes re-evaluation of the current design parameters of three of Myanmar's large storage dams to provide recommendations and guidelines on future design parameters for withstanding current and future climate change impacts on water supplies and flooding events.

3. Myanmar Climate Change Strategy & Action Plan 2016-2030 (MCCSAP) (2017)

The Ministry of Natural Resources and Environmental Conservation (MoNREC) presented MCCSAP 2016-2030 as a roadmap to guide Myanmar's strategic responses to climate related risks and opportunities. The strategic vision is to develop Myanmar as a nation that is resilient to the impacts of climate change and can harness the benefits of low carbon development for present and future generations in an inclusive manner. The Strategy has identified six key sector entry points to deliver inclusive climate resilient and low carbon development outcomes. Activities, or measures, suggested in the MCCAP, relevant for water security in the delta:

- Identifying climate-smart agricultural technology and practices such as efficient and improved water management technologies;
- Carrying out infrastructure design and studies to protect agricultural land in coastal and delta areas from saltwater intrusion;
- Developing and promoting early maturing and heat tolerant rice varieties to cope with drought and water stress;
- Strengthening capacity to improve land use maps of vulnerable townships;
- Implementing DRR and climate change adaptation activities and scale these up in townships with vulnerable groups



Urban areas in flood-prone locations or those that experience increased water runoff due to more impermeable surfaces, will increasingly lose assets and lives to the floods that result from more intense rains. Increasing water shortages may result in higher prices for services in Yangon and threaten affordability and incomes.

4. Myanmar action plan on disaster risk reduction (MAPDRR) (2009, 2017)

Myanmar experiences an average annual loss of 3 % of national GDP due to natural disasters. Therefore, an action plan on disaster risk reduction was drafted to address this issue. The plan was launched in October 2017. Vice President 2 (VP2) U Henry Van Thio, chairman of the NWRC and of

the Disaster Risk Reduction Committee said: *“This new actionable plan will ensure the achievement of the first target to be achieved under Sendai Framework for DRR by 2020 that calls for a substantial increase in national and local strategies for disaster risk reduction”*. The MAPDRR-2017 is designed to address the emerging risk of small and recurrent disasters such as riverbank erosions, strong winds, lightning strikes and localized flooding. The plan has also inspired the protection of heritage values in addition to lives, assets, livelihood and environment.

5. Agricultural sector policies and thrusts for the second 5 year short term plan (2017)

The short-term plan for agriculture consists of a clear overview of agricultural policies, goals, objectives, vision, mission and strategic thrusts. The aim of the plan is to produce a greater and more diversified range of high quality agricultural, livestock and fishery products, following the Agriculture Policy 2016 vision:



“An inclusive, competitive, food and nutrition secured and sustainable agricultural system contributing to the socio-economic well-being of farmers and rural people, and further development of the national economy”

It is important to note that the strategic thrusts are nation-wide and not delta-specific and might not always be in line with the sustainable development of the country. Below is a summary of the relevant thrusts of the Agricultural policy:

- Water Use and Management
- Modernization of existing dams, pump irrigation projects, groundwater drilling projects, water distribution and irrigation systems;
- Supporting construction and maintenance of village owned dams, ponds, irrigation and drainage system, farmer-constructed dikes;
- Exploiting groundwater and introducing drip irrigation and sprinkler irrigation system in needed locations to ensure natural water resources are not negatively affected;
- Water dikes (freshwater protection) and sea dikes (brackish water protection), construction, maintenance and drainage canals construction in prioritized locations;
- Renovation and maintenance of water storage reservoirs, small dams and ponds;
- Water user groups and awareness training on clean drinking water methods in rural areas.

6. Agriculture development strategy (ADS) and investment plan (Draft, 2017)

The Agricultural Development Strategy (ADS) is the basis for the operationalization of the Agricultural Policy. Since August 2016, MOALI with the support of development partners Asian Development Bank (ADB), Food and Agriculture Organization (FAO), and Livelihood and Food Security Trust Fund (LIFT) has been involved in the preparation of the ADS and Investment Plan for the 5-year period 2018/19 to 2022/23. The ADS refers to the Delta as follows: *“In the Ayeyarwady Delta, paddy may well be the main stay of the farming system. There have been only limited improvements in drainage and land development. Paddy fields are found to be quite difficult to convert to upland crops cultivation in summer in most part of the Delta areas thus limiting diversification away from paddy. Change from rice centric policy to food basket system requires investment in water management.”*

The potential measures, including budgets and sources, responsible departments to implement these measures and timeline of implementation which are relevant to RWSS include:

- Conducting feasibility studies of drainage investments in rain-fed areas, particularly in the Delta;
- Carrying out drainage works in Delta areas.

Yangon was addressed in relation to maximizing output and profit from fishing and aquaculture industries using sustainable practices. Also, navigation and port development were mentioned to transport food and goods.

7. WASH Strategy and Investment Plan (2016 – 2030) (2016)

The purpose of the National Strategy for Rural Water Supply Sanitation Hygiene (WASH) is to identify ways to meet the needs of the rural populations for improved domestic water supply services, access to and use of improved sanitation through the elimination of open defecation, and improved hygiene behavior by the year 2030. The Strategy is supported by Investment Plans covering a financing period 2015 to 2030 to ensure sufficient funding for development and operation of services. Departments in three Ministries have cooperated on the development of the Strategy and Investment Plans: Department of Rural Development, Department of Basic Education and Department of Public Health, with support and input from other relevant Departments. The Departments worked together in a Task Force chaired by DRD. One of the major changes in approach is a move from providing water supply and sanitation systems through time-bound projects for infrastructure, to operation of WASH as services without time limit. The emphasis is on operation, sustainability and recurrent cost financing of services that people want and can afford to pay for.



To conclude: the above seven summarized -often sectoral- initiatives include concrete objectives, actions or physical measures that may be relevant for developing water security measures.

5.3 Vision and targets

The aim of RWSS is to provide decision makers in the Yangon region with a proposal for sets of coherent investments based on an integrated vision on water security in the Yangon region. As such, it will help avoid possible adverse impacts of, and conflicts between, planned investments. Identified priority no-regret measures and investments are input for the World Bank financed Yangon IWRM project. RWSS intends to facilitate effective government decision making on water security investments and support a solid preparation of the World Bank loan.

Water security is a broad term and the RWSS study focuses specifically on the water security aspects flood safety and freshwater availability.

5.3.1 Proposed water security vision

Starting point for the vision formulation is the baseline assessment prepared in this project. It provides insight in the spatial distribution of fluvial and coastal flood safety levels in the study area, the distribution of pluvial flood prone areas as well as insights in the saltwater intrusion into the delta and its impact on the possibilities to use the rivers as freshwater sources.

The baseline assessment has been complemented by the assessment of the situation in 2040 considering estimations of socio-economic developments in the regions, climate change and upstream and regional developments. This provides a better insight in how the flood and freshwater security is expected to develop, which has been taken into account in the strategy development.

Those results have been discussed in the consultative group and in larger workshops with many stakeholders present (some of them digital because of the Covid19 pandemic outbreak during the project execution). These meetings provided insight in the expectations and the desired developments of the participants in relation to the flood and freshwater security in the Yangon Region.

Based on these inputs and inspired by the existing and exemplary visions as discussed in Section 5.2, the following vision for the flood and freshwater security of the Yangon Region is proposed:

“In 2040 the project area is sufficiently protected against damaging floods and can rely on sufficient water supply of good quality for domestic and agricultural use, serving the merging needs of the urban development. This provides the social, and economic and natural environment where all people can live safely, prosperously and pleasantly, while maintaining a healthy economy and valuable nature.”

The meaning of this vision in relation to strategies of the project was specified during many discussions, resulting in the following basic principles:

- Damaging flood risks should be reduced, but the beneficial aspects of the frequently happening non-damaging flooding of agricultural land should be maintained. In this way economic and socially vulnerable populations and properties are better protected. At the same time maintaining the value for the poorer agricultural communities who benefit from the flooding as an ecosystem service providing nutrition and revitalization of the lands. The regular shallow flooding has environmental functions for the habitat of local species as well.
- Freshwater availability to all communities in the region needs priority attention. Not only the urban areas, but also the larger and smaller communities distributed throughout the delta. Affordable and maintainable solutions should be selected to ensure that all parts of society will be reached.
- Good quality water availability to industries is a second priority, in many cases with a lower water quality requirement, yet with a high economic value.
- Where possible additional freshwater supply and improved drainage will enable increased agricultural production providing a better income to the rural population, while providing food security to expanding population in the region.
- Strategies should be balanced, in terms of affordability, benefit/cost ratio, equity, environment and impact. At the same time synergy, efficiency and integration need to be sought to obtain maximum financial, social and spatial benefits.
- Water management of rivers and canals serving other economic purposes, such as inland transport, is adjusted to maintain the required quantity and quality as required for that function.

5.3.2 Vision translated into targets

To be able to translate the above proposed Vision into strategies (i.e. programs of measures), it is necessary to specify more tangible, quantified where possible, targets. Since in the Greater Yangon Region the characteristics and the needs of the urban areas differ considerably from those of the rural areas, two specific sets of targets are developed.

Urban areas

Predominantly urban and industrial areas have traditionally received most attention and are presently better protected against floods than most rural areas. This is partly because they grew on safer locations. They also enjoy better freshwater services because in the past most investments were made in urban areas. Important to recognize is the fact that the urban population grows fast, and the urban areas are rapidly expanding. This means that areas previously rural will soon develop into urban areas with the higher demands for water supply and flood protection. For urban and industrialized areas, the following targets are proposed:

- Reduction in flood probability (below 1 in 200 years)
- Efficient use of space to enhance development (combination of functions)
- Drainage of urban areas (e.g. 70% of Yangon Region towns)
- At least 80% of 33 townships have freshwater supply
- Sufficient water for high rise buildings in urban areas - not from groundwater
- Wastewater discharge from towns and industries properly 100% treated

Rural areas

Predominantly rural areas have traditionally received less attention and are presently less protected against floods than most urban and industrial areas. Local freshwater services are limited, and quality is often a problem, especially in the southern parts closer to the coast. The following targets are proposed for the rural areas:

- Inhabitants (80%) of villages of Greater Yangon have access to freshwater all year
- Optimize (fertilizing) benefits from floods
- Freshwater availability for irrigation, boosting agricultural production by increasing the irrigated area with 50,000 hectares (reference: Draft Concept Note, AIRBM Project Component 1, 21 May 2015)
- Flood frequency less often than 1 in 50 years

5.3.3 Spatial distribution of targets

When considering the expected land use development in the Yangon Region, as represented in *Figure 75*, it becomes clear that the urban area expands very fast with significant consequences for required flood safety levels and freshwater demands. Especially the expansion of the urban area towards the west of Yangon River brings the city in areas that are presently frequently inundated by fluvial floods and also some areas prone to coastal floods, as can be seen in the baseline and future developments assessments. According to the proposed vision and targets, all these units will receive an improved flood frequency target of 1 in 200 years.

The areas in the maps with green and blue colors are expected to continue to have a rural function and are prosed to get a flood frequency target of 1 in 50 years. It is important to remind that the increase of flood safety preferably is achieved while maintaining the beneficial (lower) flooding.

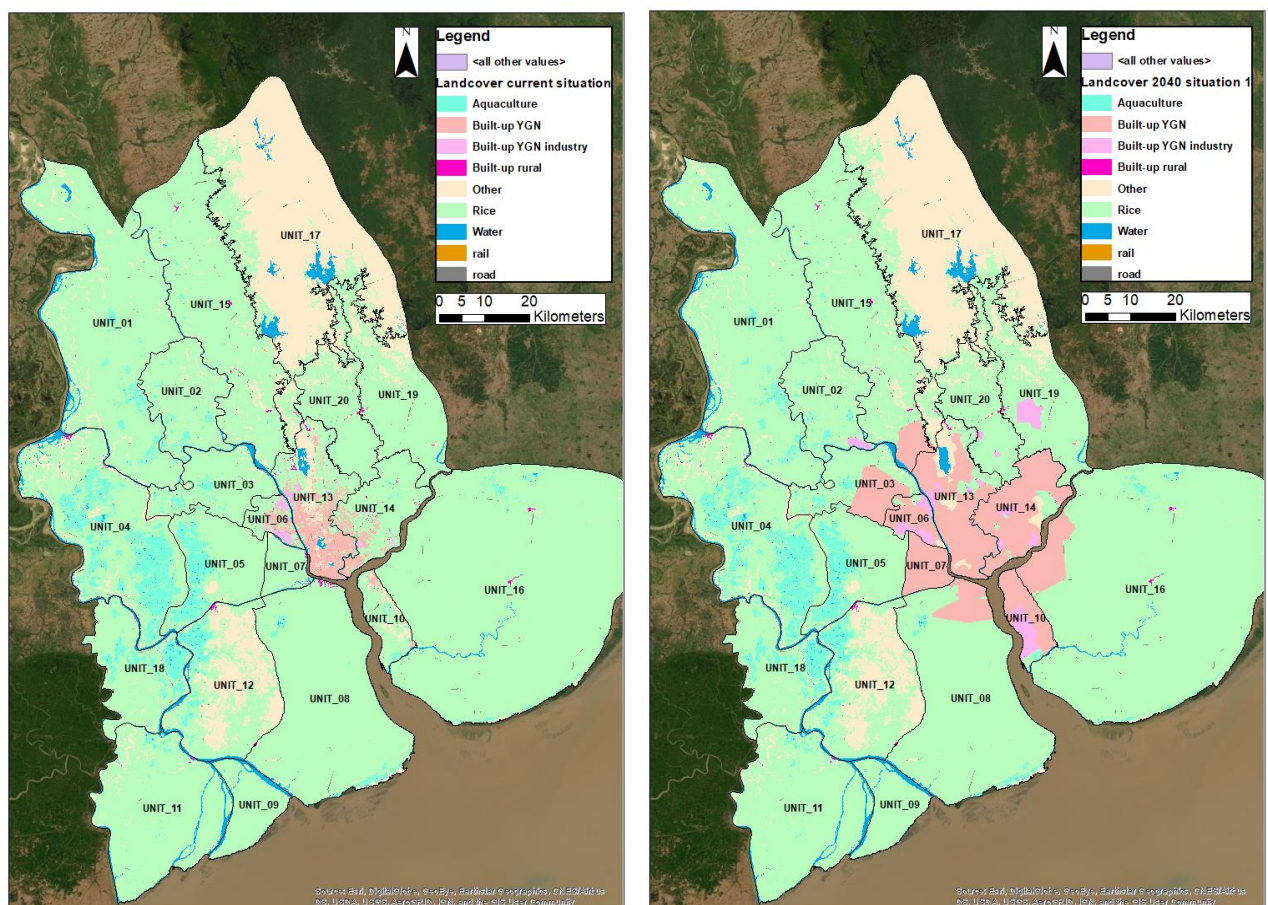


Figure 75: Land use maps for the area around Yangon for the current situation (left) and the projected situation in 2040 (right).

The freshwater demands of the greater Yangon urban area increase significantly, but the rural population also grows, although this is not visible from the land use map. *Figure 76* (left) shows the projected demand for improved water in 2040 outside the Yangon City area. From this map it becomes clear that demands are spread out over many communities, but also concentrated demands along Twante Canal and around Kungyangon and Kawhmu in the south. The figure (right) also shows the areas where there is presently rain-fed agriculture, indicating that improvement in agricultural production is achievable with additional freshwater. The rain-fed agriculture is found in small patches

over the study area where the elevation of the land or distance to a water sources make irrigation difficult locally, however, in the eastern part of Yangon South region the rain-fed agriculture is the dominant land use, indicating structural deficits in freshwater.

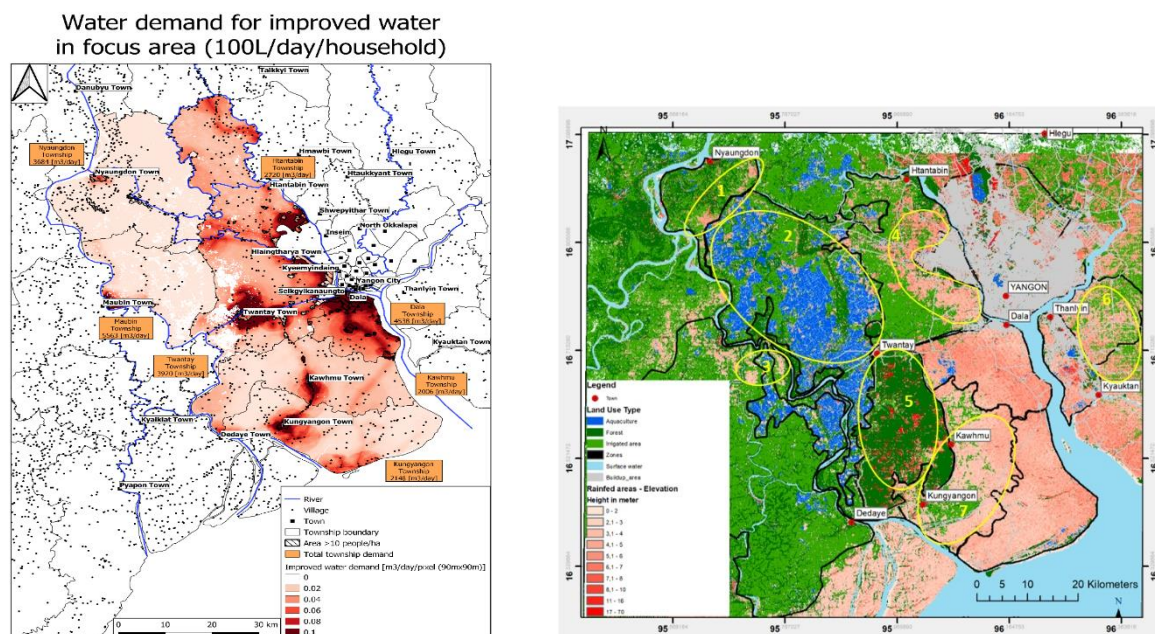


Figure 76: Projected domestic water demands in 2040 (left), and location of rain-fed agriculture (right).

These maps indicate the spatial distribution of the targets for improvements based on the proposed vision.

5.3.4 Reflection

The targets as specified in the preceding Sections form the basis for the development of a strategy consisting of programs of measures. However, existing plans have to be taken into account when developing the strategy. The masterplan for the greater Yangon region as developed in collaboration with JICA (JICA, 2017; JICA, 2018), already includes a water supply plan for the greater Yangon urban area. Therefore, the present strategy will not include the greater Yangon urban freshwater demands.

The targets proposed in the vision are tentative targets. It is important to evaluate the targets in a cost benefit analysis for each particular area. This exercise could result in lower targets if the damages and/or the benefits are limited, and the required investments would be relatively high. On the other hand, when investment costs are relatively low and for instance higher flood safety levels would incur such reduction in damages that a higher protection level is economically feasible, it can be recommendable to increase a certain target. The same approach is valid for all proposed targets (water supply, agriculture, drainage).

5.4 Strategies

To implement the vision, with the objective to reach the proposed targets, measures must be taken. Based on the vision and targets, and taking into account the inputs of stakeholders during workshops, three strategic programs have been developed that address the priority objectives:



**WEAKEST LINKS
PROGRAM**



**WATER AVAILABILITY
PROGRAM**



**DRAINAGE
MANAGEMENT AND
IRRIGATION PROGRAM**

The programs form a basis for the development of strategies, which are a logical set of measures to achieve the objectives.

Weakest Links Program

The weakest links program has the objective to upgrade dikes and levees to the desired safety level for urban and industrial areas (1 in 200 years) and rural areas (1 in 50 years), unless the benefit-cost analysis results in a different recommended level. The flood risk assessment results are used to select and prioritize. It is recommended to start investments not with an integral heightening of the complete perimeter of a certain area, but to start with those spots that have a higher probability of flooding than the rest. With this approach it is possible to achieve a significant increase of flood safety with a controlled and not excessive investment program. In this way positive cost benefit ratios can be achieved. Focus is on the two sub-areas Pan Hlaing/Nyaungdon Island & Yangon South (West).

Water availability (storage and supply) Program

The Water availability (storage and supply) program has the objective to increase the freshwater availability during the dry season. This is achieved by maximizing the collection and storage of water during the rainy season. Different ways of storage are presented, ranging from small scale ponds to larger (regional) reservoir. It is also worthwhile to consider (and study) groundwater storage of freshwater in the wet season, that can be pumped up and used in the dryer periods. The program focuses on two sub-areas Pan Hlaing / Nyaungdon Island and Yangon South (West).

A solution matrix is developed for communities ranging from household level to township or regional level with sourcing from local rainwater, drain water, river water, ground water and trucked water.

Drainage Management and Irrigation Program

The Drainage Management and Irrigation Program has the objective to reduce pluvial flooding by looking at the full drainage system and required improvements in the two sub-areas Pan Hlaing / Nyaungdon Island and Yangon South (West). Priority is given to measures that provide at least equal discharge capacity to the natural channels, which may be closed under Program 1 (Weakest Links). Second priority is given to measures that provide extra drainage capacity to reduce pluvial flooding within the most critical unit areas. Unit 8 (eastern Yangon South region) is selected as a pilot, so that pluvial flooding control throughout the wider Yangon Region can then be considered at a later stage and under a different project.

These three programs are discussed in more detail in Section 5.5.

5.5 Proposed program of measures

5.5.1 Program 1 Weakest links (flood protection)

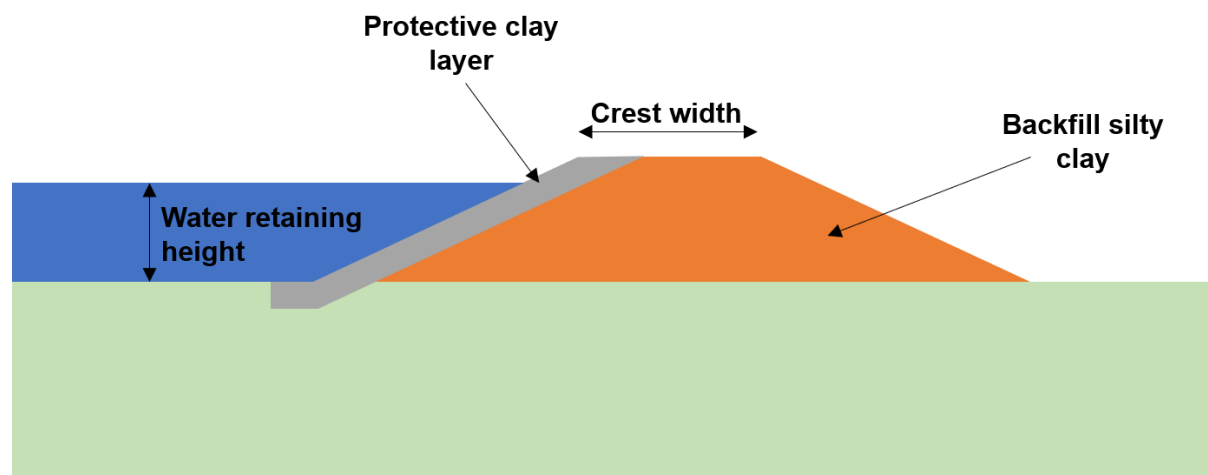
Reinforcement of dikes is an effective intervention to reduce flood risk in areas prone to both fluvial and/or coast flooding. The measures under this program focus on the weakest links in the existing embankments around the perimeter of the defined unit areas. It also addresses the requirement for new embankments to protect currently unprotected areas.

Dike reinforcement will typically comprise earthwork construction on top of the existing earth structure, or earthwork construction on top of existing ground level in the case of a new dike. This program will address the required increase in embankment heights to achieve the required safety levels and will not address the lateral or foundation stability which will need to be addressed as part of the feasibility and detailed engineering stage.

Because the weakest links in dikes are sometimes related to open connections of drains or similar situations, the dike reaches that need reinforcements are often localized but sometimes need closing of deep openings. As such, the Room-for-the-River concept that reduces flood levels by creating retention areas, is not a suitable approach. Enormous retention areas would be needed to sufficiently reduce the flood levels at the few locations needed. Room-for-the-River is more appropriate when a local retention area can prevent long distance dike heightening.

In locations where dike raising or the introduction of a new dike will close off the existing connectivity of a natural drainage path to a river and/or the sea, a sluice will be introduced to ensure drainage of rainwater collected behind the new dike within the unit area. The sluices are designed to enable beneficial flooding to continue to occur, and only to block damaging floods. A pumping station may be introduced in combination with the sluice to ensure drainage where the hydraulic conditions do not permit drainage under gravity conditions. The requirements for sluices and pumping stations will be addressed under Program 3.

Below sketch shows a pre-feasibility design (cross-section) for a new or increase of height of dike.



Required flood safety levels to be achieved

Existing dikes will be reinforced, and new dikes proposed to achieve the following safety levels (or indicator thresholds):

- Rural Areas: 1 in 50-year event
- Urban Areas: 1 in 200-year event

The flood safety level for a 1 in 50 year event may be increased up to a 1 in 100 year event if it is determined that this can be achieved with only a further small investment above that required for a 1 in 50 year event.

The areas requiring increased flood safety through dike protection have been assessed through a flood risk assessment. The approach and results of the flood risk assessment is discussed in Section 4.5. An overview of these results and how this has informed the decision-making process to reinforce particular sections of existing dikes or construct new dikes is further addressed in Chapter 6.

There are two archetypical solutions for Program 1:

- Reinforcement of an existing dike by heightening the dike.
- Construction a new dike.

For the first measure, it is assumed that most of the embankments have a typical crest width of 12 feet (approx. 4m) and a slope of 1:1.5. Based on this standard design, IWUMD maintains the profile annually after rainy season when needed.

Closing of existing drainage paths by dikes

The reinforcement of dikes will require closing of existing natural drainage paths that drain water from within the unit area to the river and sea (pluvial flooding). These closings will be realized using structures that perform two purposes. They will:

- Provide at least equal discharge capacity to the natural channels which were closed as a result of recommendations made under Program 1. The principle here is to not make the situation any worse than it was.
- Allow beneficial flooding to enter but stop the ingress of sea and river water into the unit area during damaging high tides or storm surges.

Archetypical solutions have been considered either individually or as a combination to achieve the aforementioned drainage capacity range. These are detailed in the Table below.

Table 37: details of sluices that aim to increase drainage capacity

Solution Combination	Sluice	Pumping	Channel Widening	Total Discharge Capacity
<i>Discharge Capacity (m³/s)</i>				
1	25	0	0	25
2	50	0	0	50
3	100	0	0	100
4	25	50	0	75
5	50	100	0	150
6	100	150	0	250
7	0	0	50	50
8	0	0	100	100
9	0	0	150	150

Also refer to Program 3 (Section 5.5.3) for further details.

5.5.2 Program 2 Water availability (storage and supply)

Approximately 95% of the Yangon Area's total annual rainfall occurs during the rainy season between the months of mid-May to October (See Section 3.2.6). The primary principle for measures developed under Program 2 is therefore to maximize the collection and storage of water during the rainy season to sustain water supply for use during the dry season months.

This program will focus on supplying water to communities for domestic use within the Focus Areas (Nyaungdon, Pan Hlaing Island and Yangon South (West) that will not be connected to the YCDC water supply network in the future.

This program will not focus on drinking (potable) water supply. It is considered that potable water supply could be further attained by employing water treatment facilities connected at a later point to the water supply designated for domestic use.

The areas requiring increased water supply have been assessed through a water supply risk assessment. The approach and results of the water supply risk assessment is discussed in Section 3.5.2. An overview of these results and how this has informed the decision-making process regarding the location and quantity of additional supply is further addressed in Chapter 6.

The various solution combinations which can be considered under this program are detailed in the matrix below. This matrix considers the various sources of water supply available and the various means by which the water can be stored for later use in the dry season months. A connection has also been provided between the types of storage and population through which the storage type will supply water.

The various water supply sources considered include:

- rainwater,
- drained water (pluvial),
- river water (fluvial),
- groundwater, and
- truck supply.

The various water storage types considered are:

- Tanks (property and neighborhood level),
- Pond (neighborhood to township level),
- Reservoir (township to regional level), and
- Aquifer storage (township to regional level).

In the matrix shown in *Table 38*, solution combinations colored black are considered to be feasible, blue are considered to be partially feasible and red are considered to be unfeasible. Feasible solution combinations are defined as those where the anticipated available volume of the source water is sufficient to fill the storage type during the wet season for use in the dry season and are expected to provide a practical and cost efficient engineering solution. Example: local rainwater harvesting on roofs for filling of small tanks. Conversely, unfeasible solution combinations are defined as those where the anticipated available volume of the source water is insufficient to fill the storage type and the practical and/or cost considerations are unviable. Example: filling a large reservoir with truck supplied water or pumping extracted groundwater back into the ground for aquifer recharge. Partially feasible solutions combinations are those which could be considered further, however are unlikely to lead to a practical or cost-efficient engineering solution. A discussion of each solution combination is provided further below. The estimated volume storage capacities have been assigned based on what is typically seen throughout Myanmar, what has been developed through recent associated studies and expert international experience. An example of a recent associated study is the Pan Hlaing Vision Development, part of the AIRBM Project and executed by the Arcadis consortium. Reservoirs with a surface area up to 1 km² for water supply were considered as part of this vision development to support the urbanization of the New Yangon City. This type of measure has been included in *Table 38*. Water quality related measures have not been considered as potable (drinking) water supply is not considered under Program 2, as mentioned above.

Table 38: Solution combination matrix for program 2

		Small Tank	Large Tank	Pond	Reservoir	Aquifer Storage <i>Aquifer Recharge</i>
Demand Level		Household	Household to Village level	Village to Township Level	Township to Regional level	Township or Regional level
Estimated Storage Volume		1 – 20 m ³ (1m dia x 1) - (3m dia x 3)	20 – 1,000 m ³ (3 x 3 x 2.5) - (20 x 20 x 3)	1,000 – 50,000 m ³ (20 x 20 x 3) - (100 x 100 x 5)	50,000 – 10,000,000 m ³ (100 x 100 x 5) - (1000 x 1000 x 10)	4,500,000- 9,000,000 m ³ 50m3/well/hr x 6 months x 20 – 40 wells
Source	Local rainwater	Rainwater harvesting from roofs and impermeable surfaces during rainy season only	Rainwater harvesting from roofs and impermeable surfaces during rainy season only	Rainwater harvesting from local catchment during rainy season only	Rainwater harvesting from local catchment during rainy season only	Free flow or pumped storage during rainy season only.
	Drain(ed) water (Pluvial)	Free flow/Pumped Storage during rainy season only	Free flow/pumped storage during rainy season only			Aquifer recharge during the dry season months is not applicable.
	River water (Fluvial)	Pumped Storage	Pumped Storage	Free flow/pumped storage from river source	Free flow/pumped storage from river source	
	Groundwater	Pumped storage	Pumped storage	Pumped storage	NA	NA
	Truck Supply	Truck Supply	Truck Supply	NA	NA	NA

Discussion

Small Tanks (or Vessels) – Household Level

Small tanks are considered to have a volume of 1 – 20 m³ (1m diameter and 1m height) - (3m diameter and 3m height). Assuming a consumption rate of 100 liters per day per household, this equates to a supply of 10 to 200 days per tank.

The small tanks would be located on the property of the household owner. Tanks can be filled through local rainwater harvesting (i.e. roofs, impermeable ground surfaces, etc.) during the rainy season. Depending on the size of the water tank selected, the tank may provide a portion of the required stored water supply partially through the dry season months, or if large enough, throughout the entire dry season months. Refilling through the dry season months using rainwater harvesting is not a feasible solution due to the limited rainfall during the dry season months.



The supply of water from a pluvial surface water source (i.e. small water collection pond) or fluvial water source directly to the tanks would require a water transportation pipe originating from the water source. This could be a feasible solution if the water source is located close enough to the house and it can provide the necessary water supply throughout the dry season months. This is unlikely to be a feasible solution if the water source is located too far away from the house due to the cost of the transportation pipe, including pumping requirements.

Other feasible refilling options also include groundwater supply through tube wells and truck supply. The long-term extraction of ground water across the Yangon Region has caused a substantial drop in the groundwater table and a decrease in water quality within the shallow location (upper 100m) aquifers. High level of salinity, arsenic and iron concentrations are often recorded in the extracted groundwater supply. Therefore, whilst ground extraction is a feasible and practiced option for refilling, its ongoing use should be subject to close monitoring of ground water quality and the integration with a long-term balanced aquifer recharge program. Truck supply is a feasible option for the limited storage capacity of these small sized tanks.

The small tanks would be located above ground and made from a HDPE, GRP or aluminum. Chlorination, and other chemical treatments, would be required to maintain the water quality of the stored water during the dry season months.

Large Tanks – Household to Village

Large tanks are considered to have a volume of 20 – 1000m³ (3m x 3m x 2.5m height) - (20m x 20m x 3m height). Assuming a population of 100 households each uses 100 liters per day, a tank with a volume capacity of 1000m³ would provide sufficient supply for 100 days.

Similar to small tanks, depending on the size of the water tank selected, the tank may provide a portion of the required stored water supply partially through the dry season months, or if large enough, throughout the entire dry season months.



Photo Source: watercache.com

The tanks can be filled through local rainwater harvesting (i.e. many house roofs and impermeable surfaces) during the rainy season. This would require a network (i.e. multi roof) approach for rainwater harvesting, compared to a singular roof approach as is the case for a small tank as described above. For this to be achieved, the large tanks would be located at the intersection of houses (properties) or groups of houses.

The supply of water from a pluvial surface water source (i.e. small water collection pond) or fluvial water source directly to the tanks would require a water transportation pipe originating from the water source. This could be a feasible solution if the water source is located close enough to the tank and it can provide the necessary water supply throughout the dry season months. This is unlikely to be a feasible solution if the water source is located too far away from the tank due to the cost of the transportation pipe, including pumping requirements.

Other feasible refilling options include groundwater supply through tube wells and truck supply. As discussed for small tanks, the water quality and over extraction of groundwater remains a long-term challenge. However, a deep tube well (>200 m depth) could provide the supplementary water supply required and at the desired quality for refilling purposes. It is noted that communal (multi-house) concrete tanks are commonly located throughout rural villages for drinking water supply. The tanks have a storage capacity in the order of 10 - 20 m³ and are supplied daily through deep groundwater tube wells. Refilling through truck supply is also feasible, however this becomes less feasible for the higher storage capacity tank sizes.

Typically, groups of up to 4 houses have immediate access to a tube well for their current domestic water supply. These tube wells are used during the wet and dry summer months and are typically founded in the shallower aquifers which have higher levels of contamination. Nonetheless, these accessible tube wells make water very accessible for households. This same level of accessibility would be required for the tanks to ensure the tanks are well utilized. As such, a distribution network would be required to supply water from the tank to the houses it serves in the instance where the walking distance would deter members of households from using it. This is likely the case for tanks that supply water for more than 10 households i.e. greater than 100 m³ storage capacity, however this would need to be confirmed.

The tanks maybe located above or below ground and made from reinforced concrete or GRP. Hand pumps would be required to extract water from buried tanks which are accessible within walking distance. A distribution network, including a pump and water tower, would be required to distribute water to households where the tank is not accessible within walking distance.

The tank should have the capability to allow for settling of suspended solids. Chlorination, and other chemical treatments, would also be required to maintain the water quality of the stored water during the dry season months.

Ponds – Village to Township Level

Ponds are considered to have a volume of 1,000 – 50,000m³ (20 x 20 x 3m depth) - (100m x 100m x 5m depth). Assuming a township with a population of 3000 households each use 100 liters per day, a pond with a volume capacity of 35,000m³ would provide sufficient supply for 115 days. It is noted that this excludes any consideration of evaporation which could approach or exceed 50% of the stored water volume.



Photo Source: rarsamb.kau.in.com

The ponds would be located near to villages or townships as would function as their main source of water supply. The ponds would be filled during the rainy season months through rainwater harvesting in catchments (pluvial) and/or pumping from nearby rivers. The pond could be refilled using water pumped from nearby rivers should the water collected and stored during the winter months become entirely depleted way through the dry summer months.

The river supply would need to be located near to the township to reduce the transport piping costs from the river source to the pond. Furthermore, a distribution pipe network would be required to distribute water from the pond to households and business within townships. This distribution network is anticipated to comprise pumps and water towers.

Sources of river water should be carefully considered, with consideration given to long term expected salinity concentrations. As a result of the measures of Program 1 and Program 3, there is potential to artificially create new areas of retained surface water. These areas could form a new source of surface water supply to nearby townships.

Groundwater wells could also be utilized as a source of water supply to refill ponds during the dry season months. However, this would need to be coupled with close monitoring of ground water quality and the integration with a long-term balanced aquifer recharge program.

The ponds would need to be fenced off to avoid animals contaminating the stored water and maintenance of the pond can be expected to remove settled solids on the base of the pond. Chemical treatment of the extracted water from the pond can also be expected.

Reservoirs – Township to Regional Level

Reservoirs are considered to have a volume of 50,000 – 10,000,000m³ (100 x 100 x 5m depth) - (1000m x 1000m x 10m depth). Assuming an agglomeration of townships with a population of 100,000 households each using 100 liters per day, a pond with a volume capacity of 1,000,000m³ would provide sufficient supply for 100 days. This excludes any consideration of evaporation.

Reservoirs are a practiced source of water supply across the Yangon Region. These are in elevated areas of the Yangon Region, including Unit Area 17 (i.e. Gyobyu Reservoir) and in the elevated region of Unit Area 12.



Any new reservoir would be located near to an agglomeration of townships and would be recharged through rainfall within its catchment during the rainy season months. Alternatively, water supply could be provided through pumping from nearby rivers or retained surface water. Again, the river supply would need to be located near to the township(s) to reduce the transport piping costs from the river source to the reservoir.

A distribution network would be required to transport water from the reservoir to the nearby townships. Depending on the elevation of the reservoir, this distribution network may require pumps, intermediate water storage facilities, water towers, and the like. Like ponds, maintenance and chemical treatment of extracted water from the reservoir will be required.

Aquifer Storage – Township to Regional Level

Aquifer storage is considered to have a storage volume of 4,500,000 – 9,000,000m³ (50 m³/well/hr x 6 months x 20 – 40 wells. Excludes storage loss through mixing with lower quality water and seepage loss within the aquifer.

Aquifer storage is the process of injecting suitable quality surface water into the ground water, or aquifer, to provide a long-term water supply. In this case, localized aquifer recharge could be considered near to a township(s) during the rainy season months, with the subsequent extraction of the stored water during the dry season months. This form of storage has the benefit of eliminating the water supply loss through evaporation as is the case for ponds and reservoirs. However, it does introduce potential water supply loss because of mixing with lower quality groundwater i.e. high ground water salinity, arsenic and iron levels and/or seepage loss within the aquifer.

There are two methods by which an aquifer can be recharged. These include pumped injection and natural water seepage.

Pumped Injection

In the case of pumped injection, water is pumped down drilled wells into the aquifer below. Wells are located at approximately 100m centers (typical) and are connected through a pressurized water network to the well heads. Settlement ponds are required to allow suspended solids to settle out of the sourced water, and in doing so increase the water quality before pumping into the aquifer. The settlement ponds can be continually filled during the rainy season months through water collection in their own catchments or from nearby ponds, reservoirs and rivers.

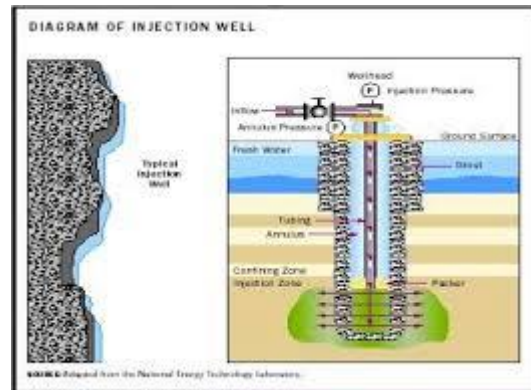


Photo Source: stateimpact.npr.org

High quality well construction and regular maintenance is required for the successful long-term operation of a pumped injection solution.

Natural water seepage

Aquifer recharge can also occur more naturally through the surface collection and seepage of rainfall and river water within the surface soils. The water is filtered and cleaned through the upper soil layers as it seeps down into the aquifer below. Unfortunately, the uppermost soil layers across the Yangon Region comprise low permeability soils or aquitards.

Figure 77 below illustrates that these low permeability soils generally extend at least 10m below ground level, with the most prominent surface aquifer located some 15m deep in the north west of the Yangon Region.

Based on these considerations, aquifer recharge from surface water seepage is not considered a feasible solution.

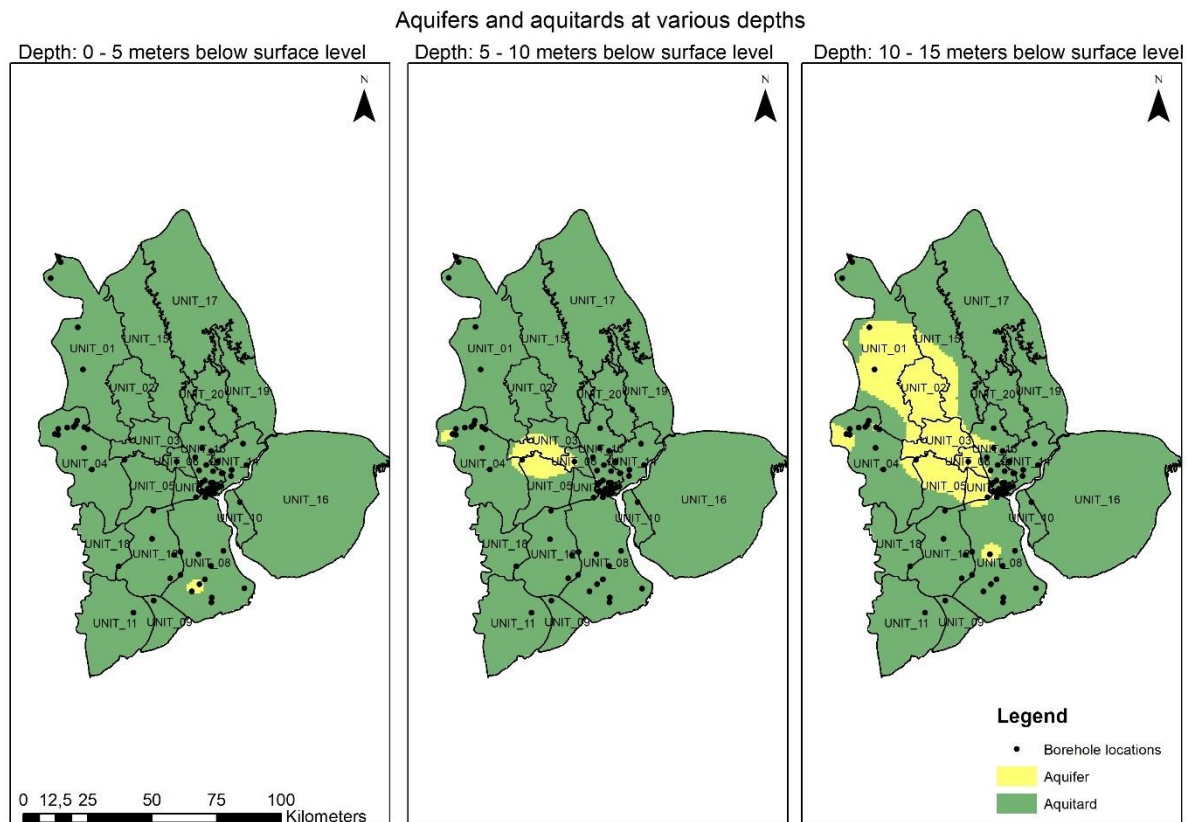


Figure 77: Aquifers and Aquitards at various depths in the project area (Goofers, 2020)

5.5.3 Program 3 Drainage Management and Irrigation

Given the complexity of estimating the behavior and extent of pluvial flooding, which requires a detailed assessment rather than a regional study, it has been decided to examine only the Focus Areas Nyaungdon, Pan Hlaing Island and Yangon South (West).

Based on inputs of stakeholders, Unit Area 8 has been selected as a first priority unit area of all unit areas as it faces many challenges across all 3 of the programs. These include:

- Urban expansion through the town of Dala;
- Coastal flooding and salt water intrusion;
- Shortages in water supply for domestic and irrigation uses
- Pluvial flooding exceeding the indicator threshold.
- Elevated impacts of cyclones compared to the other unit area

Unit Area 8 provides an opportunity to develop an integrated water management solution to address these challenges. This integrated solution, or parts of it, can then be carried forward when developing the other unit areas.

Approach

Indicator thresholds (or design limits) for pluvial flooding have been established as follows;

- Maximum inundation depth for urban areas: 0.3 m
- Maximum inundation depth for rural areas: 0.6 m

A detailed SOBEK model has been developed to model the drainage capacity of the existing drainage channels and outlet structures for Unit Area 8. This model provides the baseline understanding of the locations and levels of inundation across Unit Area 8 and will be used to conceptualize measures.

Archetypical solutions have been conceptualized to support drainage of water that exceeds the threshold indicators and/or to utilize the water (and land) for irrigation purposes. These archetypical solutions are detailed in Table 39.

Table 39 Solution combination matrix for program 3

Solution combination				
	1. Increase the discharge capacity of channels within the Unit Area and into the surrounding rivers	2.Channels are blocked and/or widened to create stored water volume for irrigation (i.e. reservoir)	3.Block existing channels open to surrounding rivers to reduce saltwater intrusion	4.Improve access to water across the unit area
Sluice		If drainage is possible under free flow conditions and all tidal conditions in the case of needing to reduce the volume of stored water.	If full drainage is possible under free flow conditions and all tidal conditions. Sluices can also be used to allow water ingress from the surrounding rivers in periods of low salinity levels.	
Sluice + Pumping	If full drainage is not possible under free flow conditions and all tidal conditions	If full drainage is not possible under free flow conditions and all tidal conditions in the case of needing to reduce the volume of stored water.	If full drainage is not possible under free flow conditions and all tidal conditions Sluices can also be used to allow water ingress from the surrounding rivers in periods of low salinity levels.	
Channel Deepening / Widening	If full drainage is possible under free flow conditions and all tidal conditions.	To increase the storage capacity of the channels		
Additional channels and water supply				Provide increased interconnectivity of within the drainage system to better distribute water, including the potential of a new natural water supply

Discussion

Solution Combination 1: Increase the discharge capacity of channels within Unit Area 8 and into the surrounding rivers.

An existing channel requires additional discharge capacity to drain water from the unit area.

Deepening or widening of the channel will increase the channel area and in doing so increase the drainage capacity of the channel. However, this option may not be feasible in the instance that high channel flows or high tides/sea levels outside of the unit area result in reverse flow and upstream flooding and also saltwater intrusion. Depending on the frequency of this type of event, an alternative is to introduce a sluice. The sluice would be closed during periods of high river flows and high tides / sea levels to restrict water inflow into the

unit area. Conversely, the sluice would be opened to allow water collected during rainfall (pluvial) to drain into the surrounding rivers or seas. Pumping capacity can be added to provide additional drainage capacity during peak flows and/or during high river or sea levels outside of the unit area.

Solution Combination 2: Channels are blocked and/or widened and deepened to create stored water volume for irrigation (i.e. reservoir).

A channel is purposely blocked to create stored water behind for the purpose of water supply for irrigation. In this instance a sluice is introduced which has the ability regulate water flow within the channel and control the upstream stored water volume and flow downstream. Depending on the location of the sluice and size of the channel in which it is located, additional pumping capacity can be provided to ensure drainage of the river during periods of peak rainfall. The channels can be widened and deepened to increase the storage volume behind the sluice.

Solution Combination 3: Block existing channels open to surrounding rivers to reduce saltwater intrusion

A sluice is constructed within the dike in the existing location of the channel outlet (similar concept to that covered under Program 1).

The sluice would be closed during periods of high flows in the surrounding rivers (fluvial) or high tides / sea levels (coastal) outside of the unit area to restrict saltwater inflow into the unit area. Conversely, the sluice would be opened to allow water collected during rainfall (pluvial) to drain into the surrounding rivers or seas. Pumping capacity can be added to provide additional drainage capacity during peak flows and/or during high river or sea levels outside of the unit area.

Solution Combination 4: Improve access to water across the unit area

Increased interconnectivity is introduced between the channels to redirect flow from one part of a unit area to another. This would increase the water supply to farms which currently experience scarcity. This could be further enhanced by adding new channel channels and/or connecting a new source of water supply.

5.6 Integrated solutions

Each of the three programs presented in the previous sections deals with a specific aspect of the water security challenges of the project area. Program 1 aims to bring flood safety in dedicated areas to sufficient levels; Program 2 aims to improve water availability especially in the less developed rural areas, and Program 3 aims to restore, secure or improve the drainage capacity so that pluvial flooding is better controlled.

For each of these programs, the RWSS develops specific measures which are worked out at conceptual and in some cases pre-feasibility levels. The latter means that design sketches are provided on the basis of which a Bill of Quantities can be prepared as well as a 50% accurate CAPEX estimate. Although a programmatic approach is proposed to implement these measures, it is still projects-based. Since the three programs are interlinked, there will be combined sets of measures that serve more than just one of the program's objectives. Finding these combinations of measures is typical for an integrated water resources management (IWRM) approach.

Flood protection (Program 1) and improving drainage capacity (Program 3) are interlinked. If, for example, a natural drainage outlet needs to be closed to improve the flood safety, then a separate measure such as a sluice is needed to at least secure the existing drainage capacity of that outlet. It may also be necessary in some cases to include pumps in the new outlet structure and, if that is the case, then the drainage canals leading to the pumping station must have sufficient conveyance capacity. If then for that reason the existing channels need to be deepened or widened, then these bigger channels may also contribute to faster drainage of the hinterland during periods of extreme rainfall and by doing so alleviate the pluvial flood damage. Vice versa, when fluvial or coastal flood is reduced, then less drainage capacity may be needed, depending on how important these two types of flooding are compared to local pluvial flooding. Drainage is an integral part of flood mitigation.

Another example of additional benefits from an integrated approach is when water storage facilities, such as widened channels, excavated ponds, or new reservoirs, can be used for water supply in dry periods and at the

same time reduce pluvial flood damage. This approach follows the logical order: collecting rainwater, then store it and then drain it. Near Kawhmu and Kungyangon, storage ponds are indeed filled with water from the drainage canals. These ponds have a combined estimated volume of $> 140,000 \text{ m}^3$. As mentioned, potentially relieving the drainage system through stormwater storage whilst providing for domestic water needs. There is however, also a back-side of this reasoning: if water is stored in ponds, widened canals and reservoirs, then the capacity for stormwater storage becomes less (more water stored under Program 2) conflicts with ways to minimize pluvial flood risk (Programs 1 and 3).

There are other examples that illustrate the potential of an integrated approach, for example:

- If floods occur less frequently, then the chance of pollution of water storage ponds is less likely;
- If an outlet / inlet sluice is adjusted, it can be combined with a ship lock, improving local navigability;
- If a dike is heightened, it offers the opportunity to develop a new waterfront or to improve the local road network.

The Figure below shows the interlinkage of the three programs as described above.

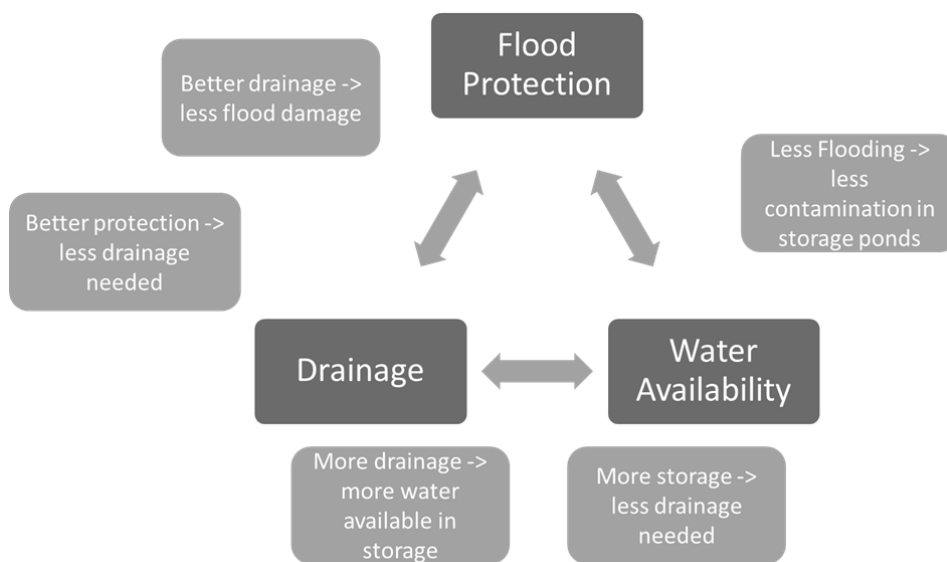


Figure 78: Relations between programs

6 CONCRETIZATION OF MEASURES

6.1 Details program 1 weakest links (flood protection)

The flood risk assessment detailed in Section 4.5 provided an overview of the need for flood protection in terms of economic risk reduction and a reduction in annual affected people for all unit areas. This risk reduction can be taken into account to see if flood protection is feasible and to what level.

Based on this, for each Unit Area an optimal level of flood protection is determined. For some unit areas, the flood risk is too little to offset the investments required to increase the level of flood protection. In this respect, the long list of unit areas is reduced to a short list by eliminating those Unit Areas that do not require increased flood protection (section 6.1.5). The result is a short list of Unit Areas and appropriate measures.

6.1.1 Results of Flood Risk Assessment

The results from the flood risk assessment which was done for the whole project area is presented in Section 4.5. Below, the main findings from this assessment are recapitulated, i.e. the outcome in terms of annual expected economic damage and annual expected people affected.

The flood risk is for three scenarios:

- Current land use, no climate change (also referred to as Baseline),
- Current land use, climate change, and
- Future land use, climate change.

Table 40 presents the top 5 of Unit areas with highest annual expected economic damage for the scenario with current land use, without the effect of climate change taken into account. In the last column to the right, the annual expected affected people per unit area is presented additional to the calculated economic flood risk. Unit area 4 has by far the highest flood risk, both in terms of economic damage and people affected.

Table 40: Top 5 Unit areas with highest annual expected economic damage (current land use, no climate change)

Unit	Current fluvial flood protection	Current coastal flood protection	Annual expected economic damage (million USD)	Annual expected affected people (thousands)
UNIT_04	1:2	<1:25	15.6	28.0
UNIT_01	1:2	1:79	5.4	14.3
UNIT_18	1:2	<1:25	4.0	14.0
UNIT_06	1:67	1:33	1.9	1.1
UNIT_13	1:118	1:28	1.7	1.8

Table 41 presents the top 5 of Unit areas with highest annual expected economic damage for the scenario with *current* land use and with the effect of climate change taken into account. In the last column to the right, the annual expected affected people per unit area is presented additional to the economic flood risk. The top 5 is similar to scenario 1: climate change affects all unit areas with more extreme flooding and corresponding economic damage and people affected.

Table 41: Top 5 Unit areas with highest annual expected economic damage (current land use, climate change)

Unit	Current fluvial flood protection	Current coastal flood protection	Annual expected economic damage (million USD)	Annual expected affected people (thousands)
UNIT_04	<1:2	<1:25	19.8	39.4
UNIT_01	<1:2	1:70	7.6	20.9
UNIT_18	<1:2	<1:25	3.1	13.3
UNIT_06	1:39	<1:25	2.5	1.8
UNIT_05	<1:2	<1:25	2.2	4.3

Table 42 presents the top 5 of Unit areas with highest annual expected economic damage for the scenario with future land use, with the effect of climate change taken into account. The top 5 is totally different compared to the previous two scenarios. Only unit area 4 is still presented in this table, on position 3. Unit area 3 and 7 now rank 1 and 2, because of the expected high degree of urbanization in these areas in the coming 20 year. It should be noted that the impact of this urbanization on affected people has not been taken into account, and the presented annual people affected are based on the current population distribution in the unit areas. It is therefore clear that the values of annual expected affected people be substantially higher than the figures provided after the urbanization of these areas.

Table 42: Top 5 Unit areas with highest annual expected economic damage (future land use, climate change)

Unit	Current fluvial flood protection	Current coastal flood protection	Annual expected economic damage (million USD)	Annual expected affected people (thousands)
UNIT_03	<1:2	<1:25	87.7	3.3
UNIT_07	<1:2	<1:25	57.0	12.0
UNIT_04	<1:2	<1:25	19.8	39.4
UNIT_06	1:39	<1:25	11.5	1.8
UNIT_02	<1:2	<1:25	9.5	2.1

6.1.2 Dike Strengthening Assessment

The objective of this assessment is to determine the effect of reinforcing existing dikes and constructing new dikes on flood risks. Two separate flood risk indicators are used to derive an optimal flood defense improvement strategy:

- Annual expected Economic Damage
- Annual expected number of people affected by flooding.

The dike strengthening assessment is done for all of the 20 unit areas and aims for an optimized flood protection level. For every unit area it was determined whether it is economically feasible to strengthen the existing dikes that protect the unit areas from flooding. Besides, the impact of flood defense investments on the number of people affected by flooding was determined. Based on the quantified effects of dike improvements, optimal flood protection levels for each unit area are derived with an accompanying improvement strategy.

Figure 79 shows the basic principle guiding the dike strengthening assessment. Economic feasibility of flood defense improvements is tested by calculating and optimizing the total costs. Total costs are defined as the sum of the investment (present value of CAPEX and OPEX) required to obtain a certain protection level and the Net Present Value (NPV) of the residual economic flood risk for a certain protection level. On the left side in Figure 79, where the orange line representing Annual expected Economic Damage (AED) touches the Y-axis, is the situation without additional protection level. Total costs at this point in the graph consists of the sum of the present value of AED over the design period. At the vertical red dashed line, total costs are lowest. Further to the right, the AED decreases further, but the required investment costs of this decrease exceed the reduction of the AED. Based on this principle, economically optimal flood protection levels are determined for every unit area. The annual flood risk is determined with the flood risk assessment summarized above. The process of estimating CAPEX and OPEX is detailed below.

As becomes clear in Figure 79, the risk reduction for enhanced flood protection varies for different protection levels. As a result, Benefit/cost ratios differ for different flood protection levels as well. In the example shown left in Figure 79, the benefit/cost ratio for a 1 in 50 year protection level is higher than for a 1 in 100 year flood protection level, while the total costs still decrease from 1 in 50 year to 1 in 100 year flood protection level. The total costs are ultimately always decisive to set a cost-optimal flood protection level. The most cost-effective solution is therefore not necessarily the solution with the highest benefit/cost ratio. The benefit/cost ratio is used as threshold to determine whether any flood defense improvement strategy results in decreased total costs relative to the situation without any intervention. The right side of Figure 79 shows a situation in which a Benefit/cost ratio below 1 indicates that investments do not pay off.

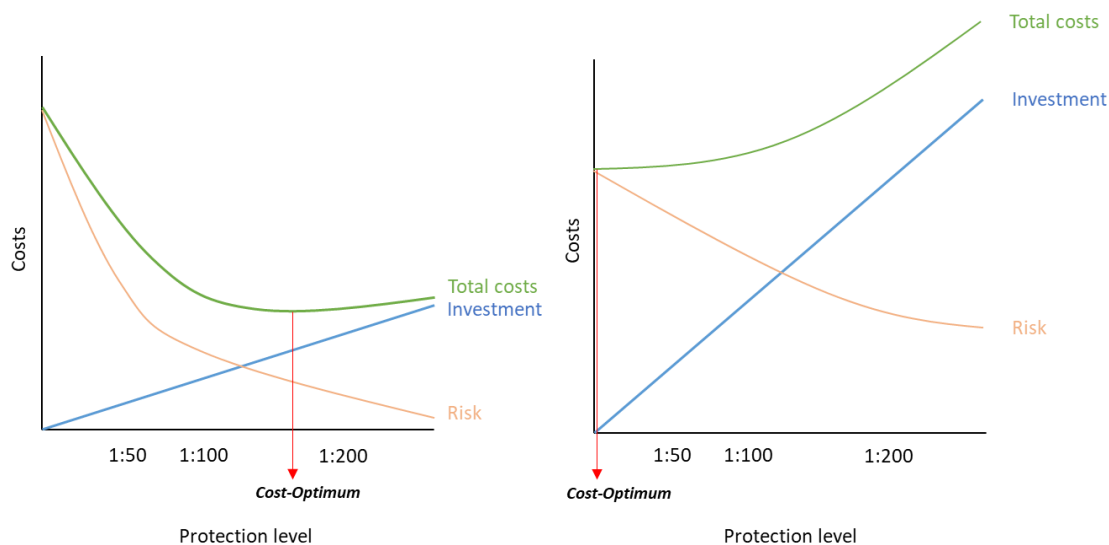


Figure 79: Example of cost-optimization for dike investments. The left figure represents an example in which investments are cost-effective, while the right figure represents a situation in which investments do not pay off.

6.1.3 Estimating investment costs

To be able to weigh the decreased annual flood risk (AED) due to an enhanced safety standard against the required investment costs to achieve this enhanced standard, the investment costs have to be quantified.

The investment costs of dike reinforcement largely depend on the required design of the reinforced dike. This design in turn depends on the dominant failure mechanisms causing the dike functioning to fail. In general, the 4 dominant dike failure mechanism are overflow and overtopping, erosion of dike revetment, sliding of inner slope, and piping. The principle of these mechanisms is presented in Figure 80.

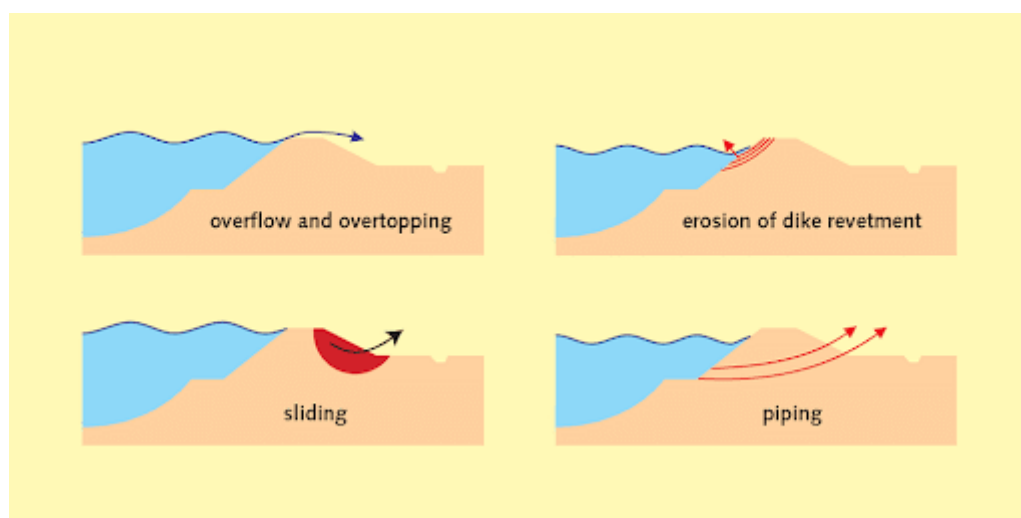


Figure 80: Failure mechanisms of dikes (source: FLOODSite)

Within the 20 unit areas, more than 1500 km of flood defenses is present (Figure 9). Although erosion of dike revetment, sliding of inner slope and piping can play a role in the strength of these flood defenses, it was impossible in this project to assess these failure mechanisms in a uniform and integral way. Given the information available, it was only possible to assess overflow and overtopping to determine the flood probability of unit areas. However, in the design of both reinforced and new dikes, erosion of dike revetment and sliding of inner slope were included in some way: a less steep slope is used to improve slope stability and a thick

outer clay layer is applied to prevent erosion of dike revetment. Piping might be of minor concern given the relatively low hydraulic head over the dike in relation to its (new) width. Besides, IWUMD carries out very adequate field inspections during high river water levels. When signs of piping are spotted effective measures are taken to stop the piping process.

- In the derivation of the investment costs per unit area required to set a certain flood security level, the existing system of dikes was used as the reference situation. Cost-estimations for dike strengthening were determined based on the extension of the existing dike profile (wider and taller), in which the existing dike body remains in place, as core for the new dike. The quantification of the investments costs in this study includes the following aspects:
- Raw material costs for dike strengthening: the acquisition of raw material to be applied in the new dike profile. The basic design philosophy followed for the estimation of required raw material quantities is based on use of sand as core material next to the existing dike body. The sand core is covered with a clay-layer to maximize erosion-resistance.
- Initial construction costs for adapted dike profiles
- Costs for construction of additional hydraulic structures: Additionally, an analysis of local rivers/streams crossing the primary dikes of each unit was made based on satellite data analysis. Costs for the construction of new hydraulic structures to close off the existing open channel crossings were included in the investment cost quantification. Streams were only considered in case these cross a dike-stretch requiring an increase in crest level.
- Maintenance: Costs for periodical maintenance of the newly constructed dikes and hydraulic structures was included.

Based on the above described basic design philosophy, the required investment costs were quantified separately for each of the unit areas, based on the hydraulic data and earlier calculated crest level deficit per return period of the currently present flood defenses. For the flood defense improvement strategy, the dike profile schematization shown in Figure 81 was followed. For the calculation of the investment costs, the following steps were taken (1 to 5):

- 1) The required crest level raise for flood defenses along the unit areas was determined based on the combined average crest level *deficit* for coastal and fluvial floods for return periods 1 in 50, 1 in 100 and 1 in 200 year. This average value was derived from the deficit for all flood defense stretches where the current crest level is below the outside water level for the climate change scenario, including a freeboard of 0.3 m.
- 2) *Table 43* presents the design parameters used to quantify the required quantities of additional raw material. *Figure 81* gives a graphical representation of a typical cross section for the dike stretches with a crest level deficit.

Table 43: design strategy parameters

Parameter	Value
Slope_current	1:1.5 (according to IWUMD)
Slope_new	1:3
T_cover	0.5m
Crest_width	3.66m (12 feet, according to IWUMD)
H_curent	Variable per Unit
H_increase	Variable per unit & design return period

The current slope and crest widths of the dike profiles have been obtained from IWUMD. To derive the current dike heights in the area, for all units an elevation sample was taken from a 90m-SRTM-dataset in the area at three locations directly behind the current dikes at locations with a crest level deficit. The required crest-level raise and the length of the flood protection for which crest-level raising is required, are both given by the crest level deficit data for the various return periods, in comparison with the crest levels of the present dikes. The new dike profile is assumed to be constructed of a combination of a sand-core around the existing dike, along with a 0.5m clay-cover on all sides, as depicted in *Figure 81*.

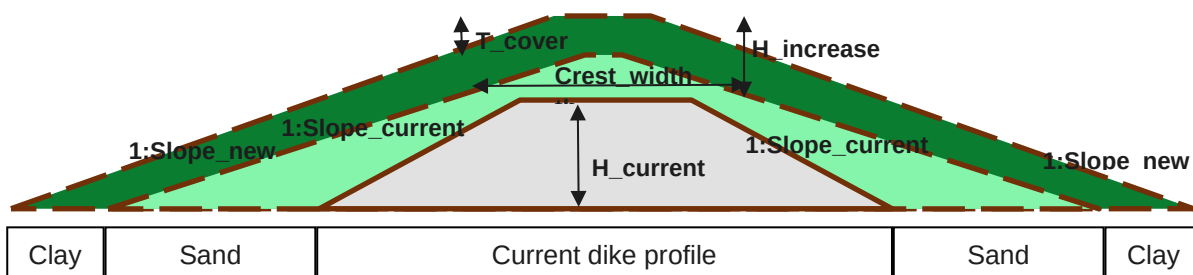


Figure 81: Typical cross section of reinforced dike

- 3) The calculated required volumes of sand and clay to strengthen the dikes according to Figure 81 for the 50, 100 and 200 year return periods are monetized by bulk cost values: 14 USD / m³ for Clay and 11.8 USD/m³ for sand. These costs cover the material & construction costs.
- 4) Additionally, the construction of raised flood protection around the unit areas in some cases also requires the construction of additional hydraulic structures at locations where local drainage channels cross future dike strengthening paths. The possible costs for those structures are incorporated in the cost-benefit analysis as well. The presence of open channels crossing the dike paths was examined based on satellite data, after which these channels were categorized according to the widths of the present channels. Accompanying cost-estimates for similar structures were used to estimate the expected construction costs for these additional hydraulic structures (Table 44). Possible costs for adjustments to existing hydraulic structures are not incorporated in the investment cost quantification. Also refer Section 6.1.7 for further details.

Table 44: Investment costs for hydraulic structures (3 sizes) based on program 3

Hydraulic structure type:	Investment costs (million USD)
Small sized hydraulic structures (<25m channel width)	1.0
Medium sized hydraulic structures (>25m, <50m channel width)	1.8
Large sized hydraulic structures (>50m, <100m channel width)	3.5

- 5) To derive the total investment costs, periodical maintenance and operating costs are added up to the initial investment costs to derive the total economic costs. Annual maintenance was set at 0.1% of the initial investment and 5-yearly periodical maintenance was set at 3% of the initial investment costs. To derive the Net Present Value (NPV) of the combined investment, a discount value of 6% was used to convert all required investments up to 2040 to the present day-value.

With the above approach, some cost-components which could as well be involved in flood defense improvement have been left out. Either because data for a proper cost-quantification of the respective components was lacking, and/or because the component is relatively insignificant compared to the costs of other components. The following components have been left out:

- Slope/Dike revetment: The necessity and type of revetment is highly susceptible to local characteristics, such as land use and hydraulic characteristics in the adjacent areas. No data was available to make a founded revetment cost-estimation.
- Land acquisition: As the design philosophy followed in program 1 is based on reuse and extension of existing dikes, land acquisition-costs areas much less prominent than they would be in case of new flood defense construction along the unit areas.
- Adaptations to existing hydraulic structures: No data is available about characteristics and crest levels of currently present hydraulic structures.
- Costs for flood defense improvement for other failure mechanisms than overflow/overtopping: As detailed information about the materials and interior of the currently present flood defenses is lacking, analyses for other failure mechanisms than overflow/overtopping could not be performed.

6.1.4 Sensitivity analysis cost-effective protection levels

The resulting cost-effective flood protection levels on unit area base depend on many uncertain input parameters and design choices. Below brief sensitivity analysis provides an overview of how several important parameters and design choices impact the resulting proposed flood protection levels.

A total of 6 different parameters are varied one by one with respect to the base scenario used in the cost-benefit analysis:

- **Agricultural flood risks (AR):** In the base scenario, the offset for agricultural and aquaculture flood risks is set at 1:2, meaning that possible calculated flood risks for the 1:2 flood scenario are neglected, as flood-patterns with small reoccurrence intervals are considered not harmful for these types of landcovers. In this sensitivity analysis, this offset for harmful floods is varied.
- **Discount rate (DR):** A discount rate of 6% is used as base scenario to calculate the net present value of investments and flood risks up to 2040. Raised discount rates are used in the sensitivity analysis.
- **Material & Construction costs (CCS, CCC):** The dike material- & construction costs impact the financial viability of investments into the current flood defense system.
- **New dike slope (DS):** The new dike slope is a design parameter impacting the quantities of required construction material, hence impacts the financial viability of flood defense investments.
- **Hydraulic structure costs (HSC):** The hydraulic structure costs impact the financial viability of flood defense improvements for units containing open channel crossings. Alternative hydraulic structure costs are considered.
- **Required hydraulic structures (RH):** In the base scenario, the assumption is made that additional hydraulic structures are required as links in the enhanced flood defense system of a unit area in case the flood defenses adjacent to an open channel crossing, show a crest level deficit for the proposed improvement strategy. If this is the case, it is assumed that inland local flood protection next to the open channel suffices as well. In case there is a crest level deficit on the flood defense stretch crossing the open channel, hydraulic structures are then required. In this sensitivity analysis, this assumption is varied. A scenario is tested in which all open channel crossings require a new hydraulic structure, assuming that inland flood protection never suffices.

The considered sensitivity analysis scenarios are summarized in Table 45, where the parameter that is changed is shaded.

Table 45: Description of the parameters used in the sensitivity analysis scenarios

Scenario-ID:	Agricultural flood risks		Discount rate	Construction material costs	New dike slope	Hydraulic structure costs	Required Hydraulic structures
Base	No flood	fluvial risks	6%	Sand: 11.8 USD/m ³ , Clay: 14 USD/m ³	1:3	Small: 1.0 Million USD Medium: 1.8 Million USD Large: 3.5 Million USD	All open channel crossings where dikes face crest level deficit
AR1	No flood	fluvial risks	6%	Sand: 11.8 USD/m ³ , Clay: 14 USD/m ³	1:3	Small: 1.0 Million USD Medium: 1.8 Million USD Large: 3.5 Million USD	All open channel crossings where dikes face crest level deficit
AR2	No flood	fluvial risks	6%	Sand: 11.8 USD/m ³ , Clay: 14 USD/m ³	1:3	Small: 1.0 Million USD Medium: 1.8 Million USD Large: 3.5 Million USD	All open channel crossings where dikes face crest level deficit
DR1	No flood	fluvial risks	8%	Sand: 11.8 USD/m ³ , Clay: 14 USD/m ³	1:3	Small: 1.0 Million USD Medium: 1.8 Million USD Large: 3.5 Million USD	All open channel crossings where dikes face crest level deficit
DR2	No flood	fluvial risks	10%	Sand: 11.8 USD/m ³ , Clay: 14 USD/m ³	1:3	Small: 1.0 Million USD Medium: 1.8 Million USD Large: 3.5 Million USD	All open channel crossings where dikes face crest level deficit
CCS1	No flood	fluvial risks	6%	Sand: 0.5*11.8 USD/m ³ , Clay: 14 USD/m ³	1:3	Small: 1.0 Million USD Medium: 1.8 Million USD Large: 3.5 Million USD	All open channel crossings where dikes face crest level deficit
CCS2	No flood	fluvial risks	6%	Sand: 1.5*11.8 USD/m ³ , Clay: 14 USD/m ³	1:3	Small: 1.0 Million USD Medium: 1.8 Million USD Large: 3.5 Million USD	All open channel crossings where

Scenario-ID:	Agricultural flood risks		Discount rate	Construction material costs	New dike slope	Hydraulic structure costs	Required Hydraulic structures
							dikes face crest level deficit
CCC1	No flood ≤1:2	fluvial risks	6%	Sand: 11.8 USD/m ³ , Clay: 0.5*14 USD/m ³	1:3	Small: 1.0 Million USD Medium: 1.8 Million USD Large: 3.5 Million USD	All open channel crossings where dikes face crest level deficit
CCC2	No flood ≤1:2	fluvial risks	6%	Sand: 11.8 USD/m ³ , Clay: 1.5*14 USD/m ³	1:3	Small: 1.0 Million USD Medium: 1.8 Million USD Large: 3.5 Million USD	All open channel crossings where dikes face crest level deficit
DS1	No flood ≤1:2	fluvial risks	6%	Sand: 11.8 USD/m ³ , Clay: 14 USD/m ³	1:1.5	Small: 1.0 Million USD Medium: 1.8 Million USD Large: 3.5 Million USD	All open channel crossings where dikes face crest level deficit
DS2	No flood ≤1:2	fluvial risks	6%	Sand: 11.8 USD/m ³ , Clay: 14 USD/m ³	1:5	Small: 1.0 Million USD Medium: 1.8 Million USD Large: 3.5 Million USD	All open channel crossings where dikes face crest level deficit
HSC1	No flood ≤1:2	fluvial risks	6%	Sand: 11.8 USD/m ³ , Clay: 14 USD/m ³	1:3	Small: 0.5 Million USD Medium: 1.0 Million USD Large: 2.0 Million USD	All open channel crossings where dikes face crest level deficit
HSC2	No flood ≤1:2	fluvial risks	6%	Sand: 11.8 USD/m ³ , Clay: 14 USD/m ³	1:3	Small: 1.5 Million USD Medium: 2.5 Million USD Large: 5.0 Million USD	All open channel crossings where dikes face crest level deficit
RHS	No flood ≤1:2	fluvial risks	6%	Sand: 11.8 USD/m ³ , Clay: 14 USD/m ³	1:3	Small: 1.0 Million USD Medium: 1.8 Million USD Large: 3.5 Million USD	All open channel crossings

The influence of the sensitivity analysis scenarios is studied for the climate change + future land use scenario. The impact of these scenarios on the economically most efficient flood protection standard are for each unit area shown in Figure 82 relative to the base scenario. Results are only shown for those unit areas that are impacted by one of the sensitivity analysis scenarios. The x-axis shows abbreviations of the studied sensitivity scenarios, as mentioned in Table 45. The economically optimal flood safety level of unit area 1, for example, varies between 1 in 50 year (e.g. DS2) to 1/200 year (DS1) depending on the choice of parameter settings. This is elaborated below.

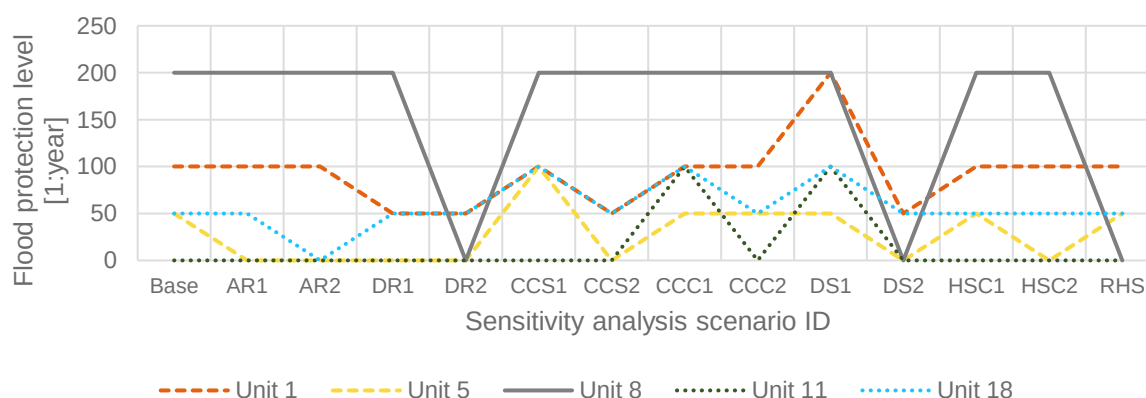


Figure 82: Sensitivity of the economically optimal flood protection level (abbreviations on the x-axis are explained in Table 45).

Agricultural flood risks: The choice for which offset return period to use for the incorporation of damage to agricultural property (AR2 for example assumes no damage occurs under 1 in 10 year fluvial flood events) only affects the benefit-cost ratios. This assumption affects a limited number of unit areas, in most of which the total flood risk is only for a small part made up by the agricultural flood risks (for the more frequent flood scenarios). Unit areas 5 and 18 are impacted by this assumption, as the flood risks are in these unit areas made up largely by agricultural flood risks. In case agricultural flood risks would be significantly lower for the

higher reoccurrence frequencies, then investments into the flood protection for these unit areas become less cost-efficient

Discount rate: The discount rate directly affects the analysis results for 3 of the 20 units (see Figure 82). In case the future discount rate would be higher than the assumed default 6%, the net present value of the future flood risk reduction becomes less valuable. As the net present value of the flood defense investment costs remains almost stable (as these investments are largely made on short term), investments then become less cost-effective. As a result, with higher discount rates the economical optimal protection level reduces. For most of the unit areas, this appears not to affect the optimal standards, because for most unit areas the margins between costs and benefits are high, hence the uncertainty in the discount rate will not affect the optimal protection level much. However, for unit areas 1, 5 and 8 this aspect is important. Especially for unit area 8, the margins are small. For this unit area, the benefits of flood defense improvement up to a 1 in 200 year FP-level only slightly outweigh the accompanying investment cost burden. The sensitivity calculations show that depending on the discount rate, the economic burden of flood defense improvements for unit area 8 could outweigh the benefits, as a consequence of which no enhanced protection level would be cost-effective.

Material- & Construction costs / New dike slope: The construction costs of the new dikes are either affected by the raw material cost uncertainty or by the design choice for the outer dike slope. The choice is most felt in the calculated economically optimal protection level for unit areas 1, 5, 8, 11 and 18 (Figure 82). For each of these unit areas, the optimal protection level can deviate significantly from the level in the base scenario. For unit areas 1 and 18, for example, the total costs (remaining flood risk + investment costs) are approximately the same for two different flood protection levels. Slightly reduced or increased construction costs therefore easily impact the optimal protection level for these unit areas. For unit areas 8 and 11, the Benefit/Cost ratio is close to 1 for a 1:100 protection level in the base scenario. The investment cost uncertainty can therefore affect the financial viability of the flood protection investment, affecting the decision to set a protection level or no improved protection level at all. For unit area 5, Benefit/Cost ratios are for all studied flood protection levels close to 1, which is why the economically optimal flood protection level fluctuates between 1 in 100 year, 1 in 50 year and no additional protection level at all.

Hydraulic structure costs / Required hydraulic structures: Both the hydraulic structure costs and the decision whether to install hydraulic structures at all open channel crossings or not, hardly impact the resulting optimal flood protection level. Most additional hydraulic structures are necessary in unit areas where the investment costs either by a large margin outweigh the flood reduction benefits, or by far do not outweigh these benefits. The hydraulic structure costs therefore hardly impact the protection level decision. Units 5 and 8 are a notable exception, as hydraulic structure costs make up a major proportion of the total investment costs. The Benefit/Cost ratios in these units are close to 1, which is why these unit are sensitive to this parameter.

Conclusions - sensitivity analysis

For unit areas 9, 12, 14, 16 and 19, the required investment costs are in the base scenario significantly higher compared to the projected reduced flood risk benefits. Additional flood defense investments are therefore not financially interesting here and none of the sensitivity analysis scenarios change this conclusion (Table 45). On the other hand, unit areas 2, 3, 4, 6, 7, 10, 13, 15, 17 and 20 are not affected by the studied sensitivity scenarios either, because the Benefit/Cost ratios (for flood protection level 200) are under all circumstances above unity (so attractive). The proposed flood protection level for each of these units is not impacted by any of the studied uncertainty parameters. For five unit areas, the economically optimal flood protection standard is sensitive to the underlying parameters and assumptions. For these five unit areas, either the Benefit/Cost-ratios are close to 1 (impacting the financial viability of flood defense investments), or the total costs (Investments + remaining flood risk) for different protection levels are very close to each other, impacting the optimal protection level. Overall, the results indicate that for some unit areas the optimal flood protection standards is impacted by the design/uncertain parameters. For this reason, this needs to be re-assessed in greater detail in follow-up (Pre)-Feasibility Studies.

Additionally, the influence of the proposed flood safety standards on the annually expected affected residents is shown and discussed. It must be noted that the protection level consequences for annually expected flood-affected residents is only available for the "Climate change + Current land use" scenario, hence the impact of future urban developments on population growth is not incorporated. Given the fact that most land use changes are expected to be accompanied with population growth, the number of affected people without improved

safety measures is likely to increase. Because of the proposed higher flood safety levels, the reduction in annual expected affected people is therefore likely to increase as well.

Importance of Mezali sluice and the Cofferdam in the Pan Hlaing river

The Pan Hlaing river is an approximately 55 km long tributary of the Kokkowa river, flowing alongside unit areas 3, 4, 5, 6 and 7, before confluenting with the Kokkowa river close to the city center of Yangon. This river contains two important structures, which fulfill an important role in the flood protection of the adjacent unit areas. Mezali sluice, right at the bifurcation point of the Pan Hlaing river, can prevent high river water levels of the Pan Hlaing river during fluvial flood events, avoiding flooding along the river downstream. On the downstream side of the river, 14 km upstream of the confluence point between the Kokkowa and Pan Hlaing rivers, the seasonal cofferdam plays an important role in protection against floods caused by flood surges during storms, by preventing flood surges propagating upstream of the Cofferdam into the Pan Hlaing river.

For the flood simulations used in the economic cost-benefit analyses in this study, it is assumed that both Mezali sluice and the Cofferdam can fulfill these flood prevention tasks under all considered flood scenarios. The river stretch between Mezali sluice and the Cofferdam is currently bordered by relatively poor flood protection, which underlines the importance of the two structures. In case either of these structures would not be able to prevent fluvial or coastal flood water from entering the Pan Hlaing river, flooding along this river would become likely. For any additional flood protection level set for the unit areas along the Pan Hlaing river, the structural integrity of these two structures is therefore an essential prerequisite. It is doubtful if the Cofferdam can provide such safety under extreme coastal events, which is one of the reasons to consider the construction of the Pan Hlaing Sluice at the river's eastern end.

Without either of these two structures, the current dikes along both sides of the river would require extensive additional strengthening to improve the flood protection level for the adjacent areas, involving high additional investment costs. Furthermore, as these areas are likely undergoing significant urban development in the next decades, the importance of the cofferdam and Mezali sluice will further increase. In correspondence with the derived optimal flood protection standards for unit areas 3 to 7, the Cofferdam should be designed with a 1:200 flood protection level. Once the proposed new sluice has been constructed on the east side of the Pan Hlaing river, there is no more need for the Cofferdam.

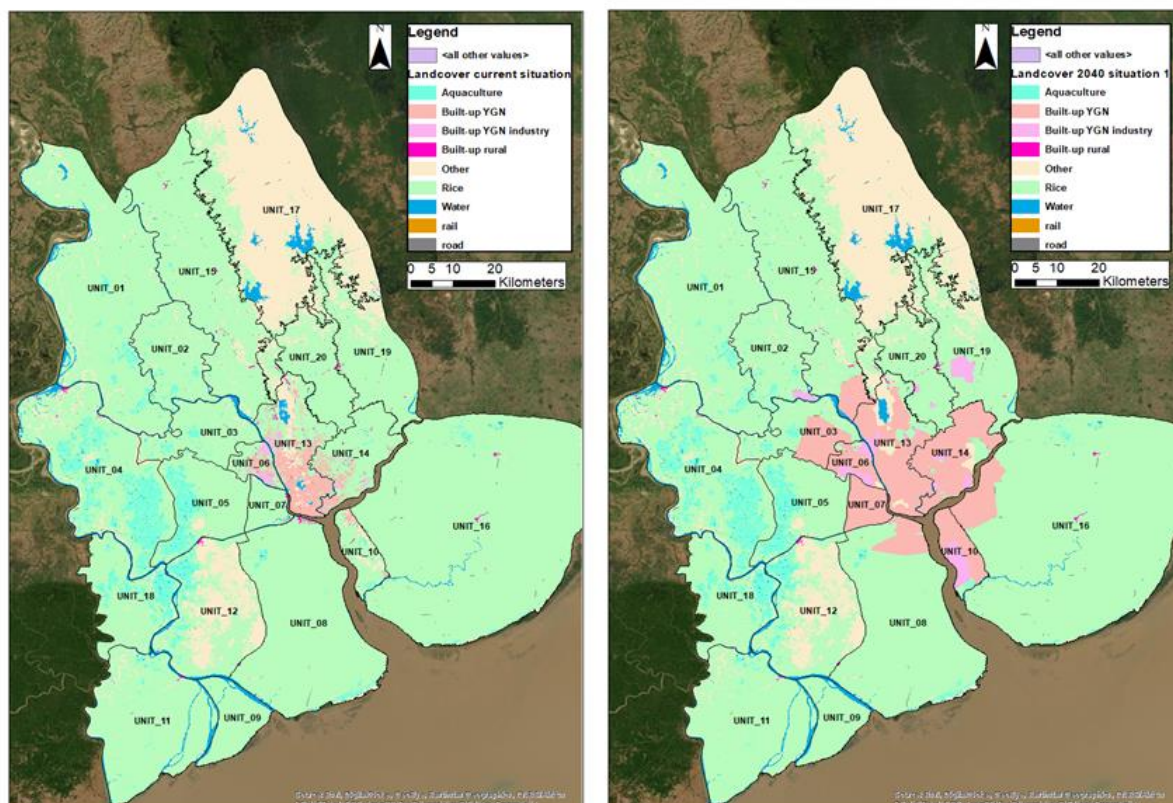


Figure 83: Land use maps

6.1.5 Proposed flood protection levels

Besides the unit area-specific cost/benefit data, the motivation for the proposed flood protection level refers to the underlying data on flood extent, elevation, land use and flood defense improvement strategy. This information is presented below. A graphical overview of the current and (expected) future land use is shown in Figure 83. Details about the fluvial and coastal flood extents for different return periods is given in Figure 85, whereas *Figure 84* shows a surface elevation map of the area. Finally, the table provides an overview of the required flood defense improvement measures for three possible flood protection levels.

In basis, separately for each unit area, the required investment costs have been weighted against the flood risk reduction benefits, to determine the economically optimal flood protection standard. It is however important to keep in mind that in case of flooding, some unit areas act as one internally linked system, without a physical border such as a river or dike. As a result, dike breaches along one unit area may result in flooding of multiple unit areas. Unit areas 3 and 6 and unit areas 4, 5 and 7, for example act as two of such interlinked systems (see Figure 86). In the derivation of optimal flood protection standards, this characteristic has been accounted for. The investment costs and flood risk reduction of these two interlinked systems are therefore considered collectively instead of individually, to assure that one uniform protection level is set for these interconnected unit areas.

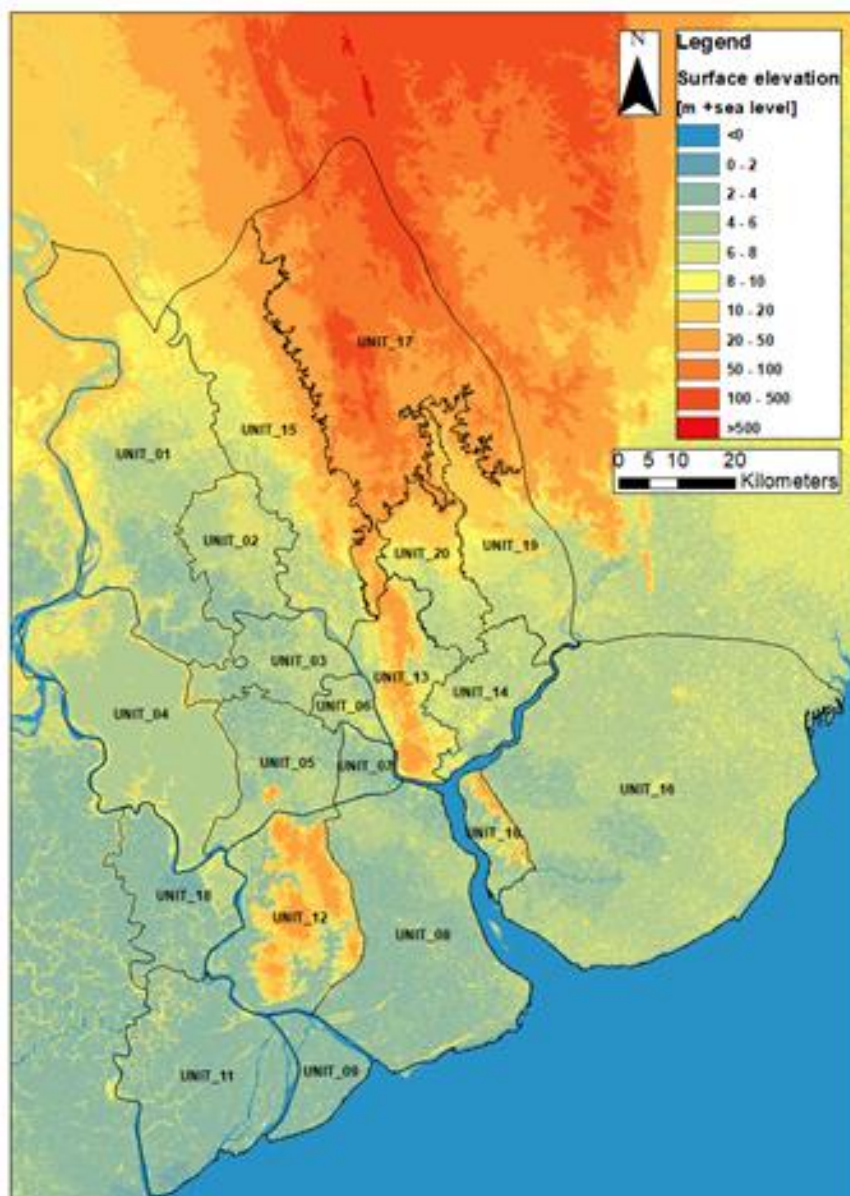


Figure 84: Elevation map of the project area

Table 46: List of required measures per unit area and per safety level

Unit	FP 1:50			FP 1:100			FP 1:200		
	Intervention length with crest level deficit [m]	Average crest level deficit [m]	Required additional hydraulic structures	Intervention length with crest level deficit [m]	Average crest level deficit [m]	Required additional hydraulic structures	Intervention length with crest level deficit [m]	Average crest level deficit [m]	Required additional hydraulic structures
1	39411	0.79	0	42935	0.92	0	48344	0.99	0
2	17885	1.42	0	19466	1.66	0	23022	1.66	0
3	27072	0.80	0	29577	1.01	0	31181	1.14	0
4	61069	0.97	3	64334	1.01	3	68049	1.04	3
5	25521	1.31	9	43534	1.46	9	44552	1.73	10
6	14473	0.31	2	22500	0.79	3	25217	1.22	3
7	21780	0.40	11	27548	1.22	11	27922	1.93	11
8	49199	0.25	5	58641	0.86	8	64655	1.35	9
9	0	0.00	0	229	0.10	0	4566	0.29	0
10	1308	0.24	0	6458	0.49	0	12890	0.51	0
11	2793	0.35	0	2793	0.47	0	13294	0.362	0
12	17838	0.61	5	25339	0.94	9	38753	1.34	17
13	13810	0.34	0	30866	0.95	0	35829	1.58	0
14	4961	0.31	0	23439	0.61	0	30453	1.16	0
15	4352	0.51	0	5690	0.71	0	9621	0.71	0
16	0	0.00	0	1136	0.14	0	10556	0.38	0
17	0	0.00	0	0	0.00	0	0	0.00	0
18	22985	1.01	0	26875	1.06	0	35924	1.15	0
19	0	0.00	0	1387	0.09	0	4225	0.70	0
20	0	0.00	0	0	0.00	0	0	0.00	0

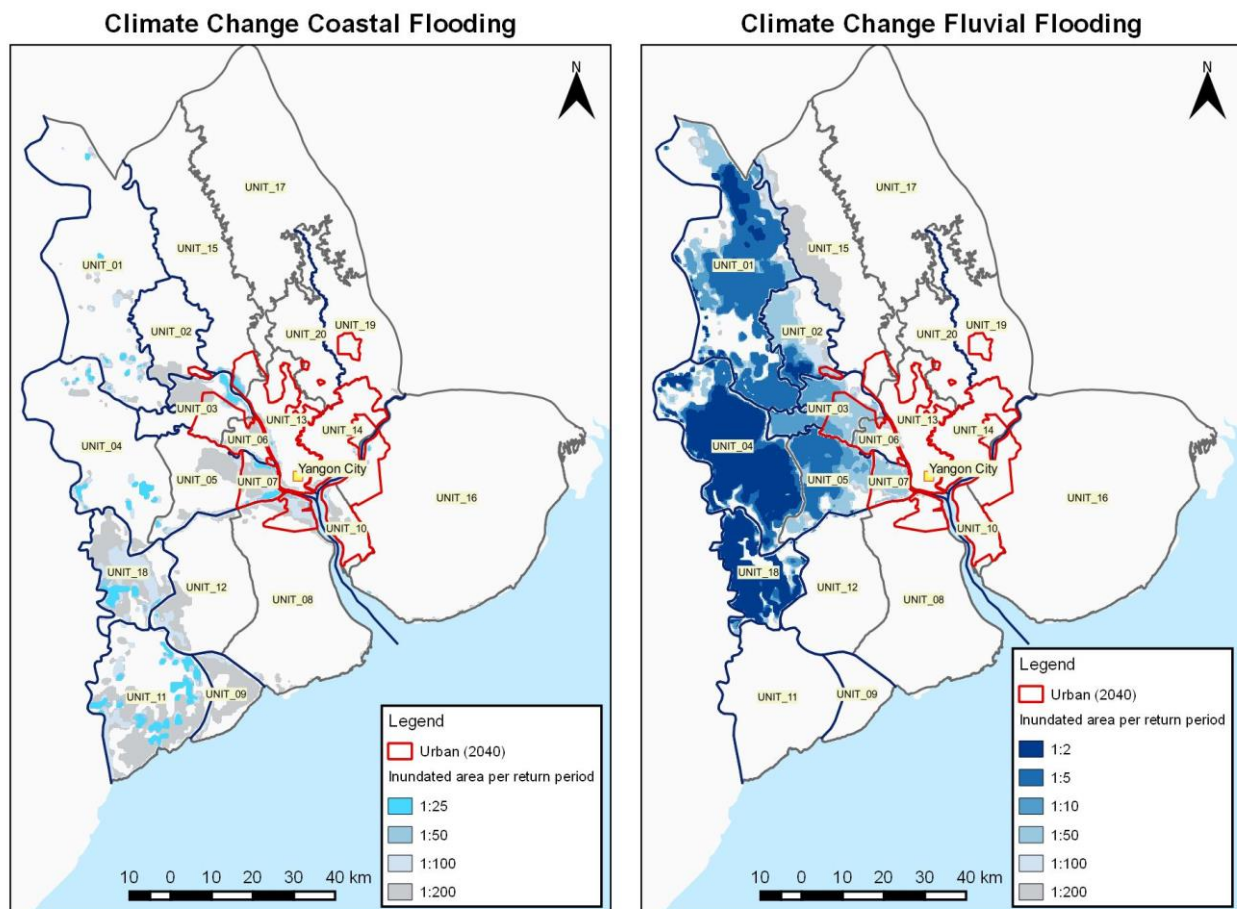


Figure 85: Flood extent patterns for coastal (left) and fluvial (right) flooding for different return periods

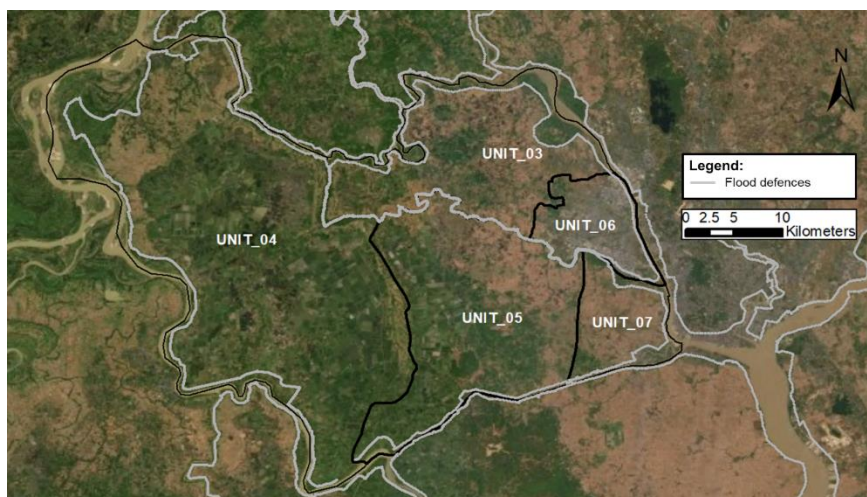


Figure 86: Details of flood defense elements in Pan Hlaing Island and Nyaungdon Island

The grey box below describes the analysis and detailed motivation for the proposed safety level per unit area. The descriptions are partly repetitive. To understand the reasoning, the reader not necessarily need to read all content.

Unit area 1:

Flood risks in unit area 1 are currently relatively high, as this rice-covered unit is large and floods easily (see Figure 85). This unit area is expected to remain mainly agricultural in the foreseeable future. As shown in Table 47, the required investments to increase the flood protection level in this unit area are relatively low, as the crest level deficit is generally small. Investments in this unit area are therefore financially viable and a flood protection level of 1 in 100 year is recommended. As the current protection level for this unit area is very low, flood risks are greatly reduced by a 1 in 100 year flood protection level. For this protection level, the total financial cost (investments + residual flood risk) is lowest.

Table 47: Summary cost benefit analysis flood protection level Unit area 1

	Current FP-level -Fluvial -Coastal	PV total Investment costs [Million USD]			PV total benefits (Flood risk reduction+residual value) [Million USD]			Proposed new FP-level:	Intervention: -Length -Crest level gain	Residual flood risk [Million USD]
		1:50	1:100	1:200	1:50	1:100	1:200			
Current Land use	<1:2 1:70	15.5	18.8	22.4	80.9	85.42	88.3	1:100	42.9km; 0.92m	4.7
Future land use	<1:2 1:70	15.6	18.8	22.4	80.9	85.42	88.3			4.7

Table 48 shows the annual expected affected people and the impact of this proposed flood protection level. For a 1:100 protection level, the annually expected number of residents which experiences water nuisance drops by approximately 95% compared to a situation without measures.

Table 48: Impact flood protection on affected people Unit area 1

	Current FP-level	Annual expected affected people without measures	Annual expected affected people under proposed new FP-level	Annual affected people reduction
Fluvial	<1:2	20904	1023	19882
Coastal	1:70	-	-	-
Total		20905	1024	19882

Unit area 2:

Unit area 2 is currently covered with agricultural lands and low flood risks, while under future land use predictions, some urban development is expected in this unit area. As a result, the flood risks as well as the benefits of flood protection investments increase significantly in the coming decades (see Table 49), while the flood defense investment costs stay relatively low due to the fact that most of the unit area is already

surrounded by sufficient flood protection. A flood protection level of 1 in 200 year is therefore recommended. However, given the high residual flood risk (for future land use), a stricter flood protection level might still be economically viable.

Table 50 shows the annual expected affected people and the impact of the proposed flood protection level. A flood protection level of 1 in 200 year results in a strong drop in annually expected residents experiencing water nuisance (approximately 93%).

Table 49: Summary cost benefit analysis flood protection level Unit area 2

	Current FP-level -Fluvial -Coastal	PV total Investment costs [Million USD]			PV total benefits (Flood risk reduction+residual value) [Million USD]			Proposed new FP-level:	Intervention: -Length -Crest level gain	Residual flood risk [Million USD]
		1:50	1:100	1:200	1:50	1:100	1:200			
Current Land use	<1:2							1:200	19.5km; 1.66m	0.7
	<1:25	7.0	8.9	10.6	7.9	9.2	10.6			
Future land use	<1:2									
	<1:25	7.0	8.9	10.6	56.3	76.9	92.9			18.0

Table 50: Impact flood protection on affected people Unit area 2

	Current FP-level	Annual expected affected people without measures	Annual expected affected people under proposed new FP-level	Annual affected people reduction
Fluvial	<1:2	2065	132	1933
Coastal	<1:25	22	15	7
Total		2087	147	1940

Unit area 3:

This currently rural unit area is characterized by a significant urban development projection in the coming decades. As a result, investing in flood protection does not pay off currently, especially as the length of insufficient dikes is extensive. When the future developments are considered, flood risks are expected to rise strongly. Large parts of this unit area flood often due to the currently poor flood protection, as shown in Figure 85. Therefore, investments are strongly recommended as they can significantly reduce flood risks. Despite the significant intervention length and associated costs, a protection level of 1 in 200 year is recommended. An even stricter flood protection level could even still pay off economically, as the residual flood risk is still significant for a 1 in 200 year flood protection level (see Table 51).

Table 52 shows the annual expected affected people and the impact of the proposed flood protection level. This flood protection strategy would also result in a significant drop in people experiencing water nuisance in this unit area, based on the current landcover. Given the projected urban extensions in this unit area the next decades, this estimate of annual expected affected people is probably be an underestimation.

Table 51: Summary cost benefit analysis flood protection level Unit area 3

	Current FP-level -Fluvial -Coastal	PV total Investment costs [Million USD]			PV total benefits (Flood risk reduction+residual value) [Million USD]			Proposed new FP-level:	Intervention: -Length -Crest level gain	Residual flood risk [Million USD]
		1:50	1:100	1:200	1:50	1:100	1:200			
Current Land use	<1:2							1:200	31.2km; 1.14m	0.8
	<1:25	5.9	7.9	9.3	7.6	9.1	10.0			
Future land use	<1:2									
	<1:25	5.9	7.9	16.4	618.4	782.5	889.9			117.2

Table 52: Impact flood protection on affected people Unit area 3

	Current FP-level	Annual expected affected people without measures	Annual expected affected people under proposed new FP-level	Annual affected people reduction
Fluvial	<1:2	3206	245	2961
Coastal	<1:25	99	42	57
Total		3305	287	3025

Unit area 4:

Unit area 4 is a relatively large area, containing many aquaculture and agricultural land plots vulnerable to flooding. This unit area is currently enclosed by poor flood protection, as both fluvial and coastal flood probabilities are high (see Table 53). As shown by Figure 85, large proportions of this area flood frequently. Furthermore, in case of flooding, deep inundations are widespread, all attributing to high total flood risks. To increase the flood protection level of this unit area, significant investments are required due to the large number of dike sections with a crest level deficit (Table 46).

The analysis shows that these investments do not exceed the reduced flood risks after flood defense improving, hence a 1 in 200 year flood protection level is proposed for this unit area. As the residual flood risk is relatively small for this protection level, 1 in 200 year is likely close to the economically optimal flood protection level for this unit area. Table 54 shows the average annually expected affected people and the impact of the proposed flood protection level. This flood protection level would provide a strong reduction in annually expected people affected by flood water (approximately 99%).

Table 53: Summary cost benefit analysis flood protection level Unit area 4

	Current FP-level -Fluvial -Coastal	PV total Investment costs [Million USD]			PV total benefits (Flood risk reduction+residual value) [Million USD]			Proposed new FP-level:	Intervention: -Length -Crest level -gain	Residual flood risk [Million USD]
		1:50	1:100	1:200	1:50	1:100	1:200			
Current Land use	<1:2 <1:25	17.4	18.6	19.9	212.9	221.5	226.1	1:200	68.0km; 1.04m	4.4
Future land use	<1:2 <1:25	17.4	18.6	19.9	212.9	221.5	226.1			4.4

Table 54: Impact flood protection on affected people Unit area 4

	Current FP-level	Annual expected affected people without measures	Annual expected affected people under proposed new FP-level	Annual affected people reduction
Fluvial	<1:2	39354	547	38807
Coastal	<1:25	6	2	4
Total		39360	549	38811

Unit area 5:

This unit is flooded regularly, by mostly fluvial floods (see Figure 85). Both in the current and future situation, this unit is foreseen to be covered by rice-fields and aquaculture. Built-up zones are very limited in this area. As a result, despite the frequent flooding, flood risks are moderately low in this unit area, both for current and future land use. Flood defense improvement costs to increase the flood protection level in this unit area are high, as there is a large crest level deficit along most of the current flood protection system (Table 46). Moreover, this unit area currently contains many small open channels which confluence with these larger rivers. The costs required to construct hydraulic structures protecting unit area 5 from flooding via these smaller streams add up to the already high flood defense improvement costs.

Table 55 indicates that the required investment costs for unit area 5 exceed the flood risk reduction benefits for all flood protection levels. Solely based on this information, a 1 in 50 year flood protection level would be recommended.

However, as mentioned earlier, unit areas 4,5 and 7 act as one internally linked system with overlapping inundation patterns. Consequentially, without enhanced flood protection level for unit area 5, flood defense investments for unit areas 4 and 7 would not be effective. As flood risk reduction benefits for unit areas 4 and 7 are large, the investments into unit area 5 pay off easily as well. Therefore, a 1 in 200 year flood protection level is recommended for unit area 5. Furthermore, as shown by Table 56, the expected number of residents experiencing flood nuisance is greatly reduced as well due to these investments.

Table 55: Summary cost benefit analysis flood protection level Unit area 5

	Current FP-level -Fluvial -Coastal	PV total Investment costs [Million USD]			PV total benefits (Flood risk reduction+residual value) [Million USD]			Proposed new FP-level:	Intervention: -Length -Crest level -gain	Residual flood risk [Million USD]
		1:50	1:100	1:200	1:50	1:100	1:200			
Current Land use	<1:2 <1:25	20.8	28.6	33.5	25.1	27.9	29.5	1:200	44.5 1.73	1.1
Future land use	<1:2 <1:25	20.8	28.6	33.5	25.1	27.9	29.5			1.1

Table 56: Impact flood protection on affected people Unit area 5

	Current FP-level	Annual expected affected people without measures	Annual expected affected people under proposed new FP-level	Annual affected people reduction
Fluvial	<1:2	4261	209	4052
Coastal	<1:25	9	6	3
Total		4270	215	4055

Unit area 6:

This unit area contains outskirts of the greater Yangon urban area, which is why the economic value in this area is high. Nevertheless, the potential flood risk in this unit area is currently relatively low (see Table 57). As the economic activity is mainly concentrated in the slightly higher-elevated eastern part of the area, flood risks are limited. Future urban development is foreseen to further increase the economic value in the area, especially westward towards the lower elevated areas. As shown in Figure 85, these areas are prone to more frequent flooding, which is why flood risks increase in this future scenario.

The present flood protection surrounding the unit is for the large majority insufficient, which is why for this small unit, flood defense improvement costs are high. The flood risk reduction benefits however outweigh these required investment costs (both for the current and future land use). A 1 in 200 year flood protection level is therefore advised for this unit area. This standard still leaves a large residual flood risk value, which shows that it might be interesting to study whether an even stricter flood protection standard is still economically viable. Table 58 shows the annually average expected affected people and the impact of the proposed flood protection level. For the proposed flood protection level, the expected number of impacted residents decreases, but stays relatively high. This is because the number of affected people rises strongly for the less frequent flood-scenarios. The annually expected number of affected people therefore remains high.

Table 57: Summary cost benefit analysis flood protection level Unit area 6

	Current FP-level	PV total Investment costs [Million USD]			PV total benefits (Flood risk reduction+residual value) [Million USD]			Proposed new FP-level:	Intervention: -Length -Crest level gain	Residual flood risk [Million USD]
	-Fluvial -Coastal	1:50	1:100	1:200	1:50	1:100	1:200			
Current Land use	1:39 <1:25	3.4	6.1	8.9	1.7	7.1	16.4	1:200	25.2km; 1.22m	13.7
Future land use	1:39 <1:25	3.4	6.1	8.9	9.6	50.1	86.4			46.6

Table 58: Impact flood protection on affected people Unit area 6

	Current FP-level	Annual expected affected people without measures	Annual expected affected people under proposed new FP-level	Annual affected people reduction
Fluvial	1:39	1116	326	790
Coastal	<1:25	715	447	268
Total		1829	773	1058

Unit area 7:

Unit area 7 is currently largely covered by agricultural lands with relatively small flood risks. As Figure 85 indicates, most of the area only floods in case of more extreme fluvial and coastal floods. Urban development of the city is expected to cover this unit area in the coming decades, which tremendously changes the flood risk and potential flood risk reduction benefits when investments are made into flood protection for this unit area (Table 59). The currently present flood defense system provides insufficient protection over a large majority of the total length and the average crest level deficit is high. Moreover, many additional hydraulic structures are required in the currently uncontrolled confluences with small local streams crossings of the flood defense system. Despite these factors, the high flood risk reduction benefits easily outweigh the required investment costs in the future land use scenario.

A flood protection level of 1 in 200 year is therefore recommended for this unit area. The residual flood risk for this protection level is still high relative to the required investment costs at the 1 in 200 year flood protection level. It might thus be interesting to consider a stricter flood protection level for this unit area. Table 60 shows the annually expected affected people and the impact of the proposed flood protection level. The reduction in

flood-affected residents is approximately 70% for this protection level. The presented absolute number of impacted residents will however likely be significantly higher when population growth is considered.

Table 59: Summary cost benefit analysis flood protection level Unit area 7

	Current FP-level -Fluvial -Coastal	PV total Investment costs [Million USD]			PV total benefits (Flood risk reduction+residual value) [Million USD]			Proposed new FP-level:	Intervention: -Length -Crest gain level	Residual flood risk [Million USD]
		1:50	1:100	1:200	1:50	1:100	1:200			
Current Land use	<1:2							1:200	27.9km; 1.93m	0.3
	<1:25	15.5	19.8	24.9	2.9	3.6	4.6			
Future land use	<1:2									
	<1:25	15.5	19.8	24.9	318.0	422.0	521.6			135.3

Table 60: Impact flood protection on affected people Unit area 7

	Current FP-level	Annual expected affected people without measures	Annual expected affected people under proposed new FP-level	Annual affected people reduction
Fluvial	<1:2	684	91	593
Coastal	<1:25	516	265	251
Total		1200	356	844

Unit area 8:

Unit area 8 is predominantly under a coastal flood threat. Significant stretches of flood defense require improvements to counter these coastal flood threats, as shown by Table 46. Furthermore, several additional hydraulic structures are required along this unit area, enhancing the total required investment costs. On the other hand, the extent of the inundation pattern is limited in this unit area, which is why flood risks are low. Flood defense improvements are therefore currently not economically viable for this agriculture-covered unit. Future expected urban expansion of Yangon within this unit however change this conclusion. The projected urban expansion takes place mostly in the flood prone areas, which strongly increases the foreseen flood risks. A minimal 1 in 200 year flood protection level is therefore recommended for this unit area. The total costs (residual flood risks + investment costs) are lowest for this protection level. Nevertheless, a stricter flood protection level might be economically viable as well, shown by the high residual flood risk for this protection level. This is caused by the fact that flood consequences sharply increase for the more extreme flood scenarios. A stricter flood protection level could be effective to further decrease the number of affected people in this unit area as well, since the percentage decrease of average annually impacted people is only about 45% for this protection level (see Table 62).

Table 61: Summary cost benefit analysis flood protection level Unit area 8

	Current FP-level -Fluvial -Coastal	PV total Investment costs [Million USD]			PV total benefits (Flood risk reduction+residual value) [Million USD]			Proposed new FP-level:	Intervention: -Length -Crest gain level	Residual flood risk [Million USD]
		1:50	1:100	1:200	1:50	1:100	1:200			
Current Land use	1:15							1:200	64.7km; 1.35m	1.1
	<1:25	10.9	25.0	35.1	1.8	4.5	6.8			
Future land use	1:15									
	<1:25	10.9	25.0	35.1	3.1	18.3	43.9			36.0

Table 62: Impact flood protection on affected people Unit area 8

	Current FP-level	Annual expected affected people without measures	Annual expected affected people under proposed new FP-level	Annual affected people reduction
Fluvial	1:15	0	0	-
Coastal	<1:25	554	302	252
Total		554	302	252

Unit area 9:

The flood safety provided by the existing dikes surrounding this unit area is relatively high compared to other unit areas. The length of flood defenses requiring measures is small, as shown in Table 46. As a consequence, investment costs are low (see Table 63). These investments however still exceed the small gains in flood risk reduction. The annually expected number of residents experiencing flood-hindrance is low as well, shown by Table 64. Hence it is recommended to stick to the current flood protection level for this unit area.

Table 63: Summary cost benefit analysis flood protection level Unit area 9

	Current FP-level -Fluvial -Coastal	PV total Investment costs [Million USD]			PV total benefits (Flood risk reduction+residual value) [Million USD]			Proposed new FP-level:	Intervention: -Length -Crest gain level	Residual flood risk [Million USD]
		1:50	1:100	1:200	1:50	1:100	1:200			
Current Land use	>1:200 1:158	-	0.02	0.71	-	0.004	0.12	-	-	0.14
Future land use	>1:200 1:158	-	0.02	0.71	-	0.004	0.12	-	-	0.14

Table 64: Impact flood protection on affected people Unit area 9

	Current FP-level	Annual expected affected people without measures	Annual expected affected people under proposed new FP-level	Annual affected people reduction
Fluvial	>1:200	0	0	-
Coastal	1:158	55	55	-
Total		55	55	-

Unit area 10:

Unit area 10 is situated close to the city of Yangon across the Bago river and is prone to coastal floods. This unit area is currently covered by a mixture of rural built-up areas and agriculture and is expected to become filled by urban expansion of Yangon city in the next decades. Due to the mostly higher elevation of this unit, flood risks remain fairly low, both in the current and future situation. As the crest level deficit of the current flood protection system is limited, the required investment for protection level improvements are low (see Table 66). As a result, despite the rather low flood risk, it is worthwhile investing in the flood defenses of this unit. A protection level of 1 in 200 year is recommended for this unit area. It must be added that flood risks do start to increase strongly for extreme flood scenarios. Therefore, the residual flood risks are still high compared to the investment costs at that level. A stricter flood protection level might therefore be economically viable as well, while this might also provide a stronger reduction in experienced flood-hindrance for residents of the unit area.

Table 65: Summary cost benefit analysis flood protection level Unit area 10

	Current FP-level -Fluvial -Coastal	PV total Investment costs [Million USD]			PV total benefits (Flood risk reduction+residual value) [Million USD]			Proposed new FP-level:	Intervention: -Length -Crest gain level	Residual flood risk [Million USD]
		1:50	1:100	1:200	1:50	1:100	1:200			
Current Land use	>1:200 1:40	0.12	1.00	1.86	0.02	0.18	0.50	1:200	12.9km; 0.51m	0.4
Future land use	>1:200 1:40	0.12	1.00	1.86	0.09	1.79	9.79			14.3

Table 66: Impact flood protection on affected people Unit area10

	Current FP-level	Annual expected affected people without measures	Annual expected affected people under proposed new FP-level	Annual affected people reduction
Fluvial	>1:200	0	0	-
Coastal	1:40	113	70	43
Total		113	70	43

Unit area 11:

Both the monetary and people-related flood risks are low in this unit area, as shown by Table 67 and Table 68. This is even though the current coastal flood protection level is very low. This is explained by the small inundation extents in the area and the fact that the unit is only covered in relatively low-valued agricultural lands. Flood consequences are therefore limited. Investments required to decrease these flood risks therefore easily exceed the benefits, despite the limited crest level deficit of the flood defenses along this unit area. Enhanced flood protection standards are therefore not recommended for this unit area.

Table 67: Summary cost benefit analysis flood protection level Unit area 11

		PV total Investment costs [Million USD]			PV total benefits (Flood risk reduction+residual value) [Million USD]			Proposed new FP-level:	Intervention: -Length -Crest gain level	Residual flood risk [Million USD]
		1:50	1:100	1:200	1:50	1:100	1:200			
Current Land use		0.34	0.42	5.43	0.19	0.32	1.21	-	-	1.1
Future land use		0.34	0.42	5.43	0.19	0.32	1.21			1.1

Table 68: Impact flood protection on affected people Unit area 11

	Current FP-level	Annual expected affected people without measures	Annual expected affected people under proposed new FP-level	Annual affected people reduction
Fluvial	>1:200	49	49	-
Coastal	<1:25	55	55	-
Total		104	104	-

Unit area 12:

The current flood protection levels of unit area 12 are low, both considering fluvial and coastal floods. Large investments are therefore required to increase the flood protection level of this unit area, as the extent of insufficient flood protection is high and the crest level deficits are as well (Table 46). What makes this unit special however, is that despite the poor flood protection, inundation extents are very limited due to the stronger elevation gains within this unit (see Figure 84).

Furthermore, this unit area is covered predominantly by agriculture and nature, which results in relatively small flood consequences. As shown by Table 69, investments in flood protection therefore do not outweigh the risk reduction. Enhanced flood protection standards are therefore not recommended for this unit. The expected flood-impacts for residents remain relatively low in this unit due to the limited flood extents (Table 70).

Table 69: Summary cost benefit analysis flood protection level Unit area 12

	Current FP-level	PV total Investment costs [Million USD]			PV total benefits (Flood risk reduction+residual value) [Million USD]			Proposed new FP-level:	Intervention: -Length -Crest gain level	Residual flood risk [Million USD]
	-Fluvial -Coastal	1:50	1:100	1:200	1:50	1:100	1:200			
Current Land use	<1:2							-	-	0.8
	<1:25	9.6	19.6	36.4	1.6	3.1	5.8			
Future land use	<1:2							-	-	0.8
	<1:25	9.6	19.6	36.4	1.6	3.1	5.8			

Table 70: Impact flood protection on affected people Unit area 12

	Current FP-level	Annual expected affected people without measures	Annual expected affected people under proposed new FP-level	Annual affected people reduction
Fluvial	<1:2	0	0	-
Coastal	<1:25	88	88	-
Total		88	88	-

Unit area 13:

Unit area 13 comprises the majority of the current urban extent of the greater Yangon urban area, but is currently poorly protected by flood defenses, as shown by Table 71. Figure 84 points out that most of the unit area has a higher surface elevation. As a result, the flood threats in this area are relatively small. This also explains why most of the historical urban development can be found in this area, because it is naturally protected from floods. This characteristic is also reflected by the food extent maps of unit area 13 (Figure 85) and can also be seen in Table 71. The potential flood risk reduction is small compared to other unit areas. Flood defense investments however do not exceed the flood reduction benefits. A 1 in 200 year protection standard is therefore recommended.

A stricter flood protection level could probably still prove economically viable. Flood consequences increase for the extreme flood scenarios, resulting in a large residual flood risk compared to the investment costs at a 1 in 200 year flood protection level. It must however be noted that the densely urban character of this unit area makes that the investment costs for flood defense improvements might be somewhat underestimated (construction activities are likely spatially more challenging).

Table 72 shows the annual expected affected people and the impact of the proposed flood protection level. This number remains relatively high for the same reason why the residual monetary flood risks remain relatively high for this protection level.

Table 71: Summary cost benefit analysis flood protection level Unit area 13

	Current FP-level -Fluvial -Coastal	PV total Investment costs [Million USD]			PV total benefits (Flood risk reduction+residual value) [Million USD]			Proposed new FP-level:	Intervention: -Length -Crest level gain	Residual flood risk [Million USD]
		1:50	1:100	1:200	1:50	1:100	1:200			
Current Land use	1:35 <1:25	0.9	5.0	10.5	0.5	5.4	14.3	1:200	35.8km; 1.58m	12.1
Future land use	1:35 <1:25	0.9	5.0	10.5	0.6	6.6	17.5			15.0

Table 72: Impact flood protection on affected people Unit area 13

	Current FP-level	Annual expected affected people without measures	Annual expected affected people under proposed new FP-level	Annual affected people reduction
Fluvial	1:35	0	0	-
Coastal	<1:25	2058	1017	1041
Total		2058	1017	1041

Unit area 14:

Unit area 14 contains large proportions of the urban sprawl of the city of Yangon. The flood risks are relatively low in this unit compared to other surrounding urban unit area, even though the coastal flood protection level provided by the current flood protection infrastructure is limited. The flood extents of coastal floods are very limited for the same reason as the limited flood extents in unit area 13. Unit area 14 is slightly higher elevated in many areas and therefore free of coastal flood threats (Figure 85).

Purely based on this cost-benefit analysis, it is therefore not directly financially viable to invest in the flood protection infrastructure of this unit area, as necessary intervention lengths and investment costs are high. Nevertheless, it is recommended to assign an enhanced flood protection standard of 1:200 for this unit area, to set a uniform flood protection policy for the urban areas of Yangon. This protection level leaves on average approximately 200 people affected by floods on an annual basis (Table 74), which mainly occur in extreme flood events.

Table 73: Summary cost benefit analysis flood protection level Unit area 14

	Current FP-level -Fluvial -Coastal	PV total Investment costs [Million USD]			PV total benefits (Flood risk reduction+residual value) [Million USD]			Proposed new FP-level:	Intervention: -Length -Crest level gain	Residual flood risk [Million USD]
		1:50	1:100	1:200	1:50	1:100	1:200			
Current Land use	>1:200 <1:25	0.44	3.29	7.79	0.11	0.79	2.21	1:200	30.4km; 1.16m	1.4
Future land use	>1:200 <1:25	0.44	3.29	7.79	0.19	1.00	3.43			3.2

Table 74: Impact flood protection on affected people Unit area 14

	Current FP-level	Annual expected affected people without measures	Annual expected affected people under proposed new FP-level	Annual affected people reduction
Fluvial	>1:200	0	0	-
Coastal	<1:25	312	208	104
Total		312	208	104

Unit area 15:

Unit area 15 is characterized by low flood risks under the current land use (mainly agricultural). Some parts of this unit area are however projected to become part of the greater Yangon urban area over the next decades. These development areas are situated exactly in the areas most prone to coastal flooding, as shown by Figure 85. As a result, potential flood risks in this area will rise significantly. The investment costs required to increase the flood protection levels of this unit area are small, as the required intervention length and crest level deficits are small (see Table 46). Investments required for measures are therefore significantly smaller than the expected flood risk reduction under future land use. A flood protection level of 1 in 200 year is therefore recommended for this unit area. However, as the investment cost estimations are small and the residual flood risk is still high for this level, an additional investment to further increase the flood protection level is likely to be economically viable as well. As indicated by Table 76, the annually expected number of people experiencing flood-nuisance reduces slightly, but the number of affected people is already relatively low. The absolute number of annually expected affected people, however, is likely to be much higher for the future land use scenario at a 1 in 200 year flood protection level.

Table 75: Summary cost benefit analysis flood protection level Unit area 15

	Current FP-level -Fluvial -Coastal	PV total Investment costs [Million USD]			PV total benefits (Flood risk reduction+residual value) [Million USD]			Proposed new FP-level:	Intervention: -Length -Crest gain level	Residual flood risk [Million USD]
		1:50	1:100	1:200	1:50	1:100	1:200			
Current Land use	<1:2 1:33	0.51	0.87	1.48	0.11	0.66	0.99	1:200	9.6km; 0.71m	0.34
Future land use	<1:2 1:33	0.51	0.87	1.48	5.14	21.79	39.71			22.79

Table 76: Impact flood protection on affected people Unit area 15

	Current FP-level	Annual expected affected people without measures	Annual expected affected people under proposed new FP-level	Annual affected people reduction
Fluvial	<1:2	172	113	59
Coastal	1:33	58	23	35
Total		230	136	94

Unit area 16:

Flood protection offered by the existing infrastructure is high compared to other unit areas in the vicinity. Flood risks and potential flood risk reduction due to measures are therefore small in this rural unit, especially as inundation patterns hardly move inland. Potential intervention lengths of the flood defense system are limited, which is why the investment costs are small as well. Nevertheless, these do exceed the expected possible gains in flood risk reduction. It is therefore recommended to maintain the current standards for this unit area. The number of flood-affected people is negligible in this unit area (see Table 78).

Table 77: Summary cost benefit analysis flood protection level Unit area 16

	Current FP-level -Fluvial -Coastal	PV total Investment costs [Million USD]			PV total benefits (Flood risk reduction+residual value) [Million USD]			Proposed new FP-level:	Intervention: -Length -Crest gain level	Residual flood risk [Million USD]
		1:50	1:100	1:200	1:50	1:100	1:200			
Current Land use	>1:200 1:108	-	0.19	2.50	-	0.03	0.36	-	-	0.004
Future land use	>1:200 1:108	-	0.19	2.50	-	0.03	0.67			1.4

Table 78: Impact flood protection on affected people Unit area 16

	Current FP-level	Annual expected affected people without measures	Annual expected affected people under proposed new FP-level	Annual affected people reduction
Fluvial	>1:200	0	0	-
Coastal	1:108	0	0	-
Total		0	0	-

Unit area 17:

The flood safety standards of the existing flood protection in this mountainous unit are strict compared to other unit areas, as large scale coastal and fluvial flooding cannot occur in this largely mountainous area. A further increase of the safety standard is therefore not recommended. The number of flood-affected people is negligible in this unit area as well.

Table 79: Summary cost benefit analysis flood protection level Unit area 17

	Current FP-level -Fluvial -Coastal	PV total Investment costs [Million USD]			PV total benefits (Flood risk reduction+residual value) [Million USD]			Proposed new FP-level:	Intervention: -Length -Crest gain level	Residual flood risk [Million USD]
		1:50	1:100	1:200	1:50	1:100	1:200			
Current Land use	>1:200 >1:200	-	-	-	-	-	-	-	-	-
Future land use	>1:200 >1:200	-	-	-	-	-	-			-

Table 80: Impact flood protection on affected people Unit area 17

	Current FP-level	Annual expected affected people without measures	Annual expected affected people under proposed new FP-level	Annual affected people reduction
Fluvial	>1:200	0	0	-
Coastal	>1:200	0	0	-
Total		0	0	-

Unit area 18:

Current flood protection infrastructure in this unit area provides little flood protection. As a result, flood risks in this agriculture-covered unit area are significant, as well as the consequences for residents in the unit area. This is enhanced by the low surface elevation levels, resulting in deep flood patterns. The flood risk reduction benefits therefore outweigh the required investment costs, hence investments are recommended. A flood protection standard of 1 in 50 year provides a cost-optimum for this unit area, which is why this protection level is recommended. Furthermore, this relatively small gain in flood protection would already greatly reduce the annually expected number of flood-impacted residents, as indicated in Table 82. Because the flood patterns for frequent floods are already extensive (see Figure 85), the flood risk reduction is strongest for flood probability reduction up to a 1 in 50 year flood protection level. The reduction in the annually expected number of flood-impacted people is significant.

Table 81: Summary cost benefit analysis flood protection level Unit area 18

	Current FP-level -Fluvial -Coastal	PV total Investment costs [Million USD]			PV total benefits (Flood risk reduction+residual value) [Million USD]			Proposed new FP-level:	Intervention: -Length -Crest level -gain	Residual flood risk [Million USD]
		1:50	1:100	1:200	1:50	1:100	1:200			
Current Land use	<1:2 <1:25	7.6	9.2	14.1	32.9	34.7	36.6	1:50	23.0km; 1.01m	4.2
Future land use	<1:2 <1:25	7.6	9.2	14.1	32.9	34.7	36.6			4.2

Table 82: Impact flood protection on affected people Unit area 18

	Current FP-level	Annual expected affected people without measures	Annual expected affected people under proposed new FP-level	Annual affected people reduction
Fluvial	<1:2	13084	746	12338
Coastal	1:70	176	176	0
Total		13260	922	12338

Unit area 19:

Coastal flood patterns can hardly propagate inland, due to the gradual elevation gain in this unit area. Flood risks are therefore low. The investment costs which would be required to further increase the safety level therefore exceed the expected flood risk reduction benefits, even though these costs are very limited as well (see Table 83). A further increase of the safety standard is therefore not recommended in this unit area. The number of flood-affected people is also negligible (Table 85).

Table 83: Summary cost benefit analysis flood protection level Unit area 19

	Current FP-level -Fluvial -Coastal	PV total Investment costs [Million USD]			PV total benefits (Flood risk reduction+residual value) [Million USD]			Proposed new FP-level:	Intervention: -Length -Crest level -gain	Residual flood risk [Million USD]
		1:50	1:100	1:200	1:50	1:100	1:200			
Current Land use	>1:200 1:118	-	0.05	0.61	-	0.01	0.09	-	-	0.001
Future land use	>1:200 1:118	-	0.05	0.61	-	0.01	0.09			0.001

Table 84: Impact flood protection on affected people Unit area 19

	Current FP-level	Annual expected affected people without measures	Annual expected affected people under proposed new FP-level	Annual affected people reduction
Fluvial	<1:2	0	0	-
Coastal	1:70	0	0	-
Total		0	0	-

Unit area 20:

This unit area is not bordered by primary bodies of water. A separate flood protection level has therefore no use here.

6.1.6 Options for flood protection levels stricter than 1:200

Within the approach in this study to define optimal flood protection standards three different standards have been considered: a 1 in 50, 1 in 100 and 1 in 200 year protection level. As has become clear in the analysis, for many of the considered unit areas, a 1 in 200 year flood protection level was derived as optimal flood protection level, based on the climate change + future land use scenario. This however raises the question to what extent an even stricter flood protection level might still be economically viable as well.

As no flood simulations were made for flood scenarios with a reoccurrence probability less than 1 in 200 year, it is currently not possible to set stricter flood protection standards based on model results. It is however possible to discuss the residual flood risk for a 1 in 200 year flood protection level and compare this data to the costs and flood risk reduction by moving from a 1 in 100 year to a 1 in 200 year level, as shown in Table 85. It becomes clear that for unit areas 5 and 14, there is no cost-efficient narrative to set a stricter FP-level, as the ratios between additional flood risk reduction and additional costs are already below 1. For Unit Areas 4, 8 and 13, these ratios are above 1, but either the residual flood risk is low for a 1 in 200 year FP-level or the additional costs to set a stricter standard are relatively high compared to the benefits. For these Unit Areas, a somewhat stricter FP-level might still be economically efficient, but 1 in 200 year is probably already close to the optimal standard. Lastly, Unit Areas 2, 3, 6, 7, 10 and 15 are all recognized by a very high ratio between benefits and costs for flood risk reduction, while the residual flood risk is still high as well for a 1 in 200 year FP-level. As a result, for these Unit Areas it is likely that a stricter FP-level would on the long term provide a more cost-efficient situation than a 1 in 200 year event. As it is currently not possible to further study this potential with the available data, this is something which could be further investigated in a continued analysis.

Table 85: Additional costs and flood risk reduction data by moving from a 1 in 100 year to a 1 in 200 year flood protection level, the accompanying ratio and the residual flood risk for a 1 in 200 year FP-level

Unit area	Additional costs to move from 1 in 100 year to 1 in 200 years FP-level [Million USD]	Additional flood risk reduction by moving from 1 in 100 year to 1 in 200 year FP-level [Million USD]	Ratio additional flood risk reduction/ additional costs	Residual flood risk for a 1 in 200 year FP-level [Million USD]	Potential for stricter FP-level?
2	1.6	15.9	9.65	18.0	Likely
3	8.6	107.2	12.51	117.2	Likely
4	1.3	4.4	3.39	4.4	Possibly
5	4.9	0.9	0.19	1.1	No
6	2.9	35.2	12.33	46.6	Likely
7	5.1	98.9	19.49	135.3	Likely
8	10.1	24.2	2.39	36.0	Possibly
10	0.9	7.9	9.25	14.3	Likely
13	5.5	10.1	1.84	15.0	Possibly
14	4.5	1.8	0.40	3.2	No
15	0.6	17.9	29.41	22.8	Likely

Additionally, it is also important to consider the definition of the Unit Areas and their relation to the future land use development. As mentioned earlier, unit areas 3 and 6, and Unit Areas 4, 5 and 7 are hydraulically interconnected and have overlapping flood patterns. As a result, without additional measures, it is not possible to set different flood protection levels for these interconnected Unit Areas. The currently proposed protection levels meet this requirement, as a 1 in 200 year flood protection level was assigned to these Unit Areas. Based on the findings in Table 85, it might however be interesting to assign stricter flood protection levels to some of these Unit Areas, especially Unit Areas 3, 6, 7 and 15. In a continued analysis for stricter flood protection levels, the connected characteristics of Unit Areas 3 and 6, as well as the interconnected Unit Areas 4, 5 and 7 are important to take into account.

As an example, if the situation for Unit Areas 4, 5 and 7 is considered, it becomes clear that a 1 in 200 year FP-level is close to the economically optimal flood protection standard for Unit Areas 4 and 5, while for unit area 7, a stricter FP-standard would likely still prove to be economically viable. Due to the significant projected urban development, the economic value of the area is expected to rise significantly, as a result of which a 1 in 200 year FP-standard might be relatively low. If the protection level of only unit area 7 would be set stricter, this would however require the construction of an additional compartmentalization dike along the western side of unit area 7. This has been schematized in Figure 87.

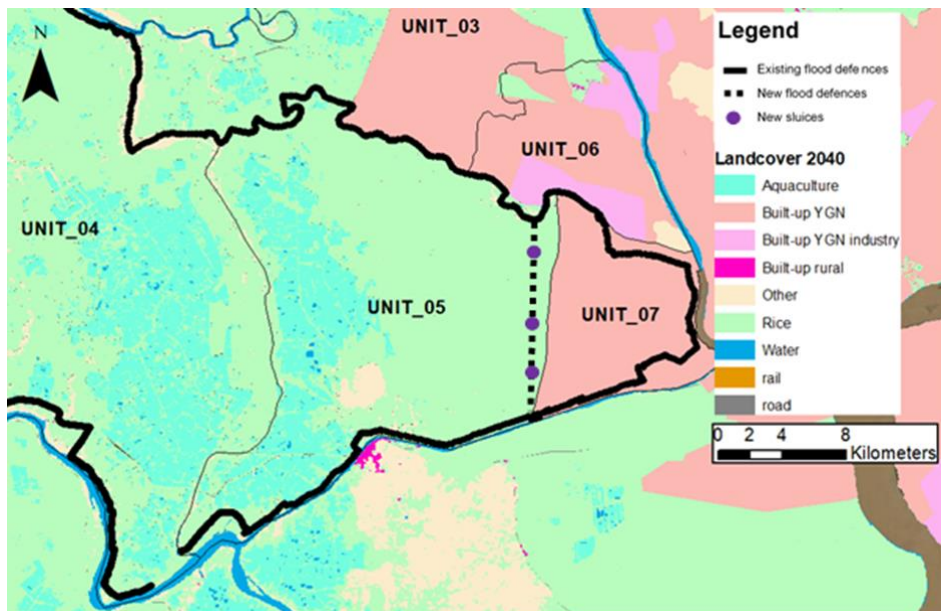


Figure 87: Detail of the flood defenses along unit areas 4,5 and 7, projected on the 2040 land use map. The location of a possible new segmentation levee is depicted here as well.

The shortest possible trajectory for a compartmentalization dike between Unit Areas 5 and 7 would be approximately 9 km long and would also involve the construction of 3 additional sluices to cross small inland streams, as shown in Figure 87. To determine whether it is economically attractive to set a stricter FP-level for this area, the associated construction costs for this new segmentation levee should be incorporated as well and should be compared to a situation in which a uniform standard would be set to both Unit Areas 4, 5 and 7.

Furthermore, providing a segmentation levee between Unit Areas 5 and 7 would allow the flood protection level of Unit Area 7 to be increased, without requiring dike reinforcement in Unit Areas 4 and 5. This would allow early investment in Unit Area 7 without having to incur the full investment required for Unit Areas 4 and 5.

Conversely, as the flow of water is from Unit Area 4 through to Unit Areas 5 and 7, early investment in Unit Area 4 is likely to have a positive impact on the current flood protection levels in Unit Areas 5 and 7. This increased flood protection in Unit Area 7 may be sufficient to meet the rate of urbanization in the short term before further investment is required to achieve the full flood protection level of 1 in 200 years in Unit Area 7.

6.1.7 Closing of existing drainage paths by dikes

In those locations where dike raising or the introduction of a new dike will close off the existing connectivity of a natural drainage path to a river and/or the sea, a sluice will be introduced to ensure drainage of rainwater collected behind the dike within the unit area. The sluice structures can be considered for several functions: retaining function due to high tides/large river discharges or to regulate the water inflow/outflow for a certain area. The real dimensions and required design strongly depend on the location and the boundary conditions. For small channels with relatively low flow velocities a simple box culvert/tube will suffice while for large channels very big structures are required: structures with a pile foundation, many (automated) gates and a stilling basin (like Mezali 2 sluice). Figure 88 below shows an impression of a typical medium size sluice structure, Kywal Lan Sluice, considered as being feasible at other locations. Figure 89 shows a simplified impression of an outlet structure considered as solution for Program 1 (channel or creek closure).



Figure 88: Example pictures of sluice structures

Some locations require a location-specific approach. This, for example, is because the river is used for navigational activities. A navigational sluice could be introduced for those specific locations, however this requires a tailored approach. A navigational sluice typically requires a larger investment and operation & maintenance budget than a non-navigational sluice. This is often not an economical solution, and therefore the following assumptions are made when conceptualizing the layouts/buildings blocks:

- Where possible the dikes more upstream will be raised;
- Where the river is minimally used for navigation activities the closure of the river is considered;
- Where the river is identified as 'medium' used for local navigation activities, a structure for temporary closure is considered. This structure can be closed during river peak discharges and by coastal events/cyclones, however, it may have an unaccepted impact on navigation because such temporary closures will likely remain closed for weeks or even months;
- For the rivers which requires a building block 'large' and where a lot of navigational activities take place a tailored solution is considered.

A typical solution for temporary closure could be a sluice with radial gates, flap gates or vertical lifting gate. Every typical gate structure has his own advantages and disadvantages.

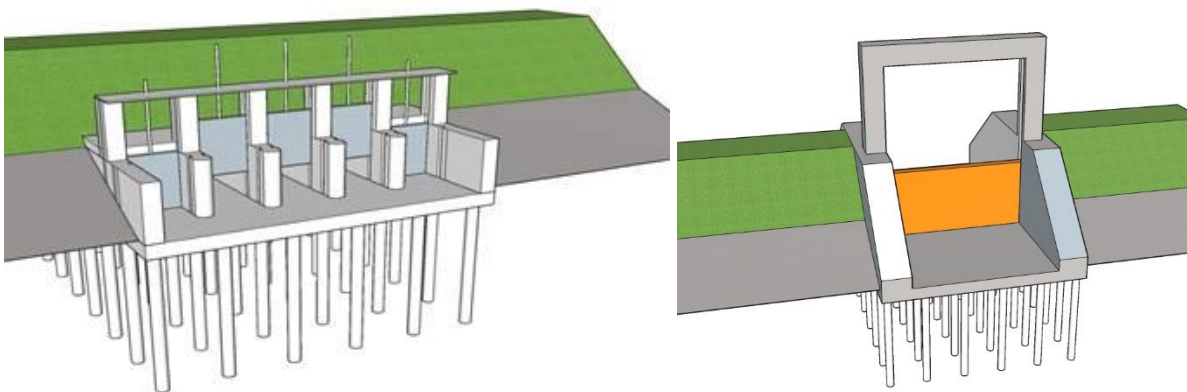


Figure 89: Example 3D sketch for an outlet structure (left) and vertical lifting gate (right)

Additional drainage capacity is required to drain the excess volume of water due to heavy rainfall (pluvial flooding). Sluice structures can drain the water under natural conditions. However, due to high river levels and high tides it is not always an option to drain under natural conditions. In that case pump capacity is required to drain the water. A pump of 50 m³/min as a vertical turbine pump or a 2 m diameter Archimedean screw pumping station is considered as modular building block. The effect of pumps is highly dependent on a well-functioning irrigation system and the power supply (or generator).

The combination of rainfall and insufficient drainage capacity can cause flooding in the area. In this case an existing channel requires additional discharge capacity to drain the area within a certain period. Deepening or

widening (or combination) of the channel will increase the channel area, reduce the flow resistance and in doing so increase the drainage capacity (water discharge capacity) of the channel. Deepening and widening of a channel will also result in additional storage capacity for water. This in combination with water regulation structures water can be stored and used for irrigation purposes (See Program 3).



Figure 90: Picture of channel reconstruction works

Starting points and boundary conditions for concretization of measures

The starting point for the chosen engineering solutions is to provide at least equal discharge capacity to the natural channels which were closed as a result of recommendations made in the weakest links program. The principle here is to not make the drainage situation any worse.

In total 3 sizes of sluice structures are considered, which will be applied as 'building blocks' for the required measures identified under the weakest links program:

- small size with 25 m² drain opening, direct costs USD 0.5-1.5 million,
- medium size with 50 m² drain opening, direct costs USD 1.0-2.5 million and
- large size with 100 m² drain opening, direct costs USD 2.0-5.0 million.

Pre-feasibility designs and dimensions

A total of 36 channel closures under Program 1 are foreseen spread over unit areas 4, 5, 6, 7 and 8. The table below shows an overview of the total foreseen 'buildings blocks' per unit area. These details are detailed in the detailed factsheets in Appendix C.

Table 86: Number of required structures per unit including construction costs

Unit area	Number of required structures (building blocks)			Construction costs (M USD)
	Small	Medium	Large	
4	2	-	1	USD 3.0 – 8.0 million
5	7	3	-	USD 6.5 – 18.0 million
6	2	1	-	USD 2.0 – 5.5 million
7	10	1	-	USD 6.0 – 17.5 million
8	7	1	1	USD 6.5 – 18.0 million
				USD 25.5 – 70.5 million

Impact construction of new hydraulic structures on navigational activities

Several new hydraulic structures were proposed to close off existing open channel crossings with hydraulic structures. This section discusses the possible implications for navigational activity on these currently open channels.

In total, 36 new hydraulic structures are proposed under Program 1 of the study, divided over 5 different unit areas. Based on analysis of satellite imagery, 6 of these 36 open channel crossings have been identified as frequently used for local navigational activities, which are depicted in Figure 91 and have been categorized according to the estimated scale of navigational use based on satellite imagery. In each of these cases, the respective streams fulfill a transport function for local people living adjacent to these channels upstream of the confluence with the main rivers in the Yangon/Ayeyarwady river delta, for instance for fishing and agricultural transport. Closing off these rivers with a permanent sluice structure could interfere with the navigational interests of these local residents. In the next phase of the project, the navigational activities on these rivers should be further analyzed to decide on whether it would be possible to close some of these channels with a non-navigable sluice-structure or if it is preferable to implement tailor-made solutions which allow a continued use for navigation. This may include implementing a navigable sluice-structure or by locating sluice structures further upstream in combination with flood defense improvements along the downstream side of these channels.

Of the 6 identified channels currently used for local navigation, channels ID 0, 3 and 28 (see Figure 91) have the widest channel and seem to be most frequently used for navigational purposes. Several industrial lands are located along the riverbanks and the navigational activity fulfills an important role for the local community along ID 3. Furthermore, this channel provides the easiest and most direct access to the main river network for the local village of Kungyangon, where a local market is situated alongside the riverbanks for which the river fulfills a role in distribution of produce. ID 28 fulfills an important function in the local navigational network of Nyaungdon island and supports access for communities and agricultural lands in the interior of Nyaungdon island.

Together with DWIR, who is responsible for the provision of navigational aids, the navigational functions of the identified streams should be further analyzed to derive suitable solutions for the entrance control to these streams, to optimally fulfill both flood protection and navigational functions for the area.

Table 87: Overview of the 6 channels proposed to shut under program 1, where navigational activity takes place.

Open channel ID:	Location (Unit area)	Navigational activity	Additional remarks
ID-0	Unit area 5	Medium scale (Highly used by locals for navigational activity with small vessels)	Provides navigable access to large aquaculture and rice fields in the area.
ID-3	Unit area 8	Medium scale (Highly used by locals for navigational activity with small vessels)	Relatively wide river (ca. 40m). Provides primary access to the large village of Kungyangon
ID-5	Unit area 7	Small scale (lightly used by locals for small scale navigational activity)	Approximately 20m wide. Provides navigational access for several small communities in unit area 7.
ID-16	Unit area 6	Small scale (lightly used by locals for small scale navigational activity)	Approximately 20m wide, situated in a highly urbanized environment.
ID-26	Unit area 5	Small scale (lightly used by locals for small scale navigational activity)	Provides navigable access to large aquaculture and rice fields in the area.
ID-28	Unit area 5	Medium scale (Highly used by locals for shipping with small vessels)	Makes up an important link into the local transportation network of Nyaungdon island and provides access to the Twante Canal.

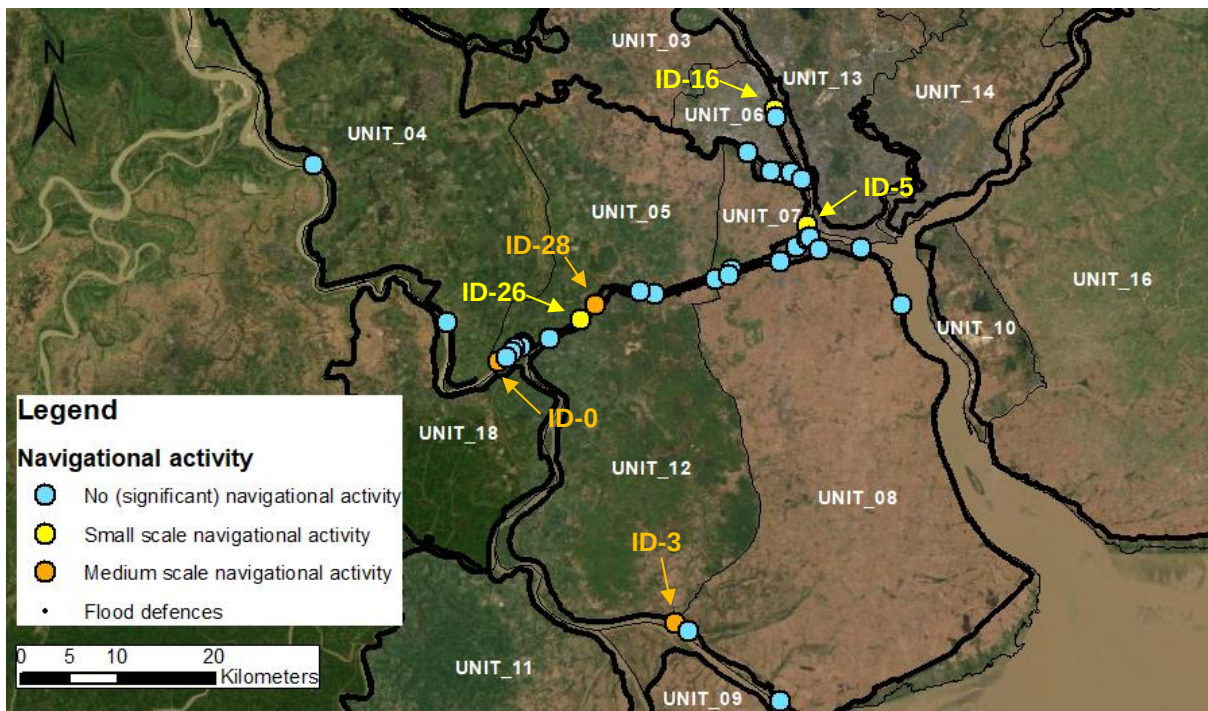


Figure 91: Locations of all 36 identified open channel crossings which require outlet structures, including locations of channels currently used for navigation

6.2 Details program 2 Water availability (storage and supply)

6.2.1 Results of Domestic Water Demand Analysis

The domestic water demand analysis detailed in Section 4.6.1 has resulted in an estimated domestic water demand distribution for 2040 across the various Unit Areas (see map with unmet water demands in *Figure 72*). Based on this, each Unit Area is further discussed below highlighting which areas require new water supply sources to meet their expected unmet water demand. The analysis also shows which units are considered to already have or will have access to sufficient water supply.

In this respect, the long list of Unit Areas is reduced to a short list by eliminating those Unit Areas that do not require increased water supply. The remaining short-listed Unit Areas are further analyzed to conceptualize measures that could be implemented. The result is a short list of Unit Areas and appropriate measures.

Pan Hlaing Island

Unit Area 6

Unit Area 6 is forecast to be connected to the YCDC water supply network by 2040. Currently approximately 90% of the domestic water demand in the Hlaingtharya township is met. It is considered that the YCDC water supply network will meet the future demands of this Unit Area and therefore no further consideration will be given for Program 2.

Unit Area 3

An area of high population density and an identified high unmet water demand of up to 0.125 m³/day/Ha is expected to the south east of Unit Area 3. This area is located near the boundary of Unit Area 6 and population growth originating from Unit Area 6 can be considered. It is envisaged that this area will also become connected to the YCDC water supply network by 2040 similar to Unit Area 6.

The more rural areas located outside of this populated area have an unmet water demand ranging from 0.05 to 0.075 m³/day/Ha, with a population density in the order of 2.5 people/Ha (Section 4.6.1). Given the presence of the neighboring Kokkowa and Pan Hlaing Rivers, there are numerous nearby sources of fluvial water sources to meet this water demand. Furthermore, these rivers are located sufficiently upstream from the coastline to mostly mitigate against the risk of elevated salinity concentration from saltwater intrusion. This is particularly the case if the Pan Hlaing Sluice Development is realized. Evidence of irrigated farming practices and some aqua culture throughout this area suggest there is adequate water supply from the surrounding rivers and internal water channels to this attain additional water supply, if necessary. Further reference is made to Section 4.6.2. Based on the above, Unit Area 3 will not be considered further for Program 2.

Nyaungdon Island

Unit Area 4

Unit Area 4 has a uniform low unmet water demand of 0.025 m³/day/Ha across the near full extent of the Unit Area, with a population density of approximately 2.5 people/Ha. The exception being the two populated locations, Nyaungdon Township in the north west and Maubin Township in the south west.

Maubin Township has an estimated 70,000 households, with approximately 15% of these located in and around the populated center of the town. The census results suggest close to 100% of the domestic water demand in the populated center is met. The remaining 85% of households are located in the more rural areas. Census results suggest only 20% of the domestic water demand for these rural households is met.

Nyaungdon Township has an estimated 50,000 households, with approximately 10% of these located in and around the populated center of the township. The census results suggest close to 40% of the domestic water demand in the populated center is met. The remaining 90% of households are located in the more rural areas. Census results suggest only 30% of the domestic water demand for these households is met.

Both these towns are located immediately adjacent to the Ayeyarwady and Toe Rivers respectively, and this fluvial source has the potential to meet the long-term water demands of the populated centers of these

townships. Furthermore, Unit Area 4 houses permanent water bodies and is predominantly utilized for aquaculture and irrigated farming throughout the year. This strongly suggests there is adequate water supply from the surrounding river sources and internal water channels across the Unit Area to meet the required unmet rural water demand of 0.025 m³/day/Ha.

Unit Area 4 will therefore not be considered further for Program 2.

Unit Area 5

Except for some urbanization along the eastern side of this Unit Area i.e. on the banks of the Hlaing River, this Unit Area is predominately rural. This rural population is associated with the Twante Township which expands across both Unit Areas 5, 12 and 8. More specifically, the estimated rural population within Unit Area 5 is 94,000 people, with a total of approximately 50 villages.

The population of the Twante Township is estimated at 50,000 households, with approximately 20% of these located in and around the populated center of Twante Town. The census results suggest close to 100% of the domestic water demand in the populated center is met.

The remaining 80% of households are located in the rural areas surrounding the Twante Township. Census results suggest approximately 30% of the domestic water demand for these households is met, with an unmet water demand ranging from 0.05 to 0.075 m³/day/Ha and with a population density in the order of 2.5 people/Ha. Water usage maps suggest the central and western areas of Unit Area 5 is utilized for irrigated farming. This suggests these areas of the Unit Area should have sufficient water supply to meet the demands of rural villages. Conversely, the eastern area of the Unit Area, and also Unit Area 7, is limited to rainfed irrigation, suggesting water demand during the dry season months could be problematic. The elevated levels of salinity and pollution within the Pan Hlaing and Hlaing Rivers are the likely cause for limiting these areas to rainfed agriculture.

Based on the above, further consideration will be given to the villages and sparsely populated areas located in the central to eastern areas of the Unit Area 5.

Unit Area 7

This Unit Area has similar characteristics to the eastern area of Unit Area 6. It does however contain several populated areas located to the east along the banks of the Hlaing River and Twante Canal. Given the proximity of these populated areas to Yangon City, it is considered that these will be connected in the future to the YCDC water supply. These townships will therefore not be considered further for the Program 2.

Notwithstanding, the rural communities located in the central and western areas of this Unit Area will be considered. The estimated rural population within Unit Area 7 is 29,000 people, with a total of approximately 10 villages. These rural communities are unlikely to be connected to the YCDC water supply network and have limited access to clean fluvial water supply sources (see Unit Area 5 above).

Yangon South (West)

Unit Area 12

Unit Area 12 comprises a predominantly elevated terrain (up to 70m in elevation) and is sparsely populated (2.5 people/Ha) with an unmet water demand in the order of 0.025 m³/day/Ha. The population located within the elevated terrain is understood to source their water supply from small ponds and other surface collection means. Given the low population and low unmet water demand, these villages will not be further considered further under Program 2.

There are several towns located at the lower boundary of this elevated terrain. Kyaiklat Town and Dedaye Town are located to the south west however these are not located within the Yangon South Region (covered under Unit Area 11). These will not be considered further given these are not located within the Priority Area. Twante Town is located to the north as discussed under Unit Area 5. Kawhmu Town and Kungyangon Town are located to the east and on the border with Unit Area 8. Kawhmu Town and Kungyangon are further discussed under Unit Area 8.

Unit Area 8

Unit Area 8 is unique compared to the other Unit Areas because its water supply sources are scarcer. Unit Area 8 borders the sea, and as a result, there are typically high salinity concentrations within the Yangon and Toe Rivers which too border Unit Area 8. Fluvial sources of water supply are therefore not considered feasible. In addition, the groundwater supply is known to have a variable salinity concentration. The above figure also indicates that Unit Area 8 is limited to rainfed irrigation, suggesting other forms of local water supply is limited during the dry season months.

Dala Town is in the northeast of Unit Area 8. Census results suggest only 10% of the domestic water demand is met. There are currently approximately 330 rainwater collecting surface ponds / lakes for domestic use. However, the township is still facing water scarcity every year. However, Dala is planned to be connected to the YCDC water supply in the future and therefore will not be considered further.

Kawhmu has an estimated 30,000 households, with approximately 10% of these located in and around the populated center of the town. The census results suggest only 10% of the domestic water demand in the populated center is met. The remaining 90% of households are located in the rural areas. Census results suggest 40% of the domestic water demand for these households is met. Census results suggest 40% of the domestic water demand for these households is met.

Kungyangon also has an estimated 30,000 households, with approximately 15% of these located in and around the populated center of the township. The census results suggest only 5% of the domestic water demand in the populated center is met. The remaining 85% of households are located in the more rural areas.

Kawhmu town is understood to source its domestic water supply from municipal groundwater wells. The town is known to experience groundwater quality problems associated with salinity. Kungyangon town is understood to partially source its domestic water supply (circa 30%) from surface reservoirs and ponds located near to or within the town centers. This is similarly the case for Ywathitkon and the other coastal populations in the south of Unit Area 8. Rainwater harvesting is not implemented in the town of Kawhmu and Kungyangon.

The rural domestic water demand for Unit Area 8 ranges from 0.025 m³/day/Ha in the south to 0.075 m³/day/Ha in the north in proximity of Dala. The total rural population of Unit Area 8 located outside of the populated town centers is estimated at 255,000 people, spread across a total of approximately 150 villages. Assuming the water demand of 40% of the rural population is met, this leaves approximately 150,000 people without access to domestic water supply.

Based on the above, the populated areas of the Kawhmu and Kungyangon Towns and the villages and sparsely populated areas of Unit Area 8 will be further considered under Program 2.

6.2.2 Water Supply Strengthening Assessment

Unit Area 5 and 7: Villages and sparsely populated areas

Villages

Localized measures located within or immediately near to villages are required to meet their domestic water demands. For this exercise, villages are assumed to contain in the order 150 - 350 households. Based on an assumed domestic water demand of 100 liters/per day/household, this equates to a total domestic water demand of 15 to 35 m³/day/village respectively. Based on the assumption that sufficient domestic water supply will be collected and stored during the wet season months in preparation for the dry season months, the total required stored water supply volume equates to approximately 2,250 to 5,250 m³ respectively (assumes the dry season months extends over 5 months).

With reference to the archetypical solutions detailed in Section 5.5.2, solutions to meet this volume demand include large tanks and small ponds. A large buried tank with dimensions 25 m (width) x 25 m (length) x 4 m (height) would provide a storage capacity of 2,500 m³. Two of these large tanks would closely meet the storage volume requirements of a village with up to 350 households. Similarly, a lined pond with dimensions 40 m x 40 m x 4 m would provide the required storage volume requirements, assuming 20% total evaporation over

the 5 month dry period (approximately equivalent to 100 mm evaporation per month in a pond with a depth of 3m).

The large tanks and/or ponds would be filled using water harvesting methods during the wet season months. Such methods include using a network of house roofs and other forms of surface runoff. The water would then be directed to the storage facility under a combination of free flow and piped conditions.

Benefit would be gained by using several small storage facilities distributed throughout the village on a neighborhood level to ensure easy accessibility to the water supply and to reduce the cost of water distribution networks to households. It is noted that recent studies in the Netherlands suggests rainwater harvesting on a neighborhood level is more cost effective than on a singular household level (Hofman & Paalman, 2014). Furthermore, it is important the water supply is as accessible as commonly used tube wells, to ensure this new measure is well adopted and to remove dependency on tube wells. As an example, a total of 10 tanks each with a volume of 500 m³ would meet the requirements of a 350-household village. These tanks would have the approximate dimensions of 15 m x 15 m x 2.3 m.

A water tower and pump would be required at the stored water location to maintain delivery pressure to households through the distribution network.

Individual Households

Households are similarly recommended to follow rainwater harvesting and water storage during the wet season months. It is noted that rainwater harvesting on a household level is a well-established practice in the rural communities of the Yangon Region. Assuming a household uses 100 liters per day over the dry season comprising 5 months, this equates to a required storage volume of 15 m³. A tank with dimensions 2.6 m diameter and 3m height would provide this required storage capacity.

Furthermore, neighboring households could combine the collective areas of their house roofs to harvest rainwater for a larger sized communal tank. This would have the effect of reducing the cost of the storage tank per household.

Unit Area 8: Villages and sparsely populated areas, including the moderately populated areas on the southern coast.

Similar to Unit Area 5 and 7, rainwater harvesting, and storage is recommended during the rainy season months in preparation for the dry season months. This is similarly recommended on both the village and household level using a combination of tanks or pond storage solutions.

Unit Area 8: Kawhmu and Kungyangon Towns

Kawhmu and Kungyangon Towns have approximately 3,000 and 4,500 household, respectively, with less than 10% of the forecast domestic water demand for these households being met. Based on a domestic water usage of 100 liters/day per household and the requirement to harvest up to 5 months water supply in preparation for the dry season, this equates to a total stored water volume demand ranging from 45,000 m³ to 67,500 m³.

With reference to the archetypal solutions detailed in Section 5.5.2, solutions to meet this volume demand include large ponds. A pond of 135 m x 135 m x 5m would provide the necessary stored volume to meet a water demand of 70,000 m³ over the dry season months, assuming 20% evaporation. A series of smaller sized ponds could also be considered and distributed across the populated areas to again reduce the magnitude of water distribution networks to households. The ponds would be filled directly through rainfall collection across the pond surface area and by collecting and redirecting surface water runoff from the surrounding areas into the pond.

Notwithstanding the above, Kungyangon Town currently has two notable man-made water supply ponds / lakes, namely the Tawpale and Kungyangon Lakes. These have a combined surface area of approximately 35,000 m². Assuming a depth of 4m in each lake, this provides a total of 140,000 m³. Assuming 20% evaporation during the dry season months, these two lakes have sufficient storage capacity to meet the required storage demand of 67,500 m³. This therefore either contradicts the census results or suggests that

the water quality within the named ponds / lakes is of insufficient water quality to consume for domestic purposes. Surface water ponds are also present in the vicinity of Kawhmu Town. Rehabilitation of the existing ponds could be considered to realize the required water supply within these towns.

Further detailed local stakeholder consultations and engineering assessments is required to assess the current total water supply and water quality within the existing ponds. Suitable measures can then be tailored specific to each town. Below table summarizes all the above shortlisted measures to be considered under the water availability program.

Table 88: Summary of shortlisted measures under program 2

Location	Proposed Measure
Unit Areas 5, 7, 8: Village Level	Rainwater harvesting on a neighborhood level. This would include medium to large sized tanks or lined ponds to store water collected during rainwater harvesting. Rainwater would be collected on roofs and localized surface water runoff.
Unit Areas 5, 7, 8: Household Level	Rainwater harvesting on a household level. This would include small sized tanks to store water collected during rainwater harvesting. Rainwater would be collected on house roofs.
Unit Area 8: Kungyangon and Kawhmu	Rehabilitation of existing ponds
	Development of new lined ponds

6.2.3 Cost / Benefit analysis

A preliminary cost / benefit analysis is done for the shortlisted measures in Table 89 and Table 90 with the aim to determine the most beneficial engineering solution. The costs of the engineering solutions should not exceed the expected benefit of the measure to ensure the measure is a sound investment. Notwithstanding this, the benefits associated with improved water supply are often socio economic related and are difficult to quantify from a financial perspective. As such, the social economic benefits have been evaluated from a qualitative perspective.

The following sets out the basis for estimating the approximate CAPEX cost of the engineering solutions that meet the objectives of the shortlisted measures. OPEX costs have not been determined in detail given they are expected to be relatively very small (i.e. less than 5% of the CAPEX cost) and of comparable magnitude across the various engineering solutions developed.

Village Level

For simplicity, two village types have been considered for this costing exercise as follows:

- 350 household village requiring a stored water volume of 5000 m³
- 150 household village requiring a stored water volume of 2500 m³

The CAPEX estimates assume the rainwater harvesting surfaces such as roofs, impermeable ground surfaces, and land run off, make use of existing infrastructure and are therefore available at no cost. Some minor costs may be required to direct the harvested water to the storage facility; however, these have not been considered.

Estimated costs can be considered to have an accuracy within the range of +/- 40%. The estimated CAPEX costs for various engineering solutions are provided in the tables below.

Table 89: Estimated CAPEX for water storage solutions – village level 350 households

Village Level (350 households requiring approx. 5000 m ³ during dry season months)					
Option	Volume	Qty	Unit Cost	CAPEX	Notes
New Pond	5,000	1	USD130,000	USD130,000	Includes pond lining, dikes, and mechanical Volume of 6,250 m ³ considered with 20% evaporation.
Distribution Network		1	USD630,000	USD630,000	Assumes 8000m of 400 mm dia HDPE pipe network across the village, with small diameter pipe household connections
Total				USD760,000	
Equivalent Cost Per Person				USD540	Based on 4 person household
New Tank (Concrete / GRP)	2500	2	USD330,000	USD660,000	Includes pump and water tower
Distribution Network		1	USD560,000	USD560,000	Assumes 7000m of 400 mm diameter HDPE pipe network across the village, with small diameter pipe household connections
Total				USD1,220,000	
Equivalent Cost Per Person				USD870	
New Tank (GRP)	500	10	USD70,000	USD700,000	Includes pump and water tower
Distribution Network		1	USD130,000	USD130,000	Assumes 2500m of 400 mm diameter HDPE pipe network across the village, with small diameter pipe household connections
Total				USD830,000	
Equivalent Cost Per Person				USD590	
Existing Pond Rehabilitation	5,000	1	USD55,000	USD55,000	
Distribution Network	Install if required - See New Pond				
Total				USD55,000	Excludes distribution pipe network

Table 90 Estimated CAPEX for water storage solutions – village level 150 households

Village Level (150 households requiring approx. 2500 m ³ during dry season months)					
Item	Volume	Qty	Unit Cost	CAPEX	Notes
New Pond	2,500	1	USD65,000	USD65,000	Includes pond lining, dikes, and mechanical Volume of 3,125 m ³ considered with 20% evaporation.
Distribution Network		1	USD270,000	USD270,000	Assumes 3500m of 400 mm dia HDPE pipe network across the village, with small diameter pipe household connections
Total				USD335,000	
Equivalent Cost Per Person				USD560	
New Tank (GRP)	500	5	USD70,000	USD350,000	The concrete tank option is more expensive than GRP for this volume
Distribution Network		1	USD55,000	USD55,000	Includes pump and water tower Assumes 1100m of 400 mm dia HDPE pipe network across the village, with small diameter pipe household connections
Total				USD405,000	
Equivalent Cost Per Person				USD675	
Existing Pond Rehabilitation	2,500	1	USD25,000	USD25,000	
Distribution Network	Install if require - See New Pond				
Total				USD25,000	Excludes distribution network

Based on the above CAPEX calculations, the following conclusions can be drawn:

- One large storage pond is notably cheaper to develop than two equivalent sized concrete or GRP tanks. Cheaper tank alternatives could be considered, such as corrugated iron, however durability considerations will need to be taken into account,
- A large pond and multiple smaller GRP tanks at neighborhood level (including the distribution network) have approximately the same CAPEX cost,
- It is anticipated that locating tanks at household level may be more cost effective for sparsely populated villages where more extensive distribution networks from the stored water source is required.

Based on the above engineering design options, the estimated CAPEX cost to achieve the unmet domestic water demand within the villages in Unit Areas 5, 7 and 8 is provided in the Table below. This exercise considers the following:

- an average of 300 households per village,
- new ponds and/or tanks are installed,
- it is considered that 35% of the population within the villages will have their water demand met using existing infrastructure, based on the census results.

Table 91: Total CAPEX to meet water supply targets

Unit Area	Village No. (approx.)	Lower bound CAPEX (million USD)	Upper Bound CAPEX (million USD)	Approx. CAPEX per person (USD/person)
Unit Area 5	50	21	26	USD 540 - USD 675
Unit Area 7	10	4	5.5	
Unit Area 8	150	63	80	

Notwithstanding the above, the concrete and GRP tank storage solutions provided above are comparatively more expensive than local solutions currently employed in Myanmar. Current local rainwater harvesting solutions make use of more cost-effective materials, such as tarpaulins for rainwater harvesting and corrugated iron or homemade storage tanks. Whilst these solutions may not have long term durability, they provide an extremely cost-effective solution that aligns with the local situation.

As an alternative, a more locally aligned engineering solution has been developed to provide the same functionality of a 500 m³ storage tank at neighborhood level:

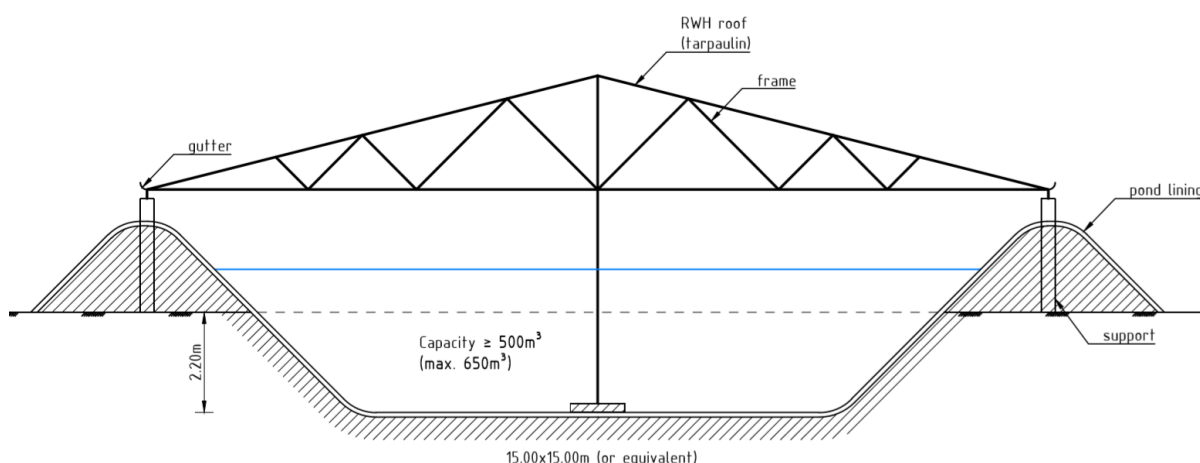


Figure 92: sketch of engineering solution for water storage tank at neighborhood level

The engineering solution in Figure 92 provides the same function as a tank, but with the lower CAPEX cost of a pond. The roof which utilizes tarpaulin for rainwater harvesting, is supported on a frame and has an area of 400 m² (20 m x 20 m). This would allow the pond to fill to 500 m³ with only 1.1 m of rainfall during the wet season. The roof would be sealed to avoid evaporation and the ingress of airborne debris into the pond. The pond would be lined to avoid seepage loss / ingress and would be surrounded by embankments to prevent contamination from surface water flows.

This engineering solution still provide a relatively high level of durability. Furthermore, it removes the reliance on household roofs to contribute to the rainwater harvesting. It is noted that house roofs and gutters in villages are of variable quality which introduces a reliability risk for the important function of rainwater harvesting. The calculated CAPEX cost for this engineering solution is provided in the two next tables:

Table 92: Estimated CAPEX new pond & distribution network for village level-350 households

Village Level (350 households requiring approx. 5000 m ³ during dry season months)					
Option	Volume	Qty	Unit Cost	CAPEX	Notes
New Pond	500	10	USD12,000	USD120,000	Includes pump and water tower
Distribution Network		1	USD130,000	USD130,000	Assumes 2500m of 400 mm dia HDPE pipe network across the village, with small diameter pipe household connections
Total				USD250,000	
Equivalent Cost Per Person				USD180	

Table 93: Estimated CAPEX new pond & distribution network for village level-150 households

Village Level (150 households requiring approx. 2500 m ³ during dry season months)					
Option	Volume	Qty	Unit Cost	CAPEX	Notes
New Pond	500	5	USD12,000	USD60,000	Includes pump and water tower
Distribution Network		1	USD130,000	USD55,000	Assumes 1100m of 400 mm dia HDPE pipe network across the village, with small diameter pipe household connections
Total				USD115,000	
Equivalent Cost Per Person				USD190	

Based on the engineering solution in Figure 92, the estimated CAPEX to achieve the unmet domestic water demand within the villages within Unit Areas 5, 7 and 8 is provided in Table 94. This exercise again considers the following:

- an average of 300 households per village,
- it is considered that 35% of the population within the villages will have their water demand met using existing infrastructure.

Table 94: Estimated total CAPEX to meet the total unmet water demand with a new solution

Unit Area	Village No. (approx.)	Lower bound CAPEX (million USD)	Upper Bound CAPEX (million USD)	Approx. CAPEX per person (USD)
Unit Area 5	50	7	7.5	USD180 - USD190
Unit Area 7	10	1.4	1.5	
Unit Area 8	150	21	23	

Household Level

Market research suggests that a supplied and installed GRP tank with a capacity of 15 m³, with connection to a house roof, will cost in the order of USD 4,000 per household (or USD 1,000 per person). Comparing to the cost per person on the village level, rainwater harvesting and storage on a household level is therefore more expensive than on a neighborhood level. This is because the costs are unable to be shared across multiple households. The above cost estimates have been developed based on the installation of a GRP tank. Locally aligned storage tank solutions for individual households can also be considered, such as those shown in the photo below. Whilst these solutions are more cost effective, consideration should be given to long term durability to ensure the reliable storage of water throughout the full dry season.

A high level cost estimate is undertaken to determine the approximate CAPEX cost to provide water security through rainwater harvesting to standalone households not located with high populated areas or villages within Units 5, 7, 8. This is further detailed below.

The total standalone households can be approximated by determining the number of houses located outside of highly populated areas and villages. Of these, it is estimated that 35% will have their water demand met using existing infrastructure based on the available census results. Assuming a locally aligned and durable rainwater capturing solution can be developed for a cost in the order of USD500 per person (or USD2000 per household), the total estimated CAPEX cost for standalone houses is then approximated as follows. This assumed cost of USD500 per person will need to be further verified locally.

Table 95: Estimated total CAPEX for standalone houses in unit areas 5, 7 and 8

Unit Area	Total Rural Population	Equivalent Households	Total living in villages	Total living outside villages	Total with met water demand	Total with unmet water demand	Total CAPEX
5	94,000	24,000	15,000	9,000	3,100	5,900	USD12,000,000
7	30,000	7,500	3,000	4,500	1,600	2,900	USD6,000,000
8	255,000	65,000	45,000	20,000	7,000	13,000	USD26,000,000

Unit Area 8: Kungyangon and Kawhmu

The estimated CAPEX cost to develop new large ponds or rehabilitate existing ponds with storage volumes ranging from 20,000 to 70,000 m³ are provided below.

Rehabilitation costs are estimated at 40% of the cost to develop a new pond, however this may vary depending on the extent of rehabilitation required. It is anticipated that the existing ponds would need to be lined, protected using perimeter dikes from contaminated surface water ingress and fenced off to avoid animal entry.

Table 96: Estimated CAPEX for new large ponds in unit area 8 – town level

Town level – New Large Ponds				
Option	Qty	Unit Cost	CAPEX	Notes
New Pond 70,000 m ³	1	USD1,850,000	USD1,850,000	Includes pond lining, dikes, mechanical. Volume of 87,500 m ³ considered with 20% evaporation.
New Pond 45,000 m ³	1	USD1,200,000	USD1,200,000	Includes pond lining, dikes, mechanical. Volume of 56,250 m ³ considered with 20% evaporation.
New Pond 20,000 m ³	1	USD525,000	USD525,000	Includes pond lining, dikes, mechanical. Volume of 25,000 m ³ considers 50% evaporation.

Table 97: Estimated CAPEX rehabilitating existing large ponds in unit area 8 – town level

Town level – Rehabilitation of Existing Large Ponds				
Option	Qty	Unit Cost	CAPEX	Notes
Existing Pond 70,000 m ³	1	USD735,000	USD735,000	As above
Existing Pond 45,000 m ³	1	USD470,000	USD470,000	As above
Existing Pond 20,000 m ³	1	USD210,000	USD210,000	As above

Based on the total stored water volume demand ranging from 45,000 m³ to 67,500 m³ for Kawhmu and Kungyangon respectively, the upper bound CAPEX cost to develop new ponds for these two towns is estimated at approximately 3 million USD. This excludes the cost of a distribution pipe network from the large ponds to the households, which could be a considerable cost depending on the extent of any existing distribution network. In the absence of any distribution networks in both towns, first order CAPEX estimates range from 4 million USD for Kawhmu and 7.5 million USD for Kungyangon.

Total upper bound CAPEX estimate and the cost per person assuming new ponds and a full distribution network, are provided in the table below:

Table 98: Estimated total CAPEX new ponds & distribution network Kawhmu and Kungyangon

Town	New Ponds	Distribution Network	Total CAPEX	Total Households	Cost per person
Kawhmu	USD1,200,000	USD4,000,000	USD5,200,000	2,200	USD590
Kungyangon	USD1,850,000	USD7,500,000	USD9,350,000	4,000	
Total			USD14,500,000		

However, as existing ponds / lakes are known to exist in these towns and some form of a distribution network is also likely to be present, the above CAPEX estimates are likely to be unrealistically high. Assuming the existing ponds / lakes can be rehabilitated, and an existing distribution network reaches 20% of the current population, the more realistic CAPEX estimate is provided below.

Table 99: Likely total CAPEX new ponds & distribution network Kawhmu and Kungyangon

Town	New Ponds	Distribution Network	Total CAPEX	Total Households	Cost per person
Kawhmu	USD470,000	USD3,200,000	USD3,670,000	2,200	USD420
Kungyangon	USD735,000	USD6,000,000	USD6,735,000	4,000	
Total			USD10,400,000		

It may be determined through further feasibility studies that establishing rainwater harvesting and storage on a neighborhood level may be more cost effective than rehabilitating existing large ponds / lakes and installing a comprehensive distribution network. This is likely the case if the locally aligned 500 m³ covered pond solution is selected. The ability to acquire land within the more populated neighborhoods within the town may however be a constraint for this solution. In this case, a buried storage tank solution may be preferable however with a higher cost.

Estimated Benefits

The benefits associated with an increased availability of higher quality domestic water supply are typically socio-economic related. These benefits may include:

- A reduction of health incidences related to diseases,
- Increased economic input due to a reduction in time loss associated with fetching water, or financial loss associated with paying for water. Often profiteering can occur in situations of water scarcity, whereby water suppliers charge above reasonable market prices,
- Overall wellbeing and quality of life of those positively affected.

Assuming the shortlisted measures and engineering solutions detailed above all meet the unmet water demand within the rural communities, the benefit per person for each shortlisted measure should be approximately the same. The various shortlisted measures and engineering solutions can therefore be further evaluated and prioritized based on cost difference only.

Cost / Benefit Analysis

The table below summarizes the costs of the shortlisted measures (CAPEX estimates can be considered to have an accuracy within the range of +/- 40%):

Table 100: Summary of CAPEX needed to meet the total unmet domestic water demand

Table 100: Summary of CAPEX needed to meet the total unmet domestic water demand			
	Equivalent cost per person	Estimated Total CAPEX to meet unmet water demand	
Village level			
New lined pond (500 m³) + tarpaulin roof + distribution network on neighborhood level.	USD185	Unit Area 5	USD7,500,000
		Unit Area 7	USD1,500,000
		Unit Area 8	USD23,000,000
Household Level			
Rainwater harvesting roof + storage tank	USD500	Unit Area 5	USD12,000,000
		Unit Area 7	USD6,000,000
		Unit Area 8	USD26,000,000
Kawhmu and Kungyangon Towns			
Rehabilitation of existing ponds + new ponds + distribution network	USD420 ¹	Kawhmu	USD3,700,000
		Kungyangon	USD6,700,000
Total Estimated CAPEX Cost			~USD85,000,000

Rural domestic water supply measures on village and household level will likely benefit most of the rural populations in all Unit Areas. Unit Areas 5, 7 and 8 have however been assigned a highest priority given during this study given the current notable shortage of water supply resources and infrastructure.

6.3 Details program 3 Drainage Management and Irrigation

An overview of the pluvial flooding in each Unit Area is described in Section 3.3.5. However, these pluvial models developed using the RWSS numerical model do not provide the level of detail required to gain an understanding of the complex behavior and extent of pluvial flooding within each Unit Area. As such, it was decided to focus on the drainage system within Yangon South (Unit Area 8) by developing a detailed hydraulic (SOBEK) model. Unit Area 8 has been selected for this exercise as it faces many challenges across all 3 of the programs. These include:

- Urban expansion through the town of Dala;
- Coastal flooding resulting in overtopping of the existing ring dikes;
- Shortages in water supply for domestic and agricultural purposes
- Pluvial flooding exceeding the indicator threshold.
- Elevated impacts of cyclones compared to the other unit area due to proximity to coastline.

Unit Area 8 provides an opportunity to develop an integrated water management solution to address these challenges. This integrated solution, or parts of it, can then be carried forward when developing the other unit areas.

The results and detailed analysis arising from the SOBEK model are presented in Appendix B. This section covers the main findings of the model analysis and translates these into conceptual measures with the aim to create an integrated water management solution for Unit Area 8 to address the above challenges.

Key limitations exist in the SOBEK model which limit the extent to which conceptual measures can be developed for Unit Area 8. These include:

- The alignment and approximate width of the internal drainage channels were determined from satellite imagery. The depths of the drainage channels are unknown and are assumed to have sufficient internal flow capacity.
- Only prominent open drainage channels through the ring dikes on the east and southeast boundaries have been modelled and are considered to be open. As no dike reinforcement is envisaged on the east and southeast boundaries under Program 1, these open channels are not proposed to be closed and are therefore modelled as open. As such, water inflow from high tides and storm surge remain a risk. Less prominent channels have also not been modelled and are therefore considered not to exist.

Further detailing of the SOBEK model is required to validate the dimensions of the open channels on the east and south east boundaries of the unit area, all internal drainage channels and the presence of any internal control structures i.e. sluices and weirs. Field visits will be required to complete this task and refine the assumptions adopted in the model.

Key model results

Figure 93 below shows the critical area's for pluvial flooding within Unit Area 8 based on the 1 in 200 year event. From the figures it can be observed that after 48 hours the inundation depth is still above the chosen threshold of 0.6m for some areas in the southwest and southeastern part of the Unit Area.

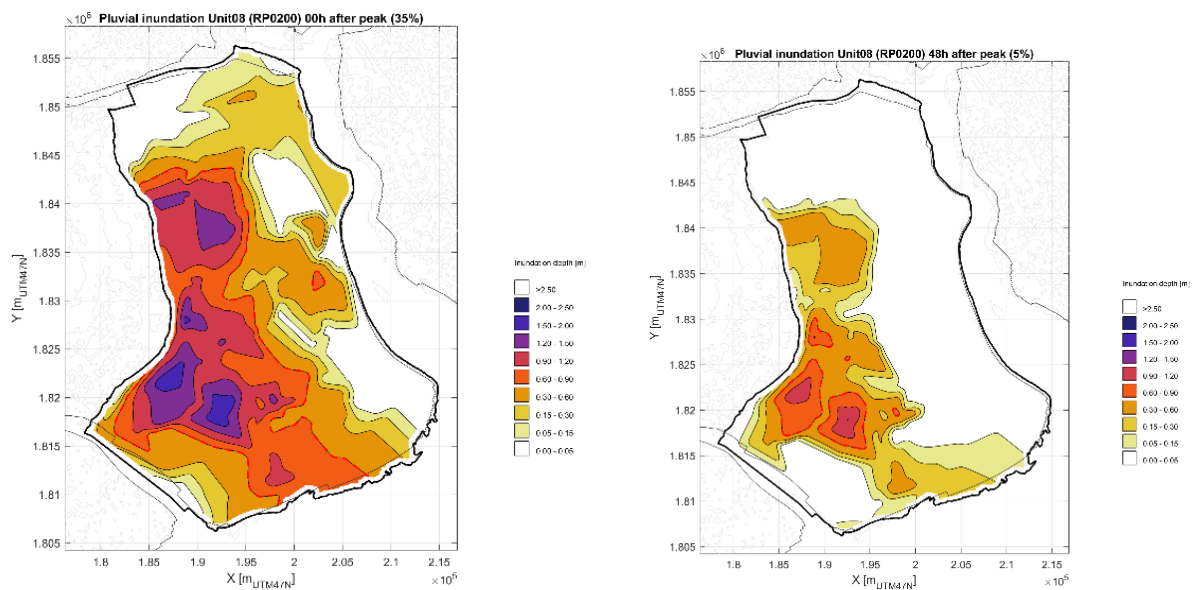


Figure 93: Simulated development of pluvial inundation in space and time for 1 in 200 year event, left 0h after peak and right 48h after peak

As presented above, pluvial flooding is concentrated on the west and southwestern section of the unit area. The measures specifically related to pluvial flooding will therefore focus only on the outlet reaches connected to the southwest and southeastern section of the unit area. The table below summarizes the related outlet reaches and model results. As mentioned above, it is assumed all other outlet reaches have sufficient internal flow capacity. The model results and how these relate to the outlet reach structure are further discussed below.

Table 101: Summary of pluvial flooding model output

Outlet Reach	Q max [m³/s]				Open/Controlled	Q percentage [%]			
	RP 1 in 1 year	RP 1 in 10 year	RP 1 in 100 year	RP 1 in 200 year		RP 1 in 1 year	RP 1 in 10 year	RP 1 in 100 year	RP 1 in 200 year
25/37	36,5	41,0	43,0	43,4	Controlled	3	2	2	2
9014	104,7	104,7	121,1	126,4	Controlled	7	5	5	5
9018	281,5	433,3	531,3	555,2	Controlled (Kungyangon)	20	20	20	20
97	213,8	352,5	435,0	455,8	Open	15	16	16	17
102	1,1	1,2	2,6	3,0	Controlled	0	0	0	0
DM336 1	25,6	28,8	30,3	30,7	Controlled (Taw Khayan East)	2	1	1	1
Qtotal	1421,6	2183,9	2650,2	2739,4					

For outlet reach 25/37, the discharge capacity for a 1 in 10 year event (41 m³/s) and 1/100 year event (43 m³/s) year's event are almost equal to the discharge for the 1 in 200 year event (43.4 m³/s). Based on this, it is considered there is no need for further measures at this location.

The same applies for outlet reach 9014, which is located outside the boundary of Unit Area 8. The discharge volume for a 1 in 50 year event is between 105 and 121 m³/s, while a discharge volume for a 1 in 200 year event is 126 m³/s. It is assumed that this slight overshoot lies in the uncertainties and assumptions within the model.

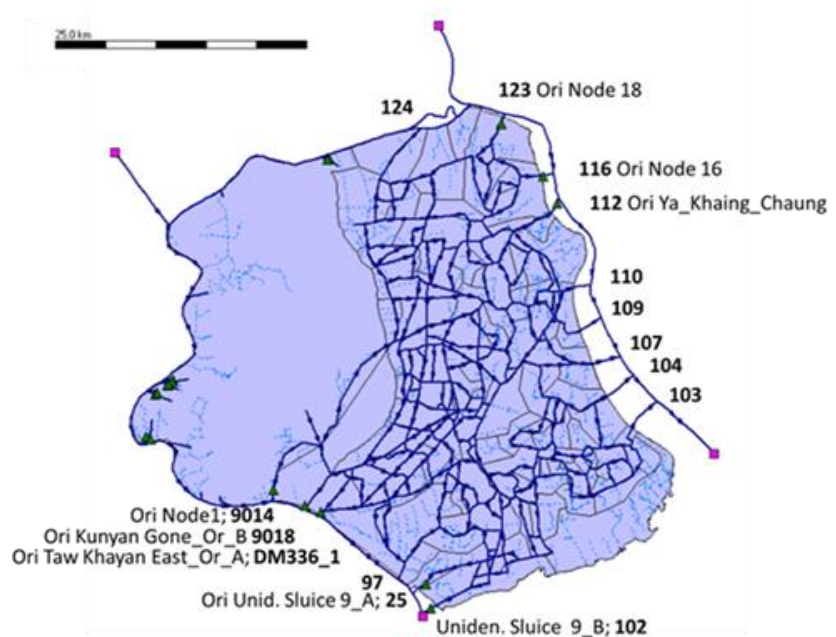


Figure 94: SOBEK Model Outlet Reach locations and drainage channels

The discharge from outlet reach 9018 is dominated with a sluice at Kungyangon. This outlet sluice has an open drain area comprising 15 openings with a dimension of 6x12 feet and a total drain area of about 100 m². The output results indicate that a capacity of 555 m³/s is required, while the 1 in 50 and 1 in 100 year events suggest discharge volumes of 433 m³/s respectively 531 m³/s. This implies that there is a need for circa 10%-15% additional discharge capacity, which can be translated into 2 to 3 additional flow openings. A building block 'small' will suffice for this, as described under Program 1. The CAPEX cost of this additional discharge capacity has been included under Program 1.

Outlet reach 97 is located at the southern side of Unit Area 8. The required additional capacity compared to the 1 in 10 and 1 in 100 year events is estimated in the order of 10 - 15%. However, it can be seen in Figure 93 that after 48 hours the inundation depth is less than the threshold in the southern section. This implies that sufficient drainage capacity is available. This channel is proposed to be blocked under Program 1. For the design of the required sluice, it should be carefully considered at what capacity this sluice structure needs to be designed, including potential widening and creating interconnectivity of the drainage channels to the sluice structure.

The outlet reaches 102 is located at the southern side of Unit Area 8. A capacity of 3 m³/s is required for the T200 year event. The discharge capacity for the 1/10 year event is about 1.2 m³/s and the discharge capacity for the T100 year event is about 2.6 m³/s. Figure 93 indicates that the inundated areas are more inland at the south-eastern area. In the model there are no outflows considered at the south-eastern side of the unit area included, whilst aerial pictures show some outlet structures and interconnectivity of drainage channels. For now, it is assumed that no additional drainage capacity is required.

For outlet reach DM336_1, the discharge capacity for a 1 in 10 year event (29 m³/s) and a 1/100 year event (30 m³/s) are almost equal to the discharge for the 1 in 200 year event (31 m³/s). Based on this, it is considered there is no need for further measures at this location.

In conclusion, when considering only pluvial events, the drainage capacity of the outlets is for the large part sufficient, with the exception being the sluice at outlet reach 1918 which requires additional discharge capacity. Outlet reach 97 requires further consideration when designing the outlet structure as additional capacity may be required for the relevant drainage channels and consequently the outlet might need to be increased in order to reduce pluvial flooding.

Model sensitivity and storm surge effects

In addition to the above pluvial flooding analysis, a combination of a pluvial and storm surge event was analyzed. For reference purposes, the storm surge and rainfall events from the Nargis event were modelled. A typical 1 in 10 year rainfall event was used considering the cumulative precipitation of Nargis (day before, during and after) combined with assumed saturated soils. This is comparable to the 1 in 10 year precipitation event considered throughout this report. The storm surge was modeled by adopting a 1.75m external water level increase and 3.25 m high tide to the boundary conditions of the SOBEK model, as derived from the larger RWSS model. This in turn simulated a storm surge in the order of 5 meters, as observed during the Nargis event.

The model shows only a slight increase in pluvial flooding compared to the previous 1 in 10 year event result without a storm surge event.

Table 102: Percentage of Unit 8 flooded during extreme events including the drainage impeding effect of a storm surge

Hours after peak inundation	RP 1 in 1 year (% area flooded)	RP 1 in 10 year (% area flooded)	RP 1 in 100 year (% area flooded)	RP 1 in 1000 year (% area flooded)	RP 1 in 10 year (Storm Surge) (% area flooded)
0	0	34	59	73	36
12	0	30	51	60	31
24	0	15	36	47	17
36	0	2	14	29	2
48	0	0	1	7	0

This gives an indication that the effect of a storm surge causes only a limited additional demand on the drainage capacity of the system. Comparing these results to the reality of the Nargis disaster may seem a discrepancy, as the Nargis flooding was much worse than these results indicate. However, the simulated percentage of 36% is the area that is inundated exceeding the indicator value of 60 cm depth. The actually inundated area is much larger as presented in Figure 17. This area covers similar areas as observed after Nargis (Figure 18).

The drainage capacity within Unit Area 8 appears to be only partly dependent on the water levels at the boundary of the unit area. This would imply that with sufficient coastal protection, the effects of a tidal surge remain rather limited, with only a small increase in areas flooded above the indicator level due to the restriction imposed to the drainage. A more in-depth analysis of the sensitivity of the model can be found in Annex B, section 7.4.

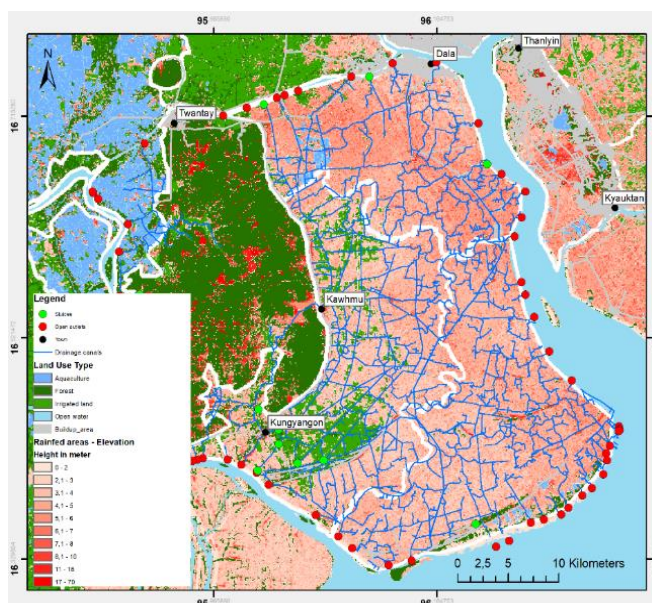


Figure 95: Mapped drainage channels within Unit Area 8

Water management within Unit Area 8

The combination of a 1.75m storm surge and 1 in 10 year rainfall event were determined to have a limited effect on inundation assuming adequate coastal protection is in place. However, Unit Area 8 consists primarily of agricultural land and suffers in most of the unit area from a lack of freshwater in the dry season. Many drainage outlets on the south and southeast coast, flowing into the Yangon River and the sea, currently have

no control structures able to block out the saltwater from flowing into the channels. See Figure 95 for locations of these drainage outlets on the south and southeast boundaries. As a result, most of the agricultural area in Unit Area 8 is limited to rainfed irrigation only, especially in the southeast (Section 4.6.2).

Moving more to the north and to the west, the drainage outlets are controlled through sluice gates. These are being closed at the beginning of the dry season to stop saltwater ingress and store freshwater in the drainage channels to be used for irrigation. This is currently enough to irrigate around 7660 ha of land, which equates to around 7% of the total agricultural area in Unit Area 8.

Transforming the agricultural land from rainfed-only to irrigated agriculture would support the growing of a second or even a third crop. Considering the difference in price for monsoon paddy rice versus irrigated dry season paddy rice the production value at current prices in one year would more than double. Going from around 800 to 1800 USD per hectare according to experts from NEPS.

Apart from supporting irrigated agriculture, the closing of control structures and storage of freshwater within the drainage channels could also be considered to contribute to the domestic water supply for the rehabilitated ponds of Kungyangon and Kawhmu proposed under Program 2. Furthermore, villages and households within rural villages could also benefit from an increase in water supply within the channels.

More freshwater needs to be made available to develop parts of Unit Area 8 as estimated in Section 4.6.2 and further explained in Appendix E. This could be achieved in three ways, or a combination of these, as described below.

- 1) Increase storage capacity by increasing the width, depth and extent of the existing drainage channels, creating surface reservoirs, or by constructing control structures intermittently along and at the end of the drainage canals. This would more evenly distribute stored freshwater across more parts of the drainage system as the water drains from the higher elevations to the outer edge of the unit areas. This would result in the ability to store more water collected during the wet season for use in the dry season. Additionally, extending the drainage network could make water available to areas that are currently un-serviced and potentially aid in reducing any isolated pluvial flooding in the area.
- 2) Bringing freshwater from the Twante Canal. The plans to use the Twante Canal as a freshwater reservoir (Section 4.3.2) would provide new opportunities for water supply from the northern border of this area. Part of this stored water can then be diverted into the unit area and used for irrigation purposes.
- 3) Using the natural tidal changes in the Toe and Yangon Rivers to allow freshwater inflow into certain channels during the low tide when freshwater is available caused by the retreat of the salinity front. It has been observed in the field that certain farmers are already implementing this on a small scale. In this instance, the farmers measure the salinity levels in the larger drainage canals and have constructed small barriers in the drainage canals surrounding their fields. Once the salinity levels are low enough, they allow freshwater to fill up their channels, after which they close them again with the small barriers. This was observed close to Kungyangon, where control structures already manage the water levels and freshwater availability to a certain extend. This gives reason to believe that this practice could be extended



Figure 96: Example of a sluice in the Ayeyarwady Delta

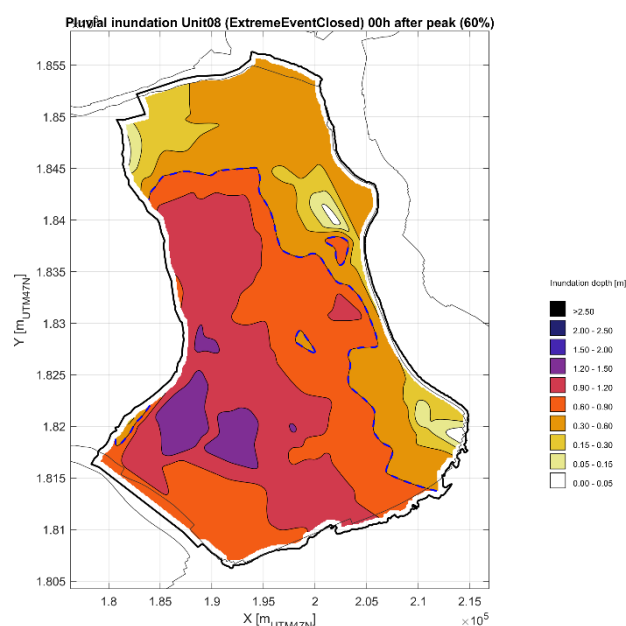


Figure 97: SOBEK Model Output – all drainage outlets closed.

to other areas in Unit area 8 by extending the amount of control structures.

As concluded under Program 1 (see Section 6.1), no dike reinforcements are proposed along the east or south coasts of Unit Area 8. As such, no blocking of the existing drainage outlets flowing into the surrounding rivers or sea are proposed. However, given the large number of drainage outlets (see Figure 95), this may need to be reconsidered if the open channels are of sufficient size or the channel inlet is low enough to permit high inflow volumes under storm surge conditions. The implementation of control structures to close these drainage outlets would allow for the whole of Unit Area 8 to manage freshwater storage within the drainage network.

This was tested using the SOBEK model by closing off all the drainage outlets. The model shows results that the areas in the south and east do in fact inundate when fully closing the drainage outlets and without managing their outflow. Comparing the flood areas in Figure 93 with Figure 97 shows that if the outlets are closed, it may be possible to store rainfall in the drainage channels without it draining to the west, or mixing with saline water. Due to model limitations and a lack of detailed field data, it is not possible to provide recommendations on where to place control structures to maximize the appropriate distribution of water storage within the drainage channels.

Unit Area 8 West: Considering the natural lay of the land, the consequential flow directions and accumulation points, the western area is suggested for irrigation development as depicted in the map shown in Figure 98. This area is located in several control areas that are currently regulated by sluice gates and totals around 28,000 hectares. This would require a total estimated water supply volume for the suggested scenario of 289 million m³ for purely the gross irrigation requirements for the crop excluding the evaporation losses. In order to achieve this, inlet structures and/or pumps would need to be developed at the Twante Canal and estimations can be made about the amount on additional storage needed.

Table 103: Required extraction volumes in m³/day x1000 to irrigate Unit area 8 West

Nov. D 3	Dec. D 1	Dec. D 2	Dec. D 3	Jan. D 1	Jan. D 2	Jan. D 3	Feb. D 1	Feb. D 2	Feb. D 3	Mar. D 1	Mar. D 2
534	1.408	2.257	3.155	3.568	3.640	3.738	3.810	3.107	2.160	1.213	243

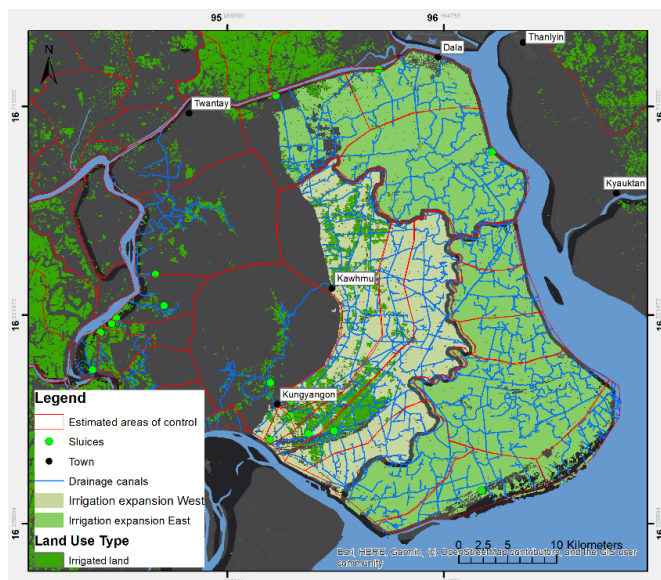


Figure 98: Existing and potential of irrigation expansion in Unit 8

freshwater would have to be extracted from the Twante Canal.

Unit Area 8 South / East: The south and east side of Unit 8 are currently 98-99% rainfed. In order to develop irrigated agriculture, the outlets that are currently open should be able to close in order to store the freshwater and keep out the saline water. As this area has around 67000 ha of rainfed-only agricultural land this would require a total of 687 million m³ of water (excluding in-channel evaporation losses) to irrigate the full area. The estimated agricultural gross revenue for the whole eastern area shown in the image would increase by about 58 million USD per year (from 52.5 million to 110.5 million). A minimum requirement for these developments may require the construction of over 30 sluice gates at all the open outlets to stop the ingress of saline water and increase storage of the freshwater during the wet season. Furthermore, a lot of additional

Table 104: Required extraction volumes in m³/day x1000 to irrigate Unit area 8 South/East

Nov. D 3	Dec. D 1	Dec. D 2	Dec. D 3	Jan. D 1	Jan. D 2	Jan. D 3	Feb. D 1	Feb. D 2	Feb. D 3	Mar. D 1	Mar. D 2
1.274	3.358	5.384	7.525	8.510	8.683	8.915	9.088	7.410	5.152	2.894	579

Water extraction from Twante Canal

Extraction of water from Twante Canal is considered feasible under the following conditions:

- Closure of Twante Canal on both ends (e.g. with sluices) to create a (freshwater) reservoir.
- Daily filling of the Twante Canal with freshwater preferably during peak river discharge to obtain a high-water level in the reservoir using just gravitational flow. Alternatively, additional stored volume (and subsequently, available head) can be created by pumping more water into the Twante Canal reservoir on top of what was stored naturally.

Please note that this is only possible when freshwater is available at the water extraction location. Assuming this is at 21 Mile, freshwater should be available year-round, only during extreme (long) droughts will salt reach 21 Mile. This might change in the future, however.

Based on the RWSS simulations, the once per year fluvial peak water level within Twante Canal is roughly 4.1 m EGM08 with a projection of 4.3 m EGM08 in 2040. Assuming this average yearly maximum is used to fill the Twante Canal reservoir with freshwater, it will be filled up to this water level. Assuming the water level is not allowed to drop below mean high tide outside (e.g. Yangon River) to prevent intrusion of saltwater via ground water flow or leakage, the water level can only drop to roughly 3.1 m EGM08. This means that a volume of $185 \times 1 \times 31,500$ (width * height * length) = almost 6 Mm³ is available for irrigation before refilling (either naturally or by pumping) is required. Which will naturally be the case because when this volume of water is equally distributed over the surface of Unit 08, only 6 mm of water is available across the whole area, not nearly enough to meet the crop water requirements. Pumping will also be required as refilling of the Twante Canal and filling it up naturally does not provide sufficient head during the dry season due to lower fluvial water levels at that time.

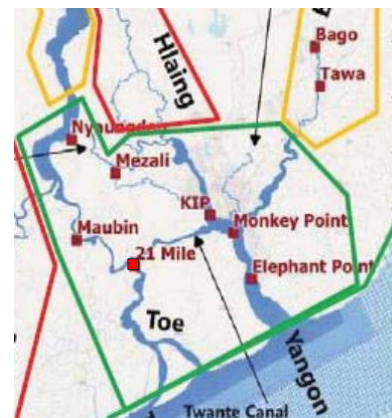


Figure 99: Significant project locations including 21 Mile

Looking at the land elevation distribution across Unit 08, 90% is located above 4.3 m EGM08 and roughly 60% is situated above 6 m EGM08 (see Figure 100). Assuming most irrigation channels currently have a depth of 2 m below local surface level, only a limited amount of the irrigation system can be supplied with freshwater using gravitational flow.

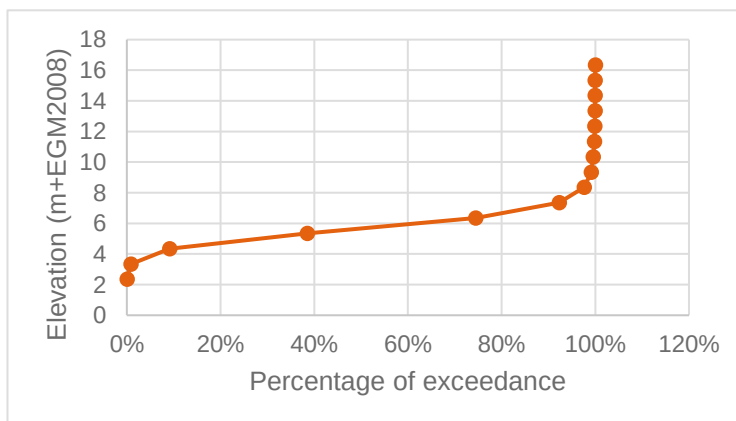


Figure 100: Height distribution over Unit 8

Two solutions are therefore proposed:

- Applying pump capacity at the inlet location(s) from Twante Canal into Unit 08. Additional head can be created, but at the cost of energy.
- Deepening the (limiting) irrigation channels to a larger depth (i.e. 4 m below surface), 75% is located at at least 2.1 m EGM or deeper, resulting in at least 1 m of water depth if a minimum of 3.1 m EGM08 is assumed in the Twante Canal reservoir (see above). Additionally, these deeper channels provide more initial storage and conveyance capacity during (extreme) pluvial events, improving the units flood security during these events.

The inlet (either with pumps or just gravitational flow) is likely located at the current 'Outlet 124' (refer to SOBEK model). It is advisable to further develop the SOBEK model to study the distribution of flow throughout the existing drainage channel network and the extents of Unit Area 8 when water is injected into Unit 08 at this location.

Required structures/measures

Due to the difference in surface water level between the Twante Canal and the water within the drainage channels, an intake structure comprising an open drain in combination with pumps is required at the Twante Canal. Additional structures/measures are also likely to be required throughout Unit Area 8, including channel

widening and deepening, dike strengthening and height increase, sluice structures, weir structures and additional pumping stations.

Intake

Derived from the extraction rates shown in Table 103 and Table 104 the required amount of water at the intake is estimated at a maximum of 14 Mm³/day or roughly 160 m³/s over a 10 day period in February. Given the fact that the ground surface elevation of Unit Area 8 is higher than the water level in the Twante Canal, there is a very limited head to irrigate using just gravitational flow, even if the channels would be deepened. The focus for the intake structure is therefore on a large-scale pumping station with an estimated cost of USD 20-30 million.

Given an extraction rate of 14 Mm³/day exceeds the maximum allowed of 6 Mm³/day from the Twante Canal, it will be necessary to ensure the drainage channels within Unit Area 8 are kept near full during the peak dry season months to provide a buffer for this reduced extraction from the Twante Canal. It is noted that evaporation from the stored water within the drainage channels is expected to be minimal.

At the intake location, the water level will reach the level equal to the flood tide, which is on average between 2 and 3 m EGM08, depending on where you are in the spring-nep tidal cycle (a bit lower during dry season and up to 4 m during peak river discharge). Looking at the land elevation distribution across Unit Area 8 as explained above and assuming most irrigation channels currently have a depth of 2 m below local surface level, the head of the pumping station should be at least around 1,5 to 2 meters. This is the starting point for selection of the type of structure and the general dimensions.

Water direction points / measures for water management

The north-eastern section of Unit Area 8 has a higher ground surface elevation compared to the elevation at intake and the elevations at the southern boundary of Unit 8. There is therefore a need for water direction points. This could be achieved using several solutions e.g. blocking the river with a dam (earthworks), a weir structure or a sluice structure.

In view of water management and irrigation purposes, water will not reach the higher elevated ground unless additional pumping stations are distributed across Unit Area 8.

The weir structure could be a so-called passive structure; a solid structure with a certain crest level with no possibility to adjust the crest height. For some locations, this type of structure could be considered ('low' CAPEX and OPEX costs), however given the local situation with sometimes too little water and sometimes too much water, there is a certain need for flexibility. Also in perspective of experimenting with a new irrigation water management system, a passive solution is not recommended. An adjustable structure can be made of wood, concrete, steel, or a combination of materials.



The costs of a weir strongly depend on the size of the structure and the type of material. Costs are site-specific and will depend on the size and type of water control structure needed at a location. These costs might range from a few thousand dollars (wooden sheet pile wall with simple stop-log weir in small channel) to many thousands of dollars for a wider and deeper channel. For example, the cost for a weir in a river with a width of 10 m and a depth of 1-2 meters would be around USD 25-50k.

For smaller pumping stations distributed across Unit Area 8 and with volumes capacities in the order of 50m³/m, a vertical turbine pump or a 2m diameter Archimedean screw pumping station will suffice. The costs for a pumping station with this volume is estimated at USD 0.25 to 0.5 million.

With the exception of the above building blocks no further overview of the CAPEX and OPEX cost estimates can be provided for an overall solution for Unit Area 8. Further mapping of the existing internal drainage channels and structures, and more granular detailing of water demands by farm size is required to further develop a design to feasibility level. It is anticipated that an integrated water management solution can be

developed for Unit Area 8 that will provide the necessary water supply for irrigation. The return on investment through the increased farming output is however expected to take many years to recover.

The use of control structures for storing water would have a significant effect on the ecology of the whole area as for a large part of the year the usual tidal influence would be removed. Fish migration could be impaired, habitats destroyed and the effects of sediment accumulation due to tidal dynamics at the downstream side of the sluices would need to be assessed. The economic impact to the farmers and the development of the agricultural areas would be significant, however. For an assessment of the potential loss of ecosystem services further in-depth assessments of the effects of the required infrastructure on both the biotic and abiotic environments are required.

7 NO-REGRET PRIORITY MEASURES

7.1 Shortlisted measures per program

This Chapter further evaluates the shortlisted measures discussed in Chapter 6 and prioritizes them based on the criteria detailed in Chapter 2.3.2.

7.1.1 Weakest Links Program

A total of 13 shortlisted measures are identified. The total estimated CAPEX cost of these measures is USD 180 Million:

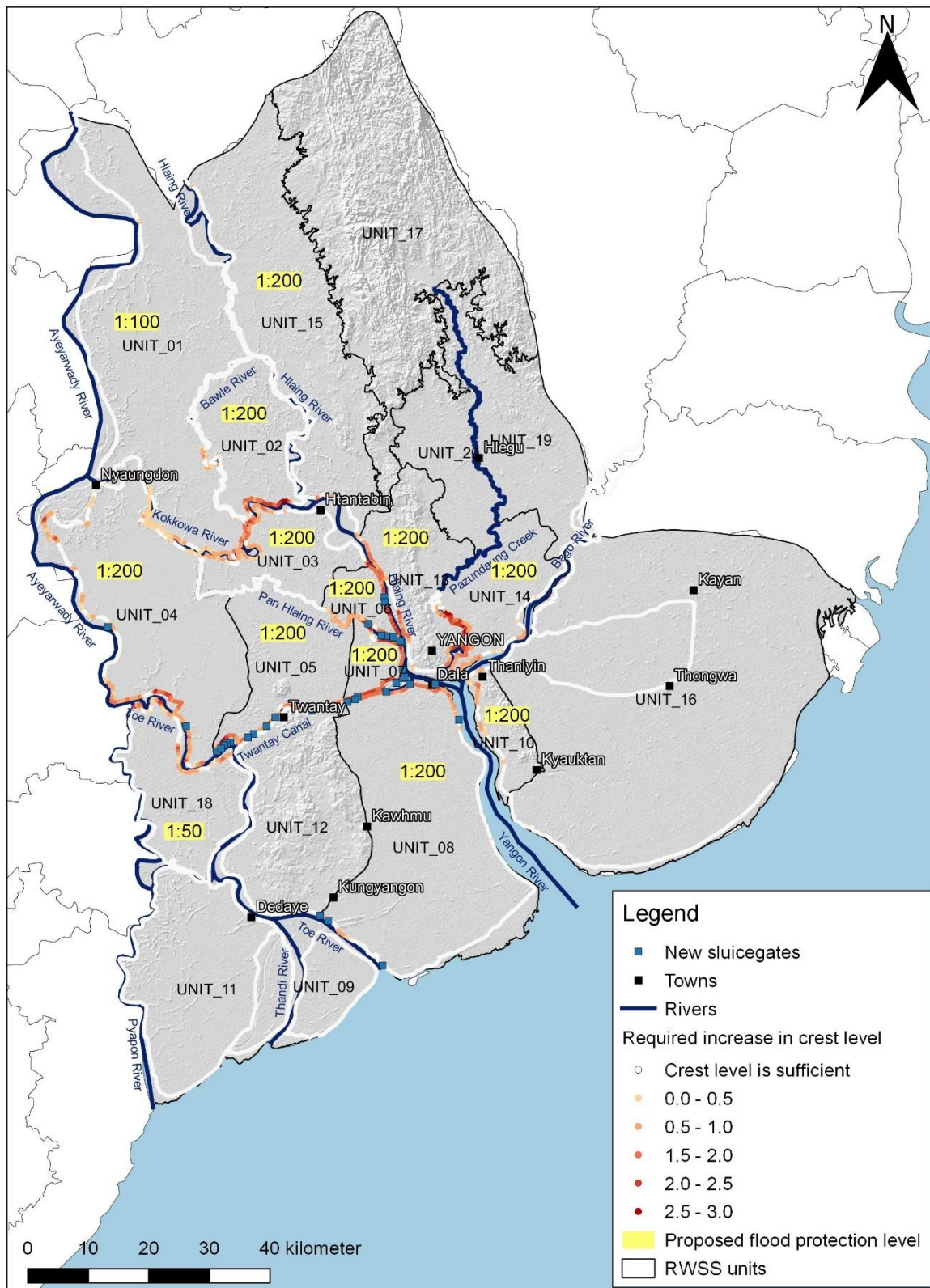
Table 105: Total estimated CAPEX for shortlisted measures program 1

Unit Area	Current Flood Protection level Fluvial	Current Flood Protection Level Coastal	Proposed Flood Protection Level	CAPEX Cost (Million USD)	B / C Ratio (for Land use 2040 scenario)	Annual Affected People Before / After
UNIT_01	<1:2	1:70	100	17.6	4.5	20905 / 1024
UNIT_02	<1:2	<1:25	200	9.9	8.8	2087 / 147
UNIT_03	<1:2	<1:25	200	8.6	96.1	3305 / 287
UNIT_04	<1:2	<1:25	200	18.6	11.3	39360 / 549
UNIT_05	<1:2	<1:25	200	33.8	0.8	4270 / 215
UNIT_06	1:39	<1:25	200	8.4	9.7	1829 / 773
UNIT_07*	<1:2	<1:25	200	23.2	20.1	1200 / 356
UNIT_08	1:15	<1:25	200	32.8	1.3	554 / 302
UNIT_10	>1:200	1:40	200	1.7	5.3	113 / 70
UNIT_13	1:35	<1:25	200	9.8	1.7	2058 / 1017
UNIT_14	>1:200	<1:25	200	7.2	0.4	312/208
UNIT_15	<1:2	1:33	200	1.4	26.9	230 / 136
UNIT_18	<1:2	<1:25	50	7.1	4.3	13260 / 922

* Unit 7 is expected to be developed by New Yangon City Development Company Ltd.

The locations of shortlisted dike reinforcements and new outlet structures within the ring dikes are included in the next figures.

Flood protection program



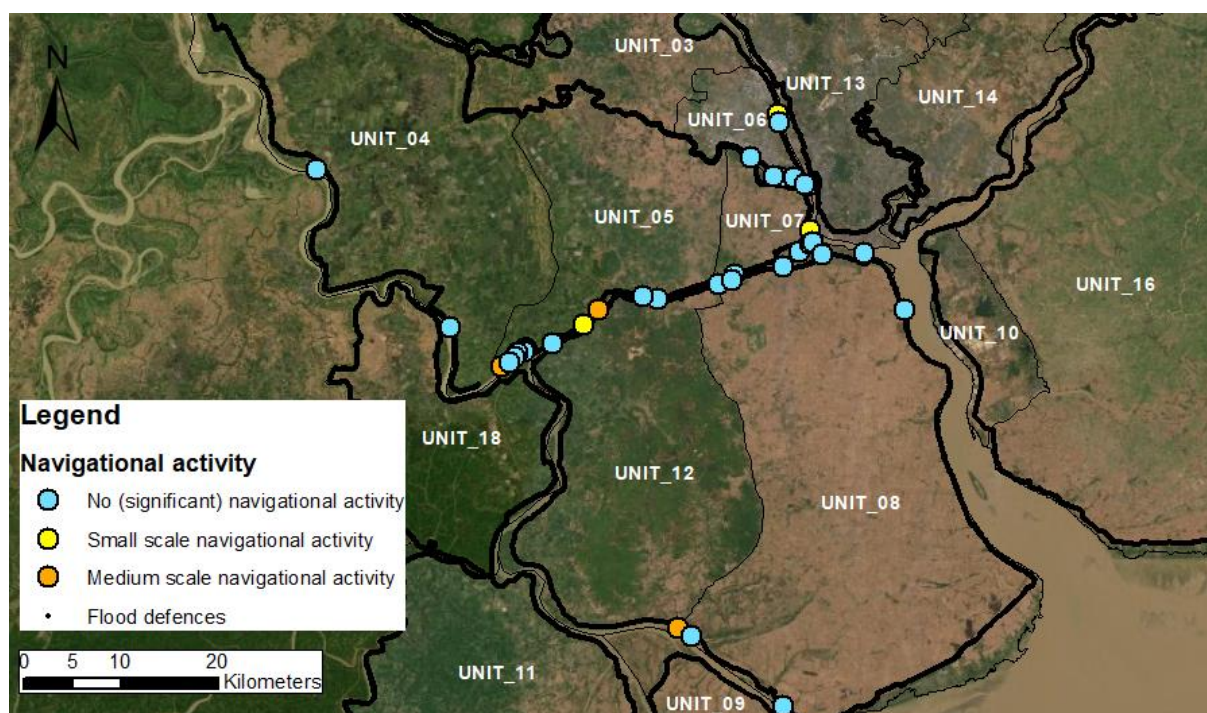


Figure 102: Locations of new outlet structures within the ring dikes

7.1.2 Water availability program

The table below summarizes the costs of the shortlisted measures. The total estimated CAPEX cost of these measures is USD 85 Million.

Table 106: Costs for shortlisted measures for program 2

	Equivalent cost per person	Estimated Total CAPEX to meet unmet water demand	
Village level			
New lined pond (500 m³) + tarpaulin roof + distribution network on neighborhood level.	USD185	Unit Area 5	USD7,500,000
		Unit Area 7	USD1,500,000
		Unit Area 8	USD23,000,000
Household Level			
Rainwater harvesting roof + storage tank	USD500	Unit Area 5	USD12,000,000
		Unit Area 7	USD6,000,000
		Unit Area 8	USD26,000,000
Kawhmu and Kungyangon Towns			
Rehabilitation of existing ponds + new ponds + distribution network	USD420 ¹	Kawhmu	USD3,700,000
		Kungyangon	USD6,700,000
Total Estimated CAPEX Cost			~USD85,000,000

* Unit 7 is expected to be developed by New Yangon City Development Company Ltd.

The focus areas for Program 2 within Unit Areas 5, 7 and 8 are approximately depicted in Figure 103 below. The exact extend of the rural population requiring increased domestic water supply will need to be confirmed during the (pre)-feasibility stage.

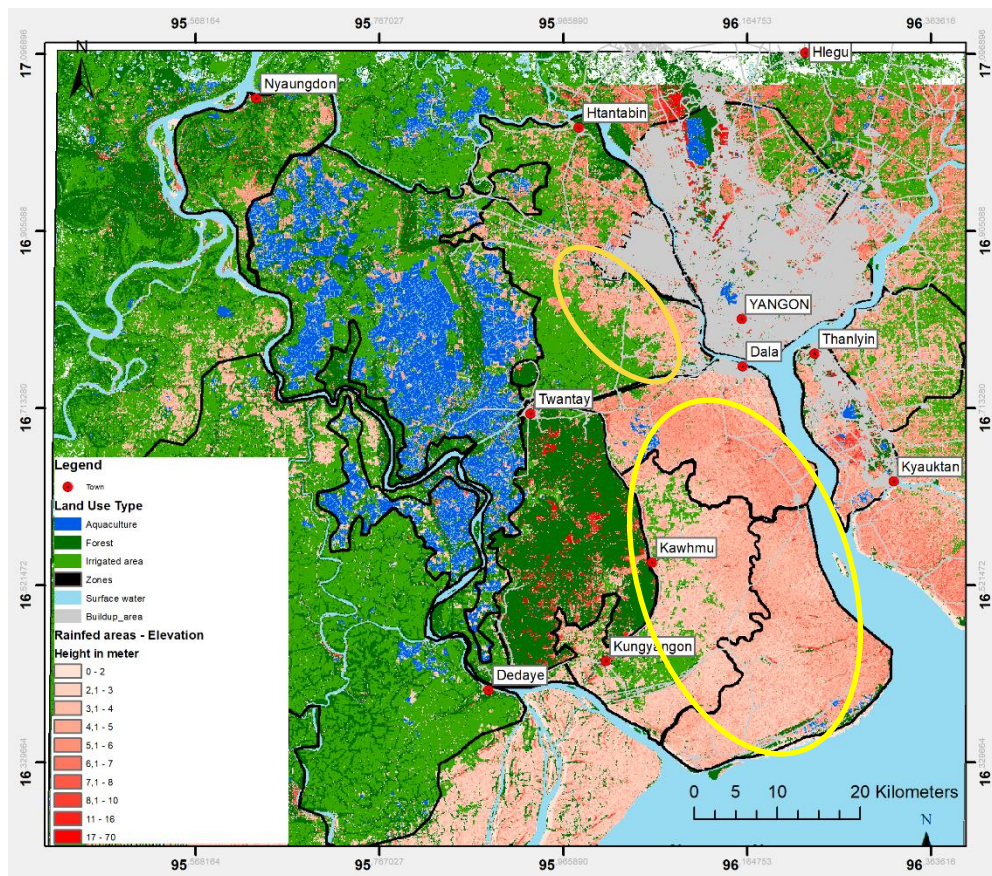


Figure 103: Approximate extent of rural populations requiring increased domestic water supply

7.1.3 Drainage Management and Irrigation Program

The program focuses on drainage and irrigation improvement within Unit Area 8 only through a variety of potential measures. The overall management of water within Unit Area 8 has been assessed using the detailed drainage (SOBEK) model, with the aim of increasing irrigation across the whole Unit Area and complementing the water supply for domestic purposes during the dry season.

An approach to achieve this has resulted in the following conceptualized measures:

- The introduction of new freshwater inlets from Twante Canal
- The introduction of control structures at all drainage outlets along the perimeter of the unit area to stop the inflow of saline water from the adjacent rivers and sea.
- The introduction of internal sluices and pumps to regulate the flow and storage of pluvial water across the unit area, including widening of drainage channels to increase water storage.

The measures for this initiative have been conceptualized only due to a lack of detailed field data of the internal drainage network across the unit area and drainage outlets along the perimeter of the unit area. Further detailed development of these conceptual measures is required under a subsequent (pre-)feasibility study to determine the scope and CAPEX cost of the required measures and if a positive benefit / cost ratio can be achieved.

The lessons taken from the above detailed exercise can then be carried forward to other unit areas for further investigation.

7.2 Prioritization of measures - General

As input for the prioritization process, which results in a shortlist of measures, the following considerations were made:

Stakeholder feedback

Feedback was sought from the Consultative Group during the presentation of intermediate project results of 25th May. During this presentation, the participants were asked to indicate their preference for different measures types. The key results from this survey are:

- The participants placed a significantly higher level of importance (80% / 20%) on domestic freshwater supply (Program 2) over flood protection (Program 1).
- A significantly higher level of importance (75% / 25%) on domestic freshwater supply over increased irrigation for rainfed areas.
- More importance on prioritizing measures under Program 1 by the number of people affected over economic damages (60% / 40%).
- More importance on rehabilitating existing ponds over introducing new rainwater harvesting measures at household / community level (70% / 30%).

A final stakeholder consultation session took place on July 14, 2020 in which the 55 participants used the online *Mentimeter* tool to score the importance of for example cost/benefit ratios in prioritization, but also to vote on preferred types of measures and focus of unit areas for measures. The detailed outputs of the session are included in the Appendix A.

Relative benefit / cost ratio provides insight in the cost efficiency of the measures

- Program 1: The dike strengthening requirements and benefits for each Unit Area has been translated into a benefit / cost ratio. Many of the benefit / cost ratios are very high due to the reasons explained in Chapter 6. The measures are prioritized in the first instance using the benefit / cost ratio.
- Program 2: A quantitative benefit / cost ratio has not been determined for these measures, but instead a cost estimate of water supply per person has been made. This cost estimate provides a basis of understanding which measure can supply water to a given population for the lowest cost and therefore a higher proportion of the population can be served with the same investment.
- Program 3: Investing in more irrigated agriculture by adjusting the existing waterways network in unit area 8, gives opportunities to increase farmer's income and at the same time alleviate pluvial flood risks.

Safeguards

Safeguards (see Appendix C) are important when implementing measures. The measures proposed in the weakest links program will result in the widening and height increase of existing dikes and the construction of new structures or rehabilitation of existing structures across the open channels. Environmental issues are most likely triggered, and these would need to be managed under an appropriate ESIA. Safeguards must be made to prevent saltwater intrusion when deepening channels. No significant safeguards are expected to be triggered, especially because the regular beneficial flooding can be maintained. The measures proposed under the Freshwater Supply Program are not expected to result in significant safeguards issues. Safeguards will therefore not be considered further in the prioritization of the measures.

Opportunities to be implemented on short term (months, years)

The construction of the measures proposed under Programs 1 and 2 are all considered appropriate for construction using local engineering techniques and labor. From a construction perspective, these measures are therefore all considered feasible for construction in the short term.

The feasibility to construct in the short term may however be hindered by land acquisition requirements, particularly where dike construction may encroach with the boundary of private landowners under Program 1. This is similarly the case under Program 2, where land may need to be acquired to permit the placement of the ponds centrally within populated areas. Knowledge of land ownership across the Yangon Region, and how it interacts with the proposed measures, is not available in sufficient detail at this stage. Therefore, this consideration does not provide additional insights to prioritize measures.

Cost recovery

The cost recovery for both dike strengthening and increased domestic water supply is most likely to be attained through internal tax revenues. Given this form of cost recovery is common to both Program 1 and 2, this will not be considered further in the prioritization.

Synergy opportunities

Different unit areas provide different synergy opportunities. Dike strengthening and the related outfall structures in the creeks that are still open in the present situation, pose opportunities to be aligned with drainage improvement and use of the drainage canals as freshwater storage as illustrated for Unit Area 8. It is therefore recommended to always consider all options of combining measures from the three programs before deciding on the final detailed design of measures.

Quantitative impact hydraulic indicators

A key element of the RWSS methodology is that proposed measures are analyzed on their potential (cumulative) impacts on the water security. Below, the impact of the implementation of the full weakest link restoration program is described. The targeted level of safety per unit, based on the cost-benefit analysis as performed for Program 1, and explained in Section 6.1) is summarized in Table 107 below.

Table 107: Optimum flood protection level per Unit

Unit	Optimum flood protection level
UNIT 01	100
UNIT 02	200
UNIT 03	200
UNIT 04	200
UNIT 05	200
UNIT 06	200
UNIT 07	200
UNIT 08	200
UNIT 10	200
UNIT 13	200
UNIT 14	200
UNIT 15	200
UNIT 18	50

In Figure 104 and Figure 105 below, an overview is given of the extent of the required dike reinforcements along the dike sections of unit 3 and unit 13 respectively, in order to attain their optimum flood protection level. The green graph shows the current (filtered) crest height along the unit and the purple graph shows the computed crest height to attain the optimal flood protection level, including a safety margin of 0.3 m.

The dike reinforcement of unit 3 is dominated by fluvial flooding. Over a length of nearly 66 km of the total of 94 km, an average increase in crest height of 0.89 m is required. Conversely, the dike reinforcement of unit 10 is dominated by coastal flooding. Over a length of nearly 13 km of the total of 29 km, an average increase in crest height of 0.51 m is required.

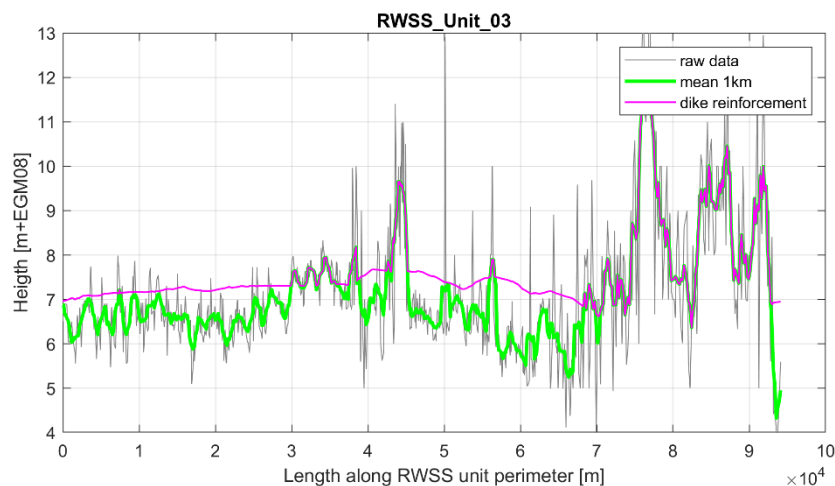


Figure 104: Overview of the dike reinforcement along Unit 03 in order to attain a flood protection level of RP200

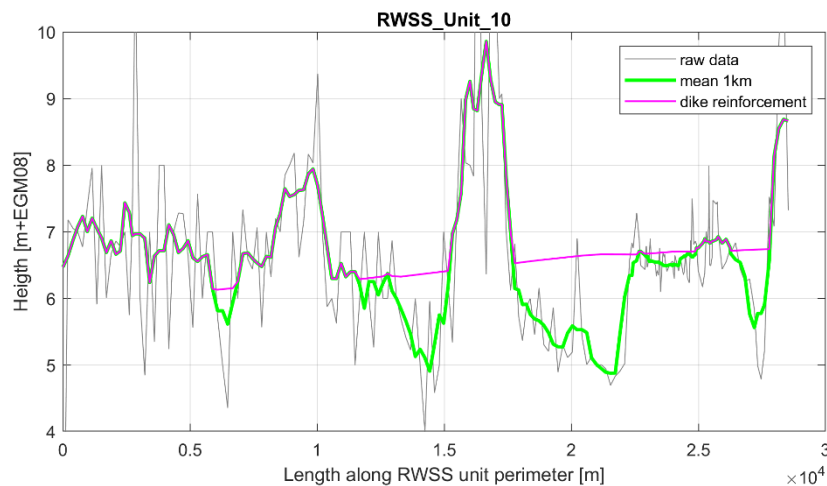


Figure 105: Overview of the dike reinforcement along Unit 10 in order to attain a flood protection level of RP200

After the implementation of the adjusted dike heights, both the fluvial and coastal scenarios, representative for the year 2040, were simulated again by running the RWSS model. The computed peak flooding levels for the RP200 condition, before and after the implementation of the dike reinforcement, have been collected in *Table 108* (fluvial flooding) and *Table 109* (coastal flooding). The resulting flood levels have increased in the range of 0.10 and 0.35 m. This increase is the result of smaller cross-sectional areas within the rivers and loss of flood retention. After all, many dikes no longer overflow and (temporarily) inundate the adjacent units, effectively storing water. This volume now needs to be conveyed through the rivers, on top of the water that is already present, further increasing the flood levels. This illustrates the fact that flooding in one area may reduce the flood risk elsewhere. For coastal events, the reduced storage of flood water pushes up the flood levels, and in addition the funneling effect increases due to the narrowing of the conveyance area. In addition, most noticeably for the fluvial event, the backwater effects caused by the local increase, stack up in a cumulative manner going upstream, leading to larger increases for the locations upstream (i.e. Mezali, Nyaungdon). As expected, the fluvial events lead to an increase in flood levels within the upstream part of the delta, whereas coastal events lead to an increase in flood levels within the downstream part. In both cases this is mainly the result of a decrease in retention of water onto the hinterlands. In the coastal section, because all water is kept within the rivers, the funneling is somewhat increased as well. In the mid-section, both events show effects and the governing increase should be considered as such extreme incidents of both events do not occur simultaneously.

Table 108: Water levels for Fluvial flooding (2040)

Fluvial flooding		Flood level [m+EGM] (2040)					
Scenario	Nyaungdon	Mezali	Maubin	KIP	Monkey Point	Twante 3.5M	Elephant Point
RP200 (2040)	9.24	7.75	6.75	4.60	4.23	4.79	4.04
RP200 (2040) + dike reinforcement	9.46	8.02	6.87	4.64	4.26	4.84	4.04
Increase	0.22	0.27	0.12	0.04	0.03	0.05	0.00

Table 109: Water levels for Coastal flooding (2040)

Coastal		Flood level [m+EGM] (2040)					
Scenario	Nyaungdon	Mezali	Maubin	KIP	Monkey Point	Twante 3.5M	Elephant Point
RP200 (2040)	7.74	6.08	5.47	6.27	5.93	5.99	5.24
RP200 (2040) + dike reinforcement	7.74	6.33	5.67	6.43	6.13	6.34	5.32
Increase	0.00	0.25	0.20	0.16	0.20	0.35	0.08

As a result of this increase in flood levels due to the proposed height increase of the dikes, the design flood protection level is not attained for all units included in Program 1, even when using the safety margin of 0.3 m in the design.

In Table 110 an overview is given of the current (i.e. 2040 situation), designed and attained flood protection level per unit, based on the RWSS model results. It can be observed that the dike reinforcement significantly increases the flood protection level of all units. Especially for the coastal flooding event, all units are either at the design flood protection level or close to it. The flood protection level regarding fluvial flooding has also increased significantly. Looking at the table, most coastal units have even attained the designed flood protection level. However, more upstream, the increase of the flood levels and their cumulative backwater effects often result in an attained flood protection level below the designed level.

Table 110: Overview of the current (2040), designed and attained fluvial and coastal protection levels per unit.

Unit	Current flood protection level (fluvial 2040)	Current flood protection level (coastal 2040)	Designed flood protection level	Attained protection (fluvial)	flood level	Attained protection (coastal)	flood level
UNIT 01	2	70	100	52		200	
UNIT 02	2	25	200	93		191	
UNIT 03	2	25	200	84		193	
UNIT 04	2	25	200	98		180	
UNIT 05	2	25	200	149		179	
UNIT 06	39	25	200	180		190	
UNIT 07	2	25	200	200		178	
UNIT 08	15	25	200	200		178	
UNIT 10	200	40	200	200		200	
UNIT 13	35	25	200	200		192	
UNIT 14	200	25	200	200		200	
UNIT 15	2	33	200	114		192	
UNIT 18	2	25	50	200		130	

To compensate for the increase in flood levels because of the dike reinforcement itself, one could opt for a larger safety margin. A value of 0.6 m or more would result in an attained flood protection equal or larger than the calculated optimum flood protection level. However, this margin is not really meant to compensate for this effect and must be regarded a safety margin for modelling uncertainties instead. In addition, this would result in an increase in crest level along the whole dike section, whereas only local dike reinforcements might be required. Instead, a second iteration of flood level computations should be performed, again looking to the (increased) peak flooding levels during fluvial and coastal flooding for the design of the crest height, including (another) safety margin of 0.3 m. For reference, when considering the current proposed flood protection, an

average additional crest height of 0.1 m would be needed for 25% of the dike section length to attain the optimal flood protection level for all remaining units.

Table 111 gives estimates for the absolute and relative increase in costs due the additional dike reinforcement to compensate for the flood level increase. It can be observed that the increase in costs is limited to a few percent for most units. However, units 1, 2 and 15 show an increase in costs of 10 to 20%. These units are located upstream and are subject to a relatively large flood level increase due to the (cumulative) backwater effects. This results in a relatively large increase in costs. Considering the high benefit-cost ratio for these units, however, the adjusted design height is still an attractive investment.

Table 111: Absolute and relative increase in costs as a result of flood level increase

Unit	Original Investment costs (without maintenance) (million USD)	2nd order Investment costs to compensate for the cumulative impact (million USD)	2nd order strengthening Length [km]	2 nd order crest level deficit [m]	2 nd order costs as percentage of 1 st order costs
1	13.5	2.8	39	0.24	20.65%
2	7.6	0.8	21	0.15	10.26%
3	13.5	0.6	22	0.13	4.21%
4	17.3	0.2	21	0.05	1.19%
6	10.6	0.0	3	0.03	0.16%
7	23.2	0.2	14	0.07	0.90%
8	32.8	0.6	45	0.07	1.98%
10	1.7	0.0			0.00%
13	9.8	0.0			0.00%
14	7.2	0.0			0.00%
15	1.0	0.1	5	0.14	9.89%
18	7.2	0.0			0.00%

Qualitative impact on environmental indicators

The Weakest Links Program proposes either height increase of existing dikes or construction of new dikes. Both measures could have potential impacts on the environment, and these are described below.

- Fresh-/saltwater gradient: Program 1 is not anticipated to affect the fresh-/saltwater gradient in the rivers surrounding Yangon. Although it is unsure how the construction of the measures will unfold, if the rivers are not blocked from water discharge and intrusion, no effect on the gradient is expected. Therefore, this impact can be scored as negligible (0).
- Sedimentation/Erosion: The changes made by Program 1 are not expected to change sedimentation significantly. Dike reinforcements or the development of new dikes will not block the river flow, and beneficial inundations, with sediment deposition, will still occur, therefore sedimentation can still occur as in the baseline situation and no major concrete solutions are include in the current measures, which could cause sedimentation around these structures. Sedimentation is therefore scored as negligible (0).
- Erosion, as highlighted in the program, can occur in the form of inner dike erosion or sliding. As the newly developed dike profiles are changing the current profile and slope, improvements can be made to reduce these types of erosion. Program 1 is therefore anticipated to improve the situation, rather than worsen it scoring positively on erosion (+).
- Water quality: Operational dikes are not expected to affect water quality of the rivers. Nevertheless, the reinforcement works, or construction of new dikes might have a temporary negative effect on the water quality, by sediment and sand being suspended in the river where construction is occurring. This could temporarily degrade water quality and construction locations. Although the impact is negative (-) the temporary nature of the impact on water quality does make it lightly negative.
- Biodiversity: Although an operational dike might not affect biodiversity significantly, the development of the dike or the area that is replaced by the dike could mean biodiversity is adversely affected. The proposed profile and slope of the new dikes and reinforcements are wider than previous dikes. This could mean that

areas will have to be cleared to complete the construction of these dikes and important areas like parts of mangroves or freshwater vegetation could be removed.

- Next to the clearance of currently vegetated areas, the development of dikes could temporarily affect the water quality due to access sediment and sand being suspended in the river, affecting water quality and increasing turbidity, which could affect fish and sight-hunting animals. These impacts are however temporary and local and will return to normal after construction has been completed. Since clearing of vegetation and potentially biodiverse areas might happen due to dike reinforcement and new dike construction, the measure is scored as negative (-).
- Invasive species: Program 1 is not anticipated to introduce or increase the susceptibility of the area to invasive species.

The Water Availability (storage and supply) Program mainly revolves around increasing rainwater harvesting capacity through storage tanks and the development and improvement of ponds for water storage. As these measures have a slightly different effect on the environment than main environmental factors highlighted by the stakeholders, this review takes on some other factors. Factors such as fresh-/saltwater gradient, sedimentation/erosion, and invasive species are not anticipated to be affected by this program.

- Soil/Groundwater: Improving water storage and increasing the ability to rely on rainwater harvested during the wet season, will be able to reduce the reliance on groundwater pumped by wells. With the increasing urbanization of the Yangon region, an over reliance on groundwater could result into ground subsidence over the longer term. This has been seen in other cities in Asia such as Bangkok, Jakarta and Ho Chi Minh. Limiting groundwater extraction is therefore key in maintaining healthy aquifers and limiting land subsidence. Hence, this factor is scored positive (+).
- Biodiversity: Smaller projects like rainwater harvesting systems are not expected to have an impact on biodiversity. For the development of very large ponds, areas might have to be cleared, which could have a biodiversity impact. Therefore, doing a quick assessment of the area when developing a large pond is advised. Nevertheless, as ponds are limited in size and most ponds are redeveloped, this impact is considered negligible (0).

The Drainage Management and Irrigation Program is mainly related to the closure or alteration of drainage channels. From an environmental point of view, this is not anticipated to significantly change the situation compared to the baseline. Although drainage might be improved, the baseline situation did not have any adverse effects from an environmental point of view before as long as salinity intrusion is prevented. Therefore, the impact of Program 3 on environmental factors, is considered negligible (0).

Qualitative impact on socio-economic indicators

For the proposed Weakest Links Program:

- Flood risk: a major reduction of coastal, fluvial and pluvial flooding can be expected due to the program, positively impacting all socioeconomic functions in the catchment area (units): agriculture, industry and housing (++).
- Water supply: depending on the type and location of the strengthening of flood protection, an impact on water supply may occur. This could be positive, for instance in the case of required constructing of reservoirs (as part of program 2). However, blocking the flow of water may also lead to shortages in water supply further downstream. The impact on water security can therefore be (+/-). Also, potential deteriorating of water quality may occur by closing off parts of the water system.
- Connectivity: constructing or adjusting dikes may to some extent negatively impact the connectivity of the water system in Myanmar, triggering problems further downstream concerning water supply, siltation, erosion etc. (0/-).
- Employment generation: Moderate impact, temporary during construction phase. Natural fertilization through moderate floodings is maintained. Positive structural due to improved protection of socioeconomic functions (households, industry, agriculture) against extremes (++).
- Equity in access: No major changes expected (0).
- Pro-poor/poverty reduction: Given the scores on water supply (water security), employment generation and equity in access, the Weakest Links program is expected to contribute to poverty reduction (+).
- Navigation: navigation can continue, assuming no major blocking of waterways (0).
- Recreation: No impact expected (0).

The overall score on socioeconomic impacts of the Weakest Links program is expected to be positive (+) with a caveat, relating to potential issues of connectivity.

For the Water Availability Program:

- Flood risk: no impact is expected (0).
- Water supply: Improving retention capacity for different water users will benefit all socioeconomic functions (agriculture, households) (+). In the case of constructing major reservoirs or basin development upstream, there may however occur negative impacts on the overall balance of freshwater availability.
- Connectivity: increasing the retention and extraction of water at some point may affect the availability of freshwater supply elsewhere in the system. So there may be negative impact (0/-).
- Employment generation: no major direct employment expected. However induced employment impacts can be expected if e.g. more water is available for agriculture (+) and, in case of basin development upstream for power generation, this impact may be bigger (+/+).
- Equity in access: better access to freshwater supply can be expected (++), depending on how the availability of freshwater will change elsewhere. Building large reservoirs may involve resettlement issues. Furthermore, the impact should be considered in relation to the connectivity issue, mentioned above. Taking all of this into account, the overall score is assessed as (+/+).
- Pro-poor/poverty reduction: Enhancing water supply will generate opportunities for employment as well as improve health conditions (++).
- Navigation: navigation can continue, assuming no major blocking of waterways (0).
- Recreation: depending on location and scale, a positive impact on recreation may be possible (landscaping) (0/+).

The Water Availability Program is expected to generate an overall positive (+) socioeconomic impact with some caveats, relating to potential issues of resettlement and connectivity.

For the Drainage Management and Irrigation Program:

- Flood risk: this program is also meant to offset and/or to enhance the impact of program 1 (Weakest Links) in the sense that essential drainage is taken care of. The impact on flood risk itself would be neutral (0).
- Water supply: No impact expected (0).
- Connectivity: restoring and/or increasing drainage may restore the water system balance that may be affected by program 1 (and perhaps also program 2). This would benefit connectivity (+).
- Employment generation: the construction and operation of the Drainage Management and Irrigation Program would generate some employment. However, the major impact is on enabling additional irrigation. This however must be in balance with potential loss of land for channel widening. No additional structural employment impact is expected (0).
- Equity in access: by balancing connectivity, some positive impact may be expected (0/+).
- Pro-poor/poverty reduction: In view of the score on equity in access, also here some modest positive impact may be expected (0/+).
- Navigation: No impact expected (0).
- Recreation: No impact expected (0).

The overall score on socioeconomic impacts of the Drainage Program is expected to be neutral to modest positive (0/+).

7.3 Prioritization of measures – evaluation

To reach the list of recommended no-regret measures the short lists of the three programs are evaluated using the criteria mentioned in Section 2.3.2 and the general considerations provided in the previous Section 7.2. Synergy between programs and practical implementability play an important role in the final selection of no-regret measures. The priority no-regret measures as these are listed below are merely the project team's suggestions based on analysis and consultations. It is of course only up to the Myanmar government and authorities to decide on priorities.

Investments in freshwater facilities only make sense if these assets are sufficiently protected against damaging floods. The same is true for improved drainage and increased agricultural activities. Similarly, construction of sluices related to the flood protection program may play a functional role for creating freshwater storage in creeks and canals for domestic or agricultural use. As such the combined application of the programs for flood protection, freshwater storage and drainage improvement in a unit is preferred. Such integrated solutions very well fit under an integrated water resources management (IWRM) approach.

This combination of measures improves the well-being and water security in the unit areas by providing the communities with freshwater as well as flood security, which enhances the health and productivity in the rural communities. Unit area 8 seems to offer the best opportunities for combined inter-programmatic measures.

Priority no-regret measures in Eastern part of South Yangon (West) Region (Unit 8)

To achieve the recommended flood protection to a 1 in 200 year event, dike improvements are required mostly along the northern side along Twante Canal and the Yangon River. Additionally, along the southwestern border of this unit area, several solitary stretches of flood defense currently do not meet the 1:200 flood protection level requirement. Flood protection will have most benefits for the expanding area around Dala. CAPEX costs are estimated at 32.8 million USD with a Benefit/Cost ratio of 1.3.

The new or adapted sluices related to the dike improvement program will be designed to allow bidirectional regulated flow to let freshwater in for beneficial flooding and freshwater provision to towns and agriculture. The drainage canal system can then be expanded and equipped with level control structures to enhance drainage during rainfall events, but also to distribute and store the freshwater for domestic and agriculture use. No CAPEX estimate is available for the drainage program due to lack of detailed local data.

Towns and communities will be equipped with freshwater storage and distribution measures suitable to the type and location of the community, making optimal use of rainwater harvesting possibilities and the improved drainage system. Estimated CAPEX costs of the freshwater programs total almost 60 million USD for unit 8 as shown in the table below.

Table 112: Freshwater program CAPEX and Cumulative CAPEX

Freshwater program		CAPEX Cost (Million USD)	CAPEX Cost Cumulative (Million USD)
Kawhmu and Kungyangon Towns			
Rehabilitation of existing ponds + new ponds + distribution network	Kawhmu	3.7	3.7
	Kungyangon	6.7	10.4
Village level			
New lined pond (500 m³) + tarpaulin roof + distribution network on neighborhood level.	Unit Area 8	23.0	33.4
Household Level			
Rainwater harvesting roof + storage tank	Unit Area 8	26.0	59.4

Priority no-regret measures for Pan Hlaing Island (Units 3 and 6)

Pan Hlaing Island will benefit significantly from dike improvements that increase its flood safety level to a 1 in 200 year event. The agricultural production is already benefitting from Mezali sluice freshwater delivery in the dry season, and the eastern part of the Island is urbanizing rapidly. So, the value of agricultural, domestic and industrial assets is high and is expected to increase.

Dike strengthening is required along the Kokkowa River on the northern part of the island, and in the south-east corner of the island along Pan Hlaing and Hlaing Rivers. Total Capex estimate for the dike improvement program is 17 million USD with a Benefit/Cost ratio of more than 50.

The drainage system is already well developed, but potentially there are lessons learned from the improved drainage program applied in unit 8 that can also benefit this area. It is expected that the Urban and Industrial area in the south-east will benefit from the Greater Yangon urban water supply scheme. Following the recommendations from the Pan Hlaing Vision and Strategy project (Arcadis, 2019), freshwater can be taken from the closed-off Pan Hlaing river to increase the total surface area of irrigated agricultural land. This would greatly improve the living standards of those farmers who now can only produce one crop per year.

Priority no-regret measures for Nyaungdon Island (Units 4, 5 and 7)

Nyaungdon Island extends from the Ayeyarwady River in the west to the new proposed urban area of New Yangon City in the east. When assessed individually both unit 4 (in the west), and unit 7 (New Yangon City), show benefit-cost ratios that would suggest a 1 in 200 year protection level. Unit 5 would require relatively long stretched of dike improvement that would justify a 1 in 50 year protection only. Interconnectivity between the units, however, implies that a unit can only be protected against flooding if the other units are also protected. Therefore, the complete island is recommended to be protected at a 1 in 200 year protection level.

Dike improvements are required along most of its western (Ayeyarwady and Toe River), southern (Twante Canal) and eastern (Hlaing and Pan Hlaing River till cofferdam) boundaries. This would require a CAPEX of about 76 million USD and has an overall benefit-cost ratio of around 9. Part of this investment is expected to be provided by the New Yangon City Development Corporation, which means that the planning and timing of the dike program for the islands needs to be well coordinated between the private and public investors.

The drainage system is already well developed, but potentially there are lessons learned from the improved drainage program applied in unit 8 that can also benefit this area. It is expected that the Urban and Industrial area of New Yangon City will benefit from the Greater Yangon urban water supply scheme, or will develop its own freshwater supply, but the rural communities will benefit greatly from the proposed freshwater program in this area.

Table 113: Current and proposed flood protection per unit area and cost-benefit ratios

Unit Area	Current Flood Protection level Fluvial	Current Flood Protection Level Coastal	Proposed Flood Protection Level	CAPEX Cost (Million USD)	B / C Ratio (for Land use 2040 scenario)	Annual Affected People Before / After
UNIT_01	<1:2	1:70	100	17.6	4.5	20905 / 1024
UNIT_02	<1:2	<1:25	200	9.9	8.8	2087 / 147
UNIT_10	>1:200	1:40	200	1.8	5.3	113 / 70
UNIT_15	<1:2	1:33	200	1.4	26.9	230 / 136
UNIT_18	<1:2	<1:25	50	7.1	4.3	13260 / 922

Other unit areas

Outside the three above-mentioned focus areas, other unit areas are suggested to be considered for dike improvement based on the large number of people potentially affected by floods and/or the high benefits (lower potential economic damage) relative to the required implementation costs. All these other units already have access to freshwater in surrounding rivers and internal drains and canals. However, individual communities may still benefit from some of the same no-regret measures as proposed in Program 2.

An overview of the above no regret measures is listed in Table 114. This list may serve as a basis for decision-makers in Myanmar and to develop an investment program for the three Programs.

Table 114: Proposed prioritization of no-regret measures

Unit Area	Program	Purpose of measure	Target	Benefit / Cost Ratio	CAPEX (USD M)	See Detailed FactSheet	Owner
8	1 – Strengthening of Dikes	Increase flood protection by: - by raising the ring dike where required - closing open channels through the ring dike where required - increasing the flow capacity of existing closures through ring dike	1 in 200 year flood	1.3	32.8	1.1.U8 3.5.U8	
8	2 – Water Supply for Domestic Purposes	Increase rural domestic water supply for Kungyangon and Kawhmu by rehabilitating or constructing new lined ponds.	100l / day / household	-	10.4	2.1	
8	2 – Water Supply for Domestic Purposes	Increase rural domestic water supply for villages through rainwater harvesting at neighborhood level.	100l / day / household	-	23.0	2.2	
8	2 – Water Supply for Domestic Purposes	Increase rural domestic water supply for individual households through rainwater harvesting at household level	100l / day / household	-	26.0	2.3	
8	3 – Drainage Management and Irrigation	Increase water supply for irrigation by: - Widening and deepening channels - Excavating new ponds - Installing sluices or weirs to regulate flow through drainage channels	2 crops per year	TBC	TBC	TBC	
3	1 – Strengthening of Dikes	Increase flood protection by: - by raising the ring dike where required - closing open channels through the ring dike where required - increasing the flow capacity of existing closures through ring dike	1 in 200 year flood	96.1	8.6	1.1 U3 3.1 U3	
6				9.7	8.4	1.1 U6 3.3 U6	
4	1 – Strengthening of Dikes	Increase flood protection by: - by raising the ring dike where required - closing open channels through the ring dike where required - increasing the flow capacity of existing closures through ring dike	1 in 200 year flood	11.3	18.6	1.1 U4 3.2 U4	
5				0.8	33.8	1.1 U5	
7*				20.1	23.2	1.1 U7 3.4 U7	
5	2 – Water Supply for Domestic Purposes	Increase rural domestic water supply for villages through rainwater harvesting at neighborhood level.	100l / day / household	-	7.5	2.1	
5	2 – Water Supply for Domestic Purposes	Increase rural domestic water supply for individual households through rainwater harvesting at household level	100l / day / household	-	11.5	2.2	

Unit Area	Program	Purpose of measure	Target	Benefit / Cost Ratio	CAPEX (USD M)	See Detailed FactSheet	Owner
7	2 – Water Supply for Domestic Purposes	Increase rural domestic water supply for villages through rainwater harvesting at neighborhood level.	100l / day / household	-	1.5	2.1	
7	2 – Water Supply for Domestic Purposes	Increase rural domestic water supply for individual households through rainwater harvesting at household level	100l / day / household	-	5.5	2.2	
1	1 – Strengthening of Dikes	Increase flood protection by: - by raising the ring dike where required - closing open channels through the ring dike where required - increasing the flow capacity of existing closures through ring dike	1 in 100 year flood	4.5	17.6	1.1 U1	
2			1 in 200 year flood	8.8	9.9	1.1 U2	
10			1 in 200 year flood	5.3	1.8	1.1 U10	
13			1 in 200 year flood	1.7	9.8	1.1 U13	
14			1 in 200 year flood	0.4	7.2	1.1 U14	
15			1 in 200 year flood	26.9	1.4	1.1 U15	
18			1 in 50 year flood	4.3	7.1	1.1 U16	

* Unit 7 is expected to be developed by New Yangon City Development Company Ltd.

Notes:

1. Rural domestic water supply measures on village and household level are likely to be required to an extent at all Unit Areas. However, Unit Areas 5, 7 and 8 have been prioritized and form part of this investment plan as the current shortage of water supply resources and infrastructure are pronounced compared to all other Unit Areas.
2. Prioritization of Unit Areas under Priority 12 will require further stakeholder engagement.
3. Refer detailed factsheets in Appendix C for further information on each measure including steps required to develop the measures to (pre)-feasibility level
4. Lessons learned from implementing measures on Unit 8 (Priorities 1-5) are to be carried forward in a programmatic approach to the subsequent unit areas in a programmatic approach (See Section 8.1)

8 NEXT STEPS

Recommendations for next steps comprise further studies that are required to progress from the current pre-feasibility stage to the feasibility stage. This also includes a short-term action plan and a monitoring plan to assess long term changes and developments in the system and allow decisions to be adapted based on any observed system changes.

8.1 Action plan: from pre-feasibility to feasibility

Recommended next steps to further develop the prioritized no regret measures to a feasibility stage are given below. This further development is necessary to understand the technical, financial, and organizational opportunities and risks for each of the components of the strategy. The implementation of the strategy requires this refinement also to provide confidence to the parties and stakeholders involved regarding the course and direction of the next steps.

8.1.1 Preparation of technical feasibility studies

In this section we explain the next steps for the three programs. As explained in Section 7.3 follow up studies on no regret measures could also focus on specific units or areas. The steps are similar as the described steps below, to implement a complete program.

Program 1 Weakest Links Program

The pre-feasibility study detailed in this report for the reinforcement of existing dikes, provides insights in the weakest sections of the current flood protection system. More detailed and localized information, however, is required to quantify the extent of the proposed no-regret measures. Work undertaken to date needs to be brought to feasibility level. It is recommended to collect more data, refine the assessments, and take on board non-technical aspects derived through the ESIA process which may influence the implementation of the measures.

As the study indicated, heightening dikes at certain locations has an impact on the flood safety elsewhere, in particular further downstream. This means that it is important to consider the whole project area in the next steps and not to focus on a few locations only.

Further Data Collection

Data collection is required on:

- Existing flood defense profiles, i.e. dike crest, toe of trailing and leading slopes, slope gradients,
- Open channels, i.e. dimensions of crossings and peak/low flow characteristics,
- Assessment of existing hydraulic structures (structural, organizational), and
- Land ownership in the area behind the dikes.

Refine assessment

The following steps are recommended:

- The current analysis focusses on overflow/overtopping as normative failure mechanism for adaptation-design of the currently present flood defense system. Based on the data collection, other possibly relevant failure mechanisms are tackled implicitly by conservative design considerations, such as working with a thick clay top layer and more gentle dike slopes. In a feasibility study it is important to extend the flood-probability analysis by explicitly tackling potential additional failure mechanisms like piping and outer dike slope instability.
- Based on the data-collection and extended flood probability analyses, it becomes possible to set up a more detailed and site-specific flood defense design. This needs to be done on the scale of the whole project area so that physical implications of different interventions can be integrated in the design.
- As a result, investment cost quantifications can be updated and possible additional costs can be incorporated as well, for instance related to adaptations to existing hydraulic structures and land-acquisition.

- In the above steps, the allocation of natural or artificial retention areas may be explored to reduce the required dike height in some places. Appropriate land-use and natural values may be managed maintaining the retention function under the 'Room-for-the-River' concept.
- A more detailed cost-benefit analysis is then required, based on the same framework used in this study. The derived cost-optimal investment programs from this study can then be confirmed or adjusted.

The dike strengthening program can be expanded upon to include multi-functional dikes to maximize the benefit of the investment. This may include adapting the dikes for additional purposes such as commercial and/or residential waterfront developments and environmental habitats. Stakeholder consultations are required to assess the most effective form of multi-purposing to be adopted based on planned future land use and community expectations.

Program 2 Water availability (storage and supply)

The concepts developed in this report under the Water availability program provide more generic insights in what may be needed to increase the freshwater availability. More information and more detailed local assessments are needed to reach a feasibility stage of the proposed measures. Compared to the Weakest links Program, the next steps for this program ask for more detailed local studies. These follow-up studies can focus on sub-areas or specific townships and do not necessarily have to consider the whole RWSS project area at once. The following steps are recommended for each of the targeted areas and locations:

Rehabilitation of Kawhmu and Kungyangon Storage Ponds

- Confirm water supply and demand requirements for up to 2040:
 - Undertake baseline study to confirm existing suitable water supply infrastructure capacity, including its condition
 - Confirm unmet domestic water demand up to year 2040.
- Confirm capacity and condition of existing ponds:
 - Catalogue feasible ponds / lakes, investigate land ownership and possibility for domestic water supply use;
 - Detailed inspection of existing ponds / lakes to assess physical conditions and rehabilitation requirements
 - Evaluation of the rainwater catchment areas of the existing ponds / lakes and water supply capacity
- Design Development
 - Undertake conceptual design of water supply ponds (including requirements for any new ponds) and distribution network.
 - Preliminary ESIA, including any impact on existing landowners.
 - Detailed planning and design development

Water supply ponds on village level and tanks on household level (Various Unit Areas)

- Confirm water supply and demand requirements for up to 2040:
 - Undertake baseline study for each village to confirm existing suitable water supply infrastructure capacity, including its condition.
 - Confirm unmet domestic water demand for each village up to year 2040.
- Design Development
 - Undertake conceptual design of water supply ponds and distribution network.
 - Preliminary ESIA (if considered necessary)
 - Detailed design development

Program 3 Drainage Management and Irrigation Program

Conceptual drainage measures to reduce the impact of pluvial flooding events have now been considered for Unit Area 8. Additional data collection is required to fine tune the model (crest heights, land levels, channel alignments and dimensions) and to confirm the possible types of measures.

A water management approach has been conceptualized with the aim of increasing the water supply for irrigation purposes within Unit Area 8. This is likely to involve widening and deepening of existing channels, the installation of flow control structures within or at the end of open channels and the supply of freshwater from Twante Canal and possibly the Yangon River.

The following key steps are considered necessary if this concept is to be considered further and measures developed to a pre-feasibility stage:

- An assessment of the available freshwater supply in the Twante Canal for irrigation purposes
- An assessment of the risks of (saline) groundwater upwelling in case of deepening
- An assessment of potential land ownerships issues in case of widening
- An assessment of the agricultural development possibilities, including possible future cropping patterns, as a basis to determine fresh irrigation water requirements
- A comprehensive analysis of the lower limits of the salt front in the Yangon River (and possibly Toe River) as an additional source of water supply
- Further numerical modelling to investigate the most effective means of distributing the increased water supply across Unit Area 8 to non-irrigated land, including the assessment of flow control structures.
- Comparison of the estimated CAPEX costs for the envisaged measures against the increased land output associated with the increased irrigation. If the business case of is positive, then proceed to the feasibility stage.

The same approach detailed in this report to increase water supply for irrigation in Unit Area 8 can be adopted for the identified irrigated areas across the various Unit Areas (See Section 4.6.2). SOBEK models should be set-up, validated and used for these other Unit Areas to quantify pluvial flooding risks and determine measures to increase drainage and/or increase water supply for irrigation. Such measures would then similarly need to be developed to a pre-feasibility and feasibility stage.

The further development and ultimate implementation of the strategy detailed in the previous three interrelated investment programs yield large economic and socio-economic benefits to communities involved. Based on the outcomes of the next (pre)feasibility stage, an update needs to be prepared on the cost-recovery of the proposed measures and financial sustainability including impacts on ecosystems and disaster risk reduction.

8.1.2 Organizational set-up

Appropriate governance is required for sustainable water management. Close relationships will be required to ensure alignment on roles and responsibilities between the various government departments and stakeholders to ensure that the programmatic approach is executed well.

The successful implementation of the strategy includes investment, planning and design, construction, and operational phases. A clear understanding on roles and responsibilities of the various institutes and stakeholders involved is required with respects to ownership of assets and costs. For each program potential involved government departments have been discussed and identified during the stakeholder workshop on July 14, 2020. The following results show a first identification based on online replies of stakeholders and discussions during the session, as shown on the figures.

Program 1 (weakest links) appears to be most relevant for IWUMD, DWIR, Yangon Region and YCDC. Actual roles and responsibilities should be discussed in the follow up of this project.



Figure 106: Proposed involvement of government departments for program 1 (RWSS Stakeholders workshop 14 July 2020)



Figure 107: Proposed involvement of stakeholders for program 2 (RWSS Stakeholders workshop 14 July 2020)

Program 2 (water availability) appears to be most relevant for DRD, YCDC and the Regional Government and somewhat for IWUMD and DWIR. Suggested involvement of NGOs, GAD, local representatives, and communities in this program is to be noticed. Actual roles and responsibilities could be discussed in the follow up of this project.

Program 3 (Drainage Management and Irrigation) appears to be most relevant for IWUMD and Yangon Region Government, and somewhat for DOA, DWIR and GAD. Actual roles and responsibilities could be discussed in the follow up of this project.



Figure 108: Proposed involvement of stakeholders for program 3 (RWSS Stakeholders workshop 14 July 2020)

Programmatic Approach

A combination of measures into an integrated program as suggested in Section 7.3 has the following benefits:

- It provides an opportunity to integrate the measures. For example:
 - Under Unit Area 8, dike reinforcements could be integrated with additional open channel closings to increase freshwater supply for irrigation along the eastern boundary of the Unit Area.
 - Under Unit Area 8, control structures could be integrated in the drainage channels near Kawhmu and Kungyangon to temporality store pluvial water as a water supply source for the rehabilitated water supply ponds.
- It provides an opportunity to learn as measures are implemented from one Unit Area to another Unit Area. This can mitigate the risk of replicating errors or omissions in design approaches from one-unit area to another. Conversely, it allows positive learnings to be replicated.
- This would require consideration of a Program Office, which requires an appropriate governance structure. During a workshop many suggestions for non-structural measures were given related to capacity building, planning, governance, monitoring and data management (Appendix A).

8.2 Monitoring Plan

No-regret measures can be taken up immediately. For the medium/long term, additional measures have to be defined within the then prevailing or expected socio-economic and physical conditions. This means that a regular update of the study and defined measures is needed. In the Netherlands this is done every six years.

Such regular evaluating and updating of the strategy requires focused and continuous monitoring. In the Yangon region the main factors to be monitored are sea level rise, river discharge statistics, and changes in the planned social-economic development that will change the Benefit-Cost ratio for measures

It is recommended to reassess the flood safety situation every five years by calculating the relevant indicators using renewed time-series of data and recalculation of the benefit-cost ratio using updated risk data. Five years because of the relatively rapid economic developments that are expected.

Recommendations are made below with respects to monitoring key locations (including key developments) within the modelled subject area as part of the basic land and water resources monitoring system. The key objectives of the monitoring plan are to:

- Provide a basis to update the numerical hydrodynamic model over the long term and as a decision support tool in the future. This is particularly important as changing conditions of climate change are observed.
- Monitoring the overall system to assess trigger points that would instigate the implementation or change to a proposed measure.
- The main items that are recommended to be monitored are detailed in the table below. Further detailing of these will be required.

Table 115: Elements of a monitoring plan

Item	Description	Related to
Fluvial Flooding	River flood levels affected by climate change	Program 1 – flood levels relative to dike crest level
Coastal Flooding	Coastal flood levels affected by climate change	Program 1 – flood levels relative to dike crest level
Rainfall Intensity	Rainfall intensity affected by climate change	Program 3 – capacity of internal drainage channels and outlet structures through dikes
Saltwater Intrusion	Saltwater intrusion concentration levels, particularly within the rivers surrounding unit areas where current rural water supply for domestic and irrigation use is through river and groundwater extraction	Program 2 – rural water supply for domestic and irrigation use through river and groundwater extraction
Urbanization	Rate of urbanization against the JICA report from which estimated damages in the risk assessment and consequential benefit / cost ratios have been derived.	Program 1 and 3 – protection of urbanized areas through increased flood protection
Expansion JCDC water supply network	Expansion of JCDC water supply network to urbanized areas located near to Yangon City	Program 2 – some urbanized areas have not been considered under Program 2 as they are expected to be connected to the YCDC water supply network in the near future i.e. Dala, eastern area of Unit Areas 6 and 7.

The Regional Water Security Study is the continuation of a long-lasting journey of the Myanmar people to live sustainably in their Ayeyarwady delta. All proposed measures in this study are no-regret measures and each of them contributes to Myanmar's development targets. By being selective in what can and must be done first, the execution of the three proposed programs is manageable. Based on regular monitoring as indicated above, and after regular re-evaluation of the water security strategy, it is possible to adapt to new circumstances if and when these arise. In this way Myanmar people continue to build on their future: step by step.

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APPENDICES

A Minutes of Meeting

B Technical Interim Report

C Factsheets of program measures

D Inventory of planned measures

E Agriculture demands

APPENDIX A MINUTES OF MEETINGS

The following stakeholder consultations were held:

Mission on Step 1: Evaluation Baseline & Indicators Framework

Step 1: Consultative Group meeting step 1 on 3 December 2019
Step 1: Meeting with IWUMD (MOALI) on 4 December 2019
Step 1: RWSS Step 1 Workshop on 5 December 2019
Step 1: Meeting NGOs and knowledge sector on environmental indicators on 5 December 2019

Mission on Step 2: Water security under present planned interventions and development plans

Step 2: Focus Group Meeting MCEA on 21 January 2020
Step 2: Meeting with Consultative Group on 23 January 2020
Step 2: Meeting with donor community on 23 January 2020

Mission on Step 3 & 4: Water security vision and strategies

Step 3 & 4: Consultative Group meeting step 3 & 4 on 11 March 2020
Step 3 & 4: Regional Water Security Vision 2040 & Interventions Workshop on 13 March 2020
Structural measures are part of the RWSS analysis and report
Summary of non-structural measures suggested by stakeholders on the next pages

Online progress presentations

Progress on improvements of steps 1 to 4 and start of step 5: 11 May 2020
Progress on development of measures of step 5: 25 May 2020

Online Final Stakeholder workshop

RWSS results and interactive *mentimeter* session: 14 July 2020
Minutes on the next pages

Presentations and minutes of above listed meetings are available on request
[*\(tanya.huizer@arcadis.com\)*](mailto:tanya.huizer@arcadis.com)

RWSS Workshop in Yangon, 13 March 2020

Regional Water Security Vision 2040 & Interventions Workshop

Based on the RWSS Workshop on 13 March 2020, participants shared their ideas on required capacity building and awareness raising in relation to water security across the Yangon Region. All measures analyzed in the report are structural while certain enabling and non-structural measures would be relevant in realizing the objectives of the strategy. Such non-structural measures would result in improved functioning of the structural measures with more benefits to water security across the Yangon Region in the long term.

A brief summary of some of the key ideas is provided below. The messages from the stakeholders are categorized in four topics focusing on:

- Capacity building and awareness raising;
- Planning, policies and regulations;
- Governance and coordination; and
- Studies, monitoring and data.

Capacity building & awareness raising

Capacity building and awareness-raising are often a first step towards changing people's behavior and could lead to material improvements in water resources use and management. Examples include:

- Awareness of water quality, pollution impacts and solid waste disposal (e.g. in drainage channels or rivers),
- Awareness of reuse/recycling of water, sustainable use of water at household level and storage practices including rainwater harvesting,
- Building knowledge on risks and consequences of fertilizers and pesticides,
- Building capacity on alternative farming systems,

Planning, policies and regulations

- Development of zoning plans, integrated plans towards economic growth for the region, policies and regulations are required to set an enabling environment for IWRM and water security.
- First zoning regulations (what can be constructed and developed where) and then protect against flooding,
- Tax/charges for (ground) water use - change pricing system for water use,
- Implement laws and regulations related to groundwater extraction,
- National groundwater extraction guidelines,
- Rules and regulation for domestic water usage,
- National land use policy,
- Establish groundwater and surface water protection zones,
- Develop masterplans for specific areas such as Nyaungdon Island,
- Alignment of future and initiatives, and
- Multipurpose and integral plan for freshwater combined with recreational opportunities.

Governance and coordination

- Management committee for IWRM / water security at Yangon Regional scale. A regional committee on IWRM could be considered with high level representatives on decision making level but also on civil servant level. As civil servant level prepares content of decisions it could be relevant to appoint one person per relevant regional department so that alignment can take place on both levels,
- Structural and higher-level coordination in the planning and management of land and water resources including involvement of the National Water Resources Committee (NWRC),
- Collaboration between different departments (from different ministries and committees and within ministries and committees) and between different levels (union, regional and city level),
- Formation of water user groups led by related departments,

- Coordination between agriculture and fish production, and
- Coordination and collaboration with local people to implement effective measures together.

Studies, monitoring & data management

- Monitor the aquifer, groundwater levels, quality, and use,
- Monitoring water quality in fishponds, rivers, creeks,
- Soil quality assessments,
- Quantity surveys on irrigation water,
- Mapping and detailed assessment of existing drainage canals, sizes, bed levels, logging (e.g. sedimentation and other potential bottlenecks or obstructions),
- Salinity intrusion survey,
- Detailed assessment on land subsidence in greater Yangon area, and
- Assessments of land use change impacts.

RWSS Final Results, 14 July 2020

Online Workshop for the Regional Water Security Study (RWSS)

1. Introduction

The workshop was arranged as an online conference on 14th July 2020 by using “Microsoft Teams” communication platform. The participants were from government organizations and departments, universities, International financial institutions, national and international companies, and from environmental related NGOs.

The objective of the workshop is to share and discuss the final results of the RWSS project and to receive recommendations from the stakeholders and in particular the RWSS Consultative Group Members, who have been actively participating in all the steps of RWSS.



Figure 1 Some Participants of the online workshop

The agenda was comprised of three parts. The first part included the quick looking back to the broader context, problems and methods of RWSS. The second part was about three proposed programs with measures. The final part were general recommendations of regional water security and discussion of next steps. The last two parts of the workshop included interactive sessions of input, feedback and questions from the stakeholders by interacting with “Mentimeter” real-time voting system.

2. Participation list

A total of 53 persons participated in the workshop.

2.1 Participants list

No	Name	Organization
1	U Aung Myo Khaing	DWIR / AIRBM C3
2	U Zaw Lwin	DWIR
3	Daw Thatoe Nwe Win	DWIR
4	Daw Nu Nu Tin	IWUMD
5	Daw Kyawt Kyawt	IWUMD
6	U Kan Chun	IWUMD
7	U Win Myint Han	DRD
8	Daw Aye Myat Thu	DRD
9	Daw Thwe Naing Oo	YRG, YCDC
10	Daw Tin Tin Kyi	Urban Planning, YCDC
11	Daw Htet Htet Wai	EMA, YCDC
12	U Than Htut	ECD
13	U Kyaw Kyaw Lin	DMH
14	U Myo Min Hlaing	DOF
15	Daw Cho Cho Win	DISI
16	Dr May Thurein Oo	Fisheries Dept, YU
17	Daw Cho Cho Thin	Fisheries Dept, YU
18	U Khin Latt	NWRC Advisory Group / NEPS
19	Tom Kompier	NL Government
20	Johan Heymans	NL Embassy

No	Name	Organization
21	U Aung Myint Oo	NL Embassy
22	Dr Khin Ni Ni Thein	HIC/C1 AIRBM
23	Dr Khin Than Yu	HIC/C1 AIRBM
24	U Phyo Wai Kyaw	HIC/C1 AIRBM
25	U Win Maung	EMC
26	Mr Nabesaka	JICA
27	U Chit Bo Bo Win	JICA
28	U Kyaw Kyaw Myo	MERN
29	Frank van der Valk	WWF
30	Salai Thura Zaw	WWF
31	Eisse Wijma	World Bank
32	Shelly Win	DHI
33	Dr Kyi Pyar Shwe	Training Unit
34	Daw Hnin Thida Htwe	Training Unit
35	Daw Saw Sanda Win	Training Unit

Figure 2 Information of the participants

There are the responses of organization's main interests with regard to Water Security of the participants:

- Flood safety
- Fresh water
- Capacity building
- Disaster Risk Reduction
- Water quality
- Urban Flood and Drinkable water resources
- Flooding impact
- Urban security
- Climate resilience
- Water availability
- Water resources management
- IWRM
- Conservation of river to improve navigation
- Urban economic development
- Purified drinking water for rural people
- Preserving or restoring nature while maintaining people's livelihoods
- Urban flooding and urban water supply
- Sustainable use of fresh water
- Water shortage
- Water security in general
- Conservation river bank, watershed area and aquaculture ecosystem to improve water quality
- Ground water
- Agri, domestic, hydropower, navigation, industrial uses
- Sustainable development
- Irrigation water supply

3.1 Program (1): Weakest Link

The discussion of the program 1 based on the following questions:

1. Ideas or suggestions for program 1 and next steps?
2. Which government organization(s) could play a role in next steps of program 1?

The results are concluded as followings with the responses from the participants and the number of votes. All the voters are regarded as the anonymous.

Ideas or suggestions for program 1 and next steps? (Multiple submissions possible) ARCADIS

Environmental sensitivity mapping for project area

Finance

restore existing infrastructure

Suvey

need to study for feasibility survey

collaboration between is important, to revise policy of YCDC

Collaboration with different levels and ministries

Reclamation of existing sluices

more precise topo data and hydrological data for your analysis

18

Figure 3 Program (1): Responses to the question 1

Ideas or suggestions for program 1 and next steps? (Multiple submissions possible)

ESIA seems very important	multi functional solutions (waterfront)	Collaboration between departments
poor pro	survey	Need to do fesibility study for detail design
Flood risk analysis and regional economic development	land acquisition	Upgrade the water gate

18



Figure 4 Program (1): Responses to the question 1

Which government organisation(s) could play a role in next steps of program 1? (Mention max 3)

ygn gov
 local gov
 doa
 ycdc
 moli
 planning and finance
 regional gov ycdc
 dwir
 dwir regional govt
 local government
 yrg
 irrigation department
 iwumnd
 mopf
 mopfi
 regional government

24



Figure 5 Program (1): Responses to the question 2

3.2 Program (2): Fresh Water Availability

The discussion of the program 2 based on the following questions:

3. Do you have any questions or suggestions for program 2?
4. Who could play a role in next steps of program 2?
5. What should be the most important focus to fulfill rural water demands?

The results are concluded as followings with the responses from the participants and the number of votes. All the voters are regarded as the anonymous.

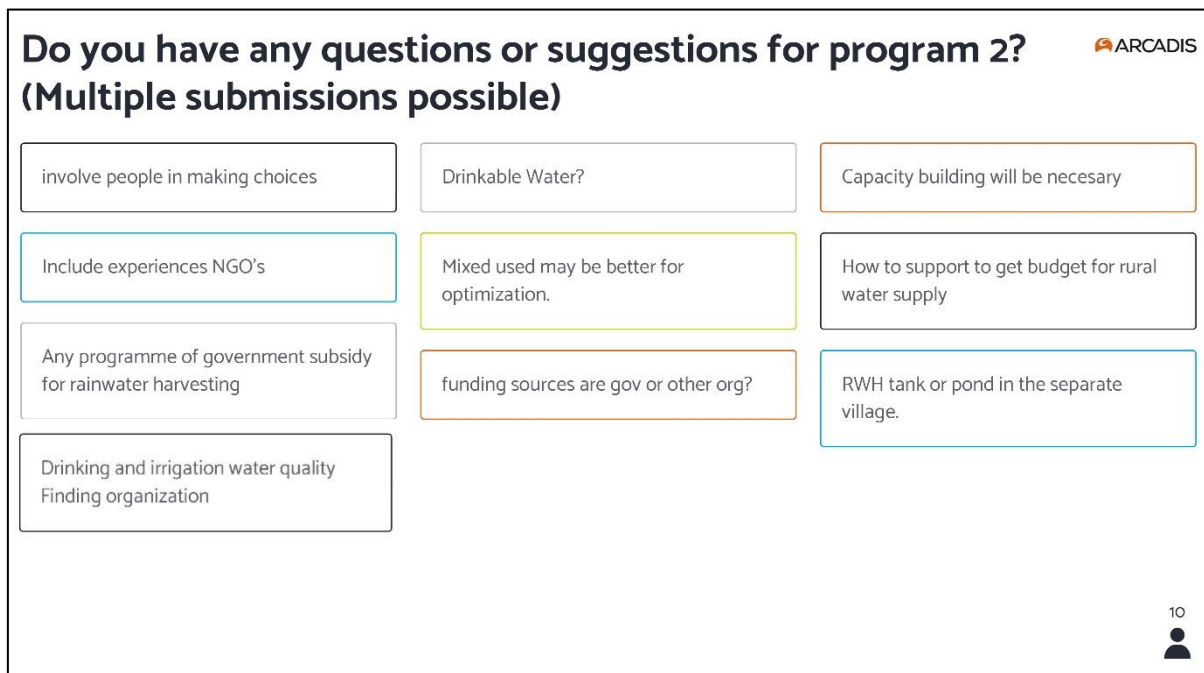


Figure 7 Program (2): Responses to the question 4



Figure 6 Program (2): Responses to the question 5

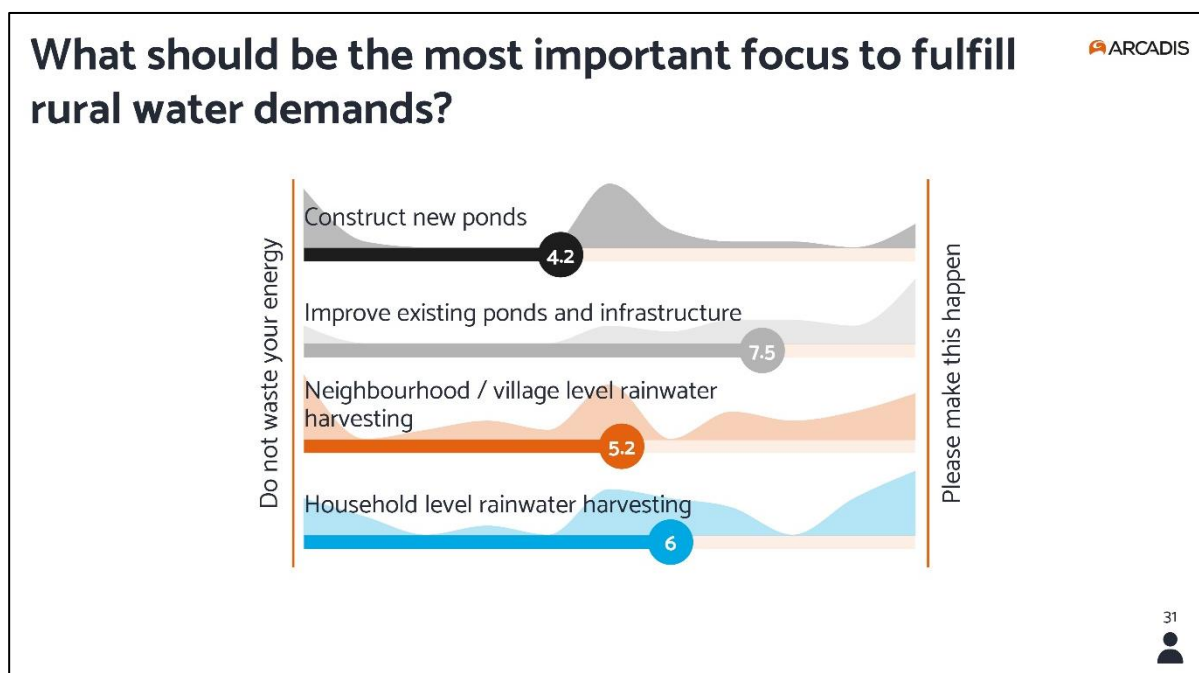


Figure 8 Program (2): Responses to the question 3

3.3 Program (3): Drainage System Improvement

The discussion of the program 2 based on the following questions:

6. Any comments or suggestions for program 3?
7. Which organization(s) could play a role in the next steps of Program 3?

The results are concluded as followings with the responses from the participants and the number of votes. All the voters are regarded as the anonymous.

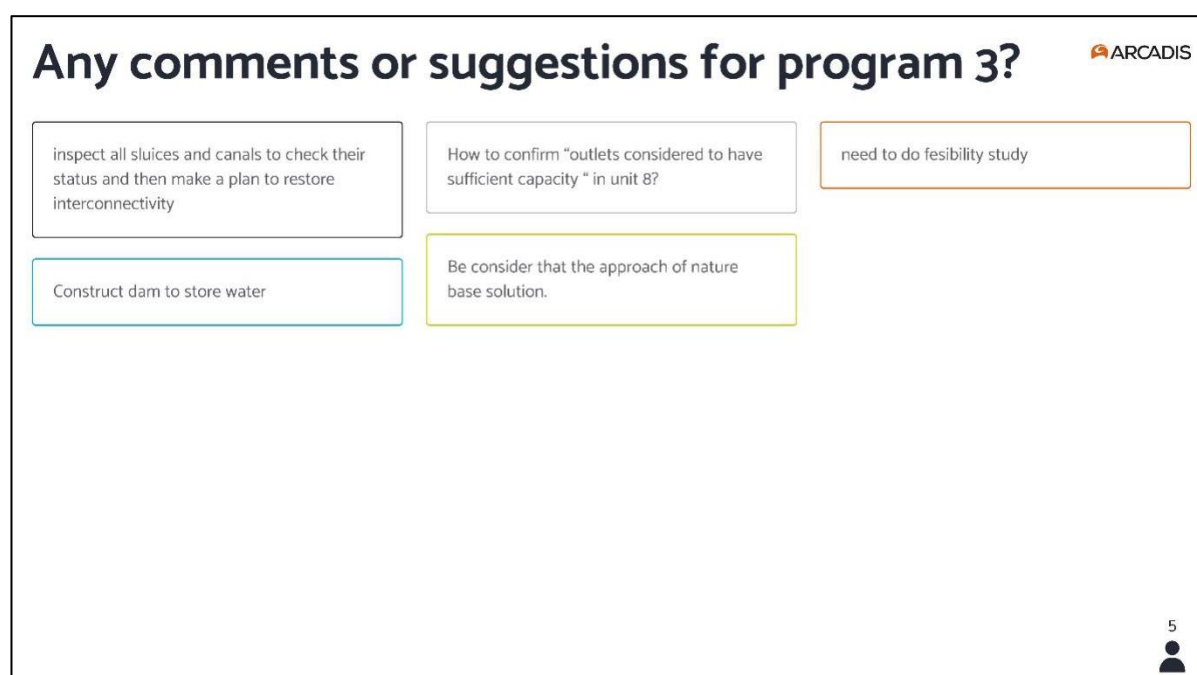


Figure 9 Program (3): Responses to the question 6

Which organisation(s) could play a role in the next steps of Program 3?

ARCADIS



15

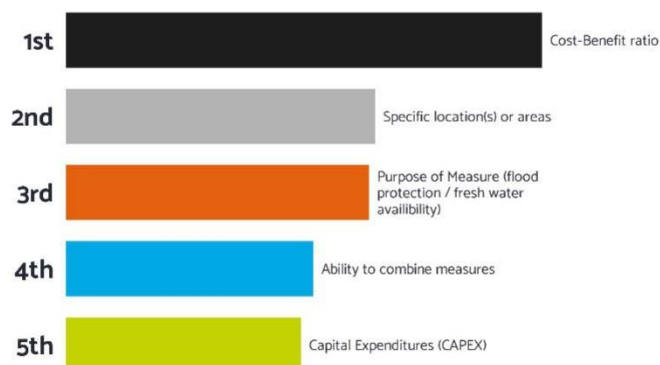
Figure 10 Program (3): Responses to the question 7

3.4 General feedbacks and recommendations for regional water security

The results are concluded as followings with the responses from the participants and the number of votes. All the voters are regarded as the anonymous.

Please rank how you would prioritize different measures? What is most important in prioritization? Top 5

ARCADIS



22

Figure 11 Responses from the participants

Participants response that Cost-Benefit ratio is needed to be prioritize among choosing different measures.

Priorization of P1 by (1) raising the ring dike 2) closing open channels through the ring dike 3) increasing flow capacity of existing closures

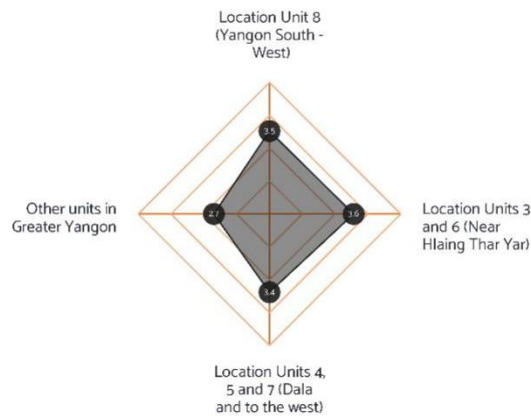


Figure 12 Responses from the participants

By prioritizing some possible locations for program 1, the responses are as follow:

- Participants suggest to focus on Location Units 3 and 6 (Near Hlaing Thar Yar) by the degree 3.6/5
- Participants suggest to focus on Location Units 8 (Yangon South-West) by the degree 3.5/5
- Participants suggest to focus on Location Units 4, 5 and 7 (Dala and to the West) by the degree 3.4/5
- Participants suggest to focus on Other units in Greater Yangon by the degree 2.7/5

It is clear that the locations are all important, no significant differences in scores are shown.

Fresh water supply measures and units prioritization P2

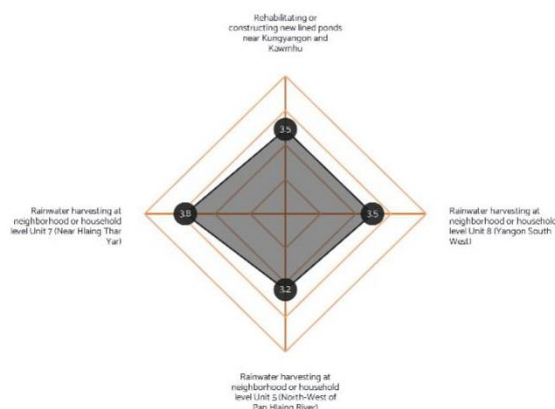


Figure 13 Responses from the participants

By prioritizing measures of program 2, the responses are as follow:

- Participants suggest to focus on Rehabilitating or constructing new lined ponds near Kungyangon and Kawmhu by the degree 3.5/5
- Participants suggest to focus on Rainwater harvesting at neighborhood or household level Unit 8 (Yangon South West) by the degree 3.5/5
- Rainwater harvesting at neighborhood or household level Unit 5 (North-West of Pan Hlaing River) by the degree 3.2/5
- Rainwater harvesting at neighborhood or household level Unit 7 (Near Hlaing Thar Yar) by the degree 3.8/5

It is clear that the locations are all important, no significant differences in scores are shown

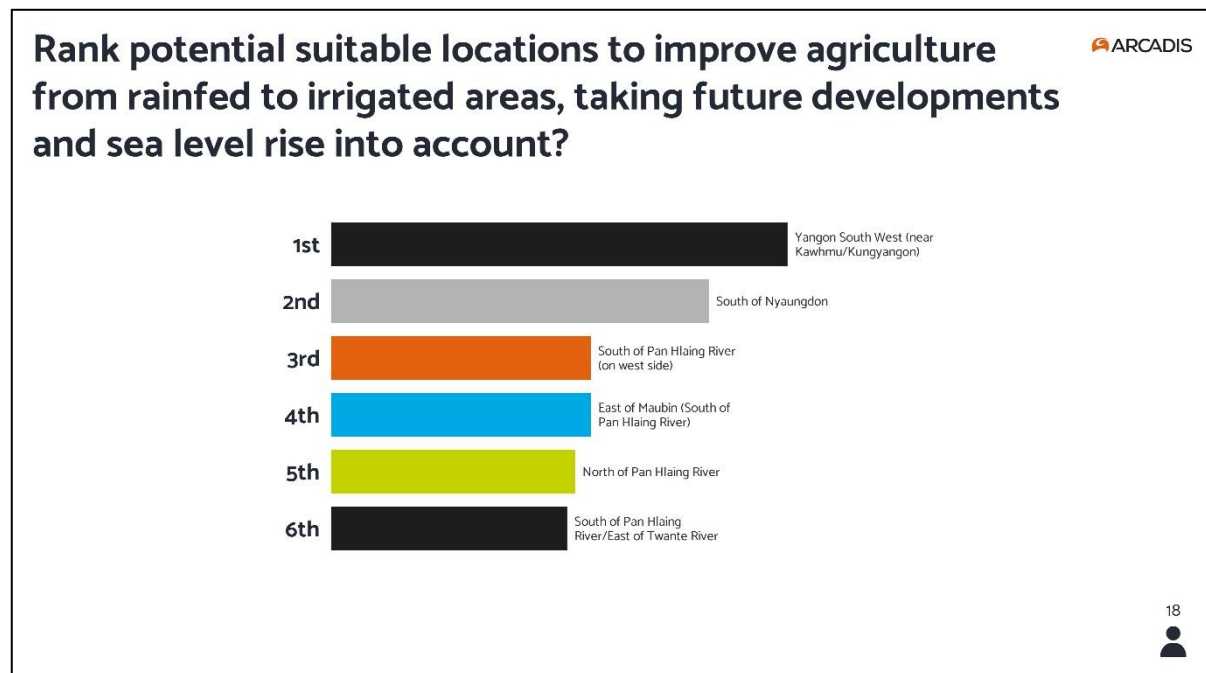


Figure 14 Responses from the participants

With regard to potential suitable locations to improve agriculture production by irrigation, taking into account future developments and sea level rise, the participants response that Yangon South West near Kawmhu/ Kungyangon is the most potential suitable locations. Followed by South of Nyaungdon.

The suggested non-structural measures are expressed in Figure 16 and Figure 15.

What non-structural measures do you suggest? (Multiple submissions possible)



AWARENESS TRAINING	Integrated planning	Public consultation for rain water harvesting
Coordination body to discuss water saving rate among all of stakeholder	proper interdisciplinary collaboration IWRM	Village Book
Land-use, IWRM, DRR	Technical Hydrology Training	Educate local people

13



Figure 16 Responses from the participants

What non-structural measures do you suggest? (Multiple submissions possible)



Committe to decide on prioritization by collabrating all different departmentsData bank	IWRM	should do gap analysis for freshwater of drinking and agricultral purposes
Include spatial planning		

13



Figure 15 Responses from the participants

Participants suggests the most relevant other recommendation (measures) by the following percentages:

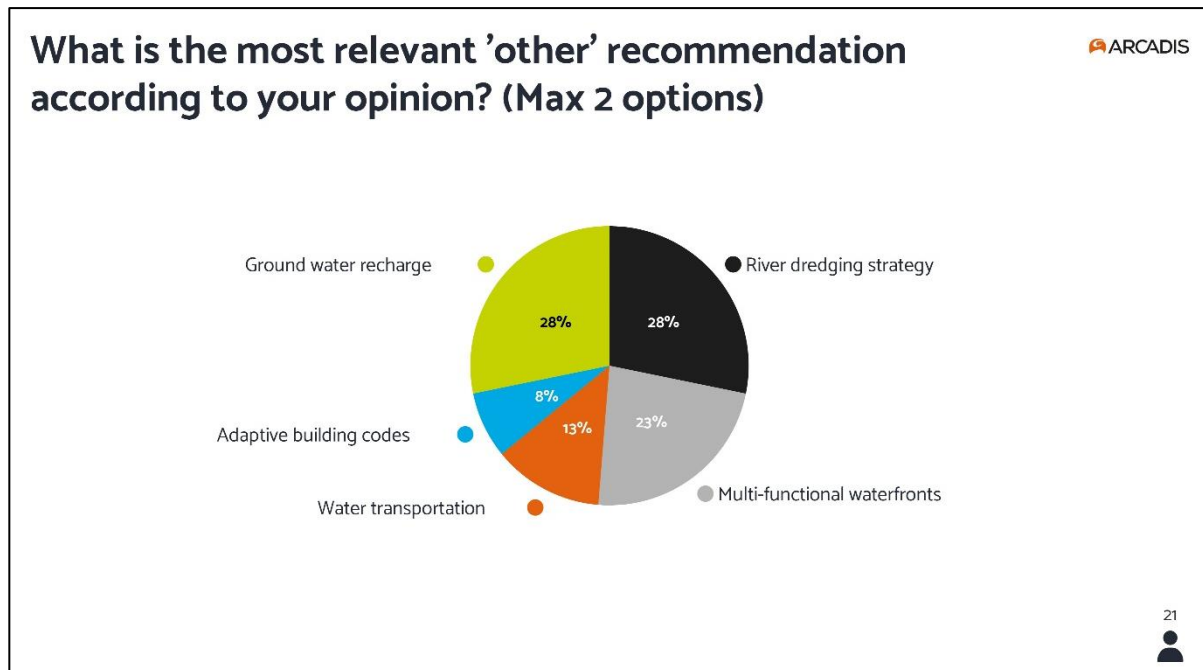


Figure 17 Responses from the participants

- River dredging strategy → 28%
- Ground water recharge → 28%
- Multi-functional waterfronts → 23%
- Water transportation → 13%
- Adaptive building codes → 8%

Any final questions or comments?

ARCADIS

nice work

Thank you

Thank you for the RWSSI!

Thank you

I do prefer to do wide consultation with many people for this important project.

Data bank,Multi lateral dialogue

Thank You

Thank you arcadis for your best effort for rwss

Consultation with stakeholders still needed

10

Figure 18 Responses from the participants

At the end of the session, participants are welcomed to leave any final questions or comments which are describe in Figure 18.

4. Reflection and Closure

Program (1): Weakest Link

IWUMD and YRG could have been a key role in Program 1. DWIR supports in protection bank erosions and dykes and sluices which are implemented or upgraded by IWUMD.

Program 2: Fresh Water Availability

DRD is now implementing the new ponds/ lakes and upgrading the old ones. Groundwater recharge or household rainwater harvesting programs are not implemented so far.

Program 3: Drainage System Improvement

According to the ideas of Program 3, sufficient water for dry season could not be stored in the existing channels even though they are deepened/widened. If Twante canal would be closed with sluice near Dala Township, freshwater can be taken to nearby areas in dry season. Feasibility study will be required when there is a plan to implement the sluices or widen/deepen the channels.

Widening/deepening the existing channels will not solve the problems. Freshwater can be taken only from Toe river and Twante canal whereas the Yangon river is saline. Freshwater goes into the channel to the island which is used as irrigation water while high flood pushes into. So, Feasibility study will be required for that program.

The wetland area is required to be considered. There is no intrusion of saline water into the island previously. Because of the drainage channels which changes the regulation of fresh water and saline water, salt intrusion comes into it and results the wetland area there.

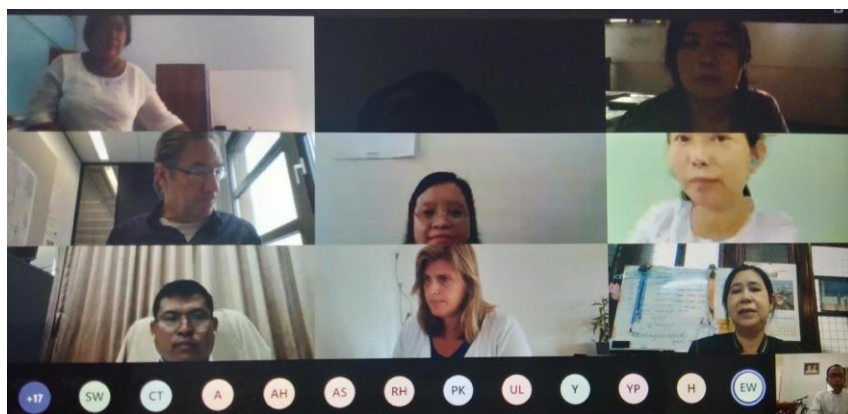
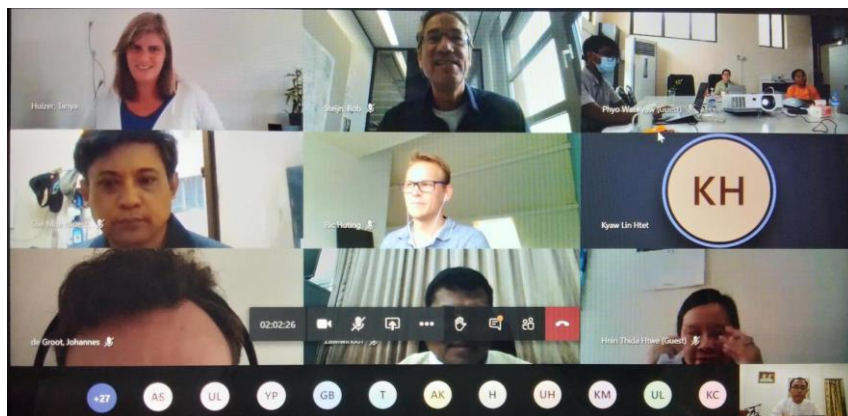


Figure 19 Participants of the online workshop

APPENDIX B

MODEL DEVELOPMENT AND APPLICATION

(UPDATED TECHNICAL INTERIM REPORT – REGIONAL WATER SECURITY STUDY)



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1 INTRODUCTION

The objective of the water security baseline assessment is to understand quantitatively the current water security challenges of the project area. These challenges can for example be related to (a shortage of) freshwater resources for specific functions in the area (such as rice production), or flood hazards that limit economic developments in urban areas. Or a more upstream movement of the salinity front that may jeopardize the (planned) intake of drinking water. After quantifying the baseline water security based on multiple comprehensive extreme events, the Indicator Framework can be used to provide important steering in linking the assessment of the baseline water security to the decision-making process.

1.1 Determining the baseline water security

The current level of water security in the Yangon Region pertains to multiple different threats, occurring under different circumstances. A clear, comprehensive list of extreme events, formed by the occurrence of one or more simultaneous threats, has been composed. The boundary conditions for each of these events is schematized to be used for modelling. The next step is to run the hydrodynamic model suite of the Greater Yangon Region for the current situation while forcing the different events for the current climate scenario. The model output will be assessed quantitatively, which will in turn provide input for the Indicator Framework.

First, the different extreme events will be determined that form the governing conditions for:

- Different types of high water levels and possibly, subsequent inundation;
This requires the simulation of scenarios describing the occurrence of (combined) spring tide, high river discharge, storm surge (e.g. cyclone) and/or extreme rainfall.
- The baseline for (fresh) water scarcity and distribution;
This requires the simulation of scenarios describing typical low river discharges, including all known (fresh) water extractions currently present in the system.
- The baseline for salt intrusion;
This requires the simulation of scenarios describing extremely low river discharges in combination with spring tidal forcing.

Secondly, these events will be schematized for modelling and assessed based on the model results, focusing on the pre-determined water security indicators for this phase; water level, inundation depth, discharge (distribution) and salinity content (PSU).

1.2 Baseline scenarios

The following four extreme events and their respective boundary conditions, have been identified:

1. Riverine flooding high river discharge + spring tide;
2. Freshwater scarcity low river discharge + spring tide;
3. Coastal flooding low river discharge + spring tide + storm surge (e.g. cyclone event);
4. Pluvial flooding average river discharge + spring tide + extreme rainfall event.

These four events cover all different (combinations) of water threats to the Greater Yangon Region. Please note that salinity intrusion is included in the freshwater scarcity event as salinity content is a key indicator for discerning freshwater and brackish-saline water.

The available data used for determining the governing hydrodynamic river conditions in the Greater Yangon Region is based on a timeseries covering the period 1966-2015 (DMH, 2017). This timeseries is applied to perform a statistical analysis for both the high river discharges (high discharge as function of return period and discharge wave shape) and low river discharges (low discharge in combination with persistency as a function of return period).

For each of these extreme events, a brief description is given below.

1.2.1 Fluvial Flooding

Fluvial flooding, also referred to as riverine flooding, is most likely to occur in the middle- and upper delta where high river discharges from upstream will cause a rise of the water level between the embankments.

Severe flooding is most likely to occur in combination with spring tide in the lower parts of the delta, because of the backwater effect of the large tidal amplitude (up to 7 meters).

1.2.2 Water Scarcity

For the extreme event “freshwater scarcity”, the most severe situation occurs during extremely low river discharges from upstream in combination with spring tide. When this situation occurs, the least amount of freshwater is available from upstream, in combination with a relatively large degree of salinity intrusion into the delta, rendering that water unusable for most purposes.

At present, most water that is extracted from the various river branches, is mainly used for irrigation and aquaculture. In the future, however, the demand for freshwater will increase due to the expansion of irrigated areas and more water needs for domestic and industrial purposes.

1.2.3 Pluvial Flooding

The most common kind of flooding that occurs on a regular basis in the Ayeyarwady Delta is pluvial flooding. Due to the large amounts of precipitation during the rainy season and medium to high discharges from upstream, the drainage capacity can be insufficient. An example is urban flooding of Yangon city during spring tide. With high water levels in the river, sluiceways must close, and no water can freely drain into the river. When this occurs in combination with extreme precipitation, large parts of Yangon city will temporarily flood.

1.2.4 Coastal Flooding

Coastal flooding, such as during cyclone Nargis in 2008, can have a tremendous impact on the people who live and work in the Ayeyarwady Delta. Although the probability is smaller, they can have a devastating effect on the region, resulting in a higher risk. The combination of a storm surge, high tide during spring tide and extreme rainfall, results in extreme water levels in the downstream area of the delta. Such events, while occurring less frequently than an isolated extreme rainfall event, represents extreme flooding and therefore the highest probability of a disaster in the southern part of the Yangon Region.

1.3 Reader

The Baseline Assessment report first provides an overview of the applied model boundary conditions, and their derivations, for the four extreme events. The model boundaries are intrinsically related to their geographic location within the model. Data for these locations was then collected from various institutes/resources after which a statistical extreme value analysis was performed to determine return intervals. These return intervals defined the input boundary condition data.

The third chapter describes how the hydrodynamic model was used and which methodology was applied for the analysis of each of the defined extreme events, i.e. Riverine Flooding, Water Scarcity, Pluvial Flooding and Coastal Flooding. The fourth chapter then presents the baseline results for these extreme events from which a water security indication is obtained using the Indicator Framework which links the assessment of the baseline water security to the decision-making process.

The fifth and sixth chapters present the impact analysis of both the climate change scenarios and the considered future interventions, respectively.

The seventh chapter describes the pluvial modelling using SOBEK.

2 BOUNDARY CONDITIONS FOR EXTREME EVENTS

2.1 Description of boundaries

2.1.1 Overview

The hydrodynamic Delft 3D FM model both requires internal and external boundary definitions. For each of the modelled extreme events the boundary conditions are different. In Sections 2.2 through 2.5, for each event separately, a detailed description of these boundary conditions is presented. Below a description of the applicable types of boundary forcing are presented.

2.1.1.1 External Boundaries

River inflow

The model has two independent inflow regions, i.e. at Pyay from the Ayeyarwady River and at Bago from the Bago River. Both inflow boundaries are related to statistically determined return period discharges.

Offshore/sea

At the offshore boundaries the model is forced with spatially varying tidal constituents (amplitudes and phases) from the global tide model FES2012 (Carrère et al., 2012), and a uniform salinity value of 30 ppt. The phase has been adapted to convert to MMT. Furthermore, a correction from MSL to EGM2008 is applied using a shift of 0.35 m along the sea boundaries. No additional surge component was assigned at the boundary. While wind setup at the open boundary can safely be neglected because of the deep water locally (except near the shoreline), the (non-tidal) effect of local pressure will be significant. The impact of this is approximated by adding an Inverse Barometer Correction (IBC) to the tidal water levels forced at the open boundaries. This correction is a function of the time- and space-varying local air pressure.

Meteorological forcing

The meteorological forcing varies per application of the model, but can include wind, atmospheric pressure at sea level, total precipitation and evaporation.

2.1.1.2 Internal Boundaries

River overflow

The model has two internal boundaries that are forced manually. These boundaries represent the branching of the Ayeyarwady River towards Patheingyi river at Htein Taw and the overflow of the Ayeyarwady River at Monywa to the Hlaing River via Hle Seik (Figure 3). These flows are related to the main discharge in the Ayeyarwady river and based on DMH data. Diversion to Hlaing River only occurs during the higher river discharges.

Groundwater flow

Most model boundaries are located within rivers and coastal domains that continue outside the model domain. Hydrodynamic conditions at those boundaries are forced accordingly, as described above. At the boundary for the Upper Hlaing River, to the north of Hle Seik, no clear-cut (river) boundary suffices. As mentioned above, the river discharge is only present in case of overflow from the Ayeyarwady River. However, there still exists discharge at Hle Seik when no overflow is present. This is the result of groundwater flow. Based on the DMH data, a baseline for the groundwater flow is deduced and forced at the model boundary to the north of Hle Seik, in addition to the river discharge.

Structures

The functioning of hydraulic structures (such as the Mezali and Nga Moe Yeik sluices) are forced using timeseries controlling the crest and/or gate heights of these structures.

2.1.2 Visual overview of model domain and boundaries

Three different types of models have been developed with a dedicated computational grid-design ('domain'):

- A. Channel flow model with a domain covering the main river channels within the project area. This domain is meant for channel-flow and does not allow for overland flow. This model can also be used for high discharge simulations without overbank inundation.

For the river domain the grid has been extended 300 km in upstream direction to Pyay. In offshore direction the grid extends 150 km up to a depth of at least 50 m. The grid extension in offshore direction allows for a better inclusion of tidal constituents from the global tide model at deeper water and provides space for the river run-off to be incorporated in the model. The alongshore direction is 600 km by which the other river tributaries could be incorporated in the model as well. The grid is set up in local coordinates, UTM47N. A curvilinear grid has been set-up as basis. The grid resolution increases gradually with decreasing water depth, following the Courant-criterion (Deltares, 2019) and thereby optimizing the time-step of the model simulation. In the coastal and river domain a curvilinear approach was applied to get an optimal grid resolution and alignment to the coastline and rivers. Offshore, grid cells have an average size of 3.5 km and decrease to a minimum size of 200 to 300 m at the transition from coastal area and river domain, leading to a total of approximately 130,000 active flow cells for the combined grid. The resulting grid for the model without overland flow is shown in Figure 1.

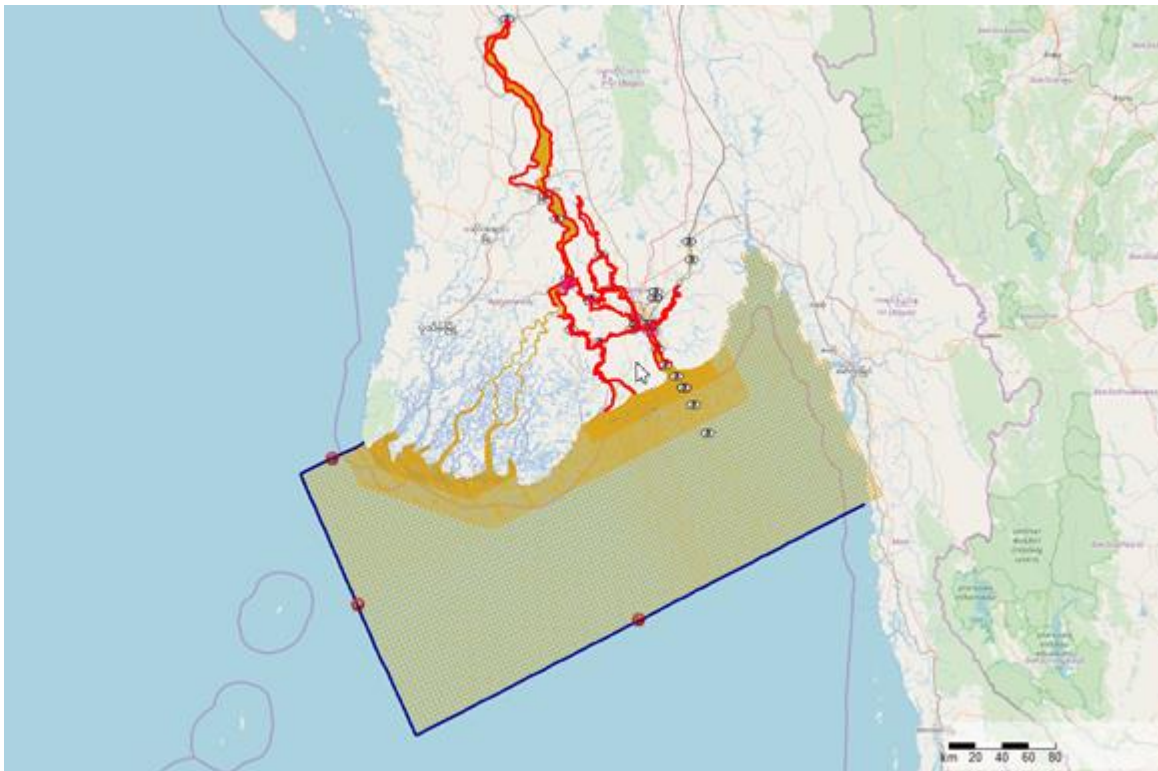


Figure 1: Overview of Delft3D FM grid for the Greater Yangon Region

- B. Overland flow model with a domain covering the main channels and the 'dry' areas in between, at least for the Yangon area. This model allows for simulation of both overland flow and channel flow, including basic rainfall runoff modelling.

The "dry" area in-between and surrounding the river in the 'Channel Flow Model' has been added to the model extent to be able to also simulate overland flow. Therefore, the Channel Flow Model is extended so the grid covers all the area within the model domain (Figure 2).



Figure 2: Model extent including the overland flow grid

C. A dedicated 3-dimensional version of “model A”, to simulate the (3D) intrusion of salt.

The horizontal extent of the grid of the 3D salt intrusion model is identical to the 2D ‘channel flow model’ as the salt intrusion is critical during the dry season (no need to include overland-flow areas). To enable 3D flow, the water column is divided into 20 vertical layers. This is done using the sigma coordinate system in which the thickness of each vertical layer depends on the water depth every timestep. For capturing the vertical profiles and bed and surface boundaries (top and bottom), the layers are finer near the river/ocean bed and the water/sea surface.

Hence, all models are forced with hydrodynamic boundary conditions at identical geographic locations. The model has a tidal forcing along the southern boundary and four upstream river boundaries (Figure 3):

1. Ayeyarwady River at Pyay;
2. Hlaing River near Aing Ka Laung;
3. Bago River at Bago Town;
4. Pazundaung Creek, just upstream of Dagon Myothit.

A further description of boundary conditions is presented in Chapter 2 of this Appendix.

D. Finally, a SOBEK model covering RWSS unit 08 has been set-up specifically for the modelling of pluvial events. This model is explained separately in Chapter 7.

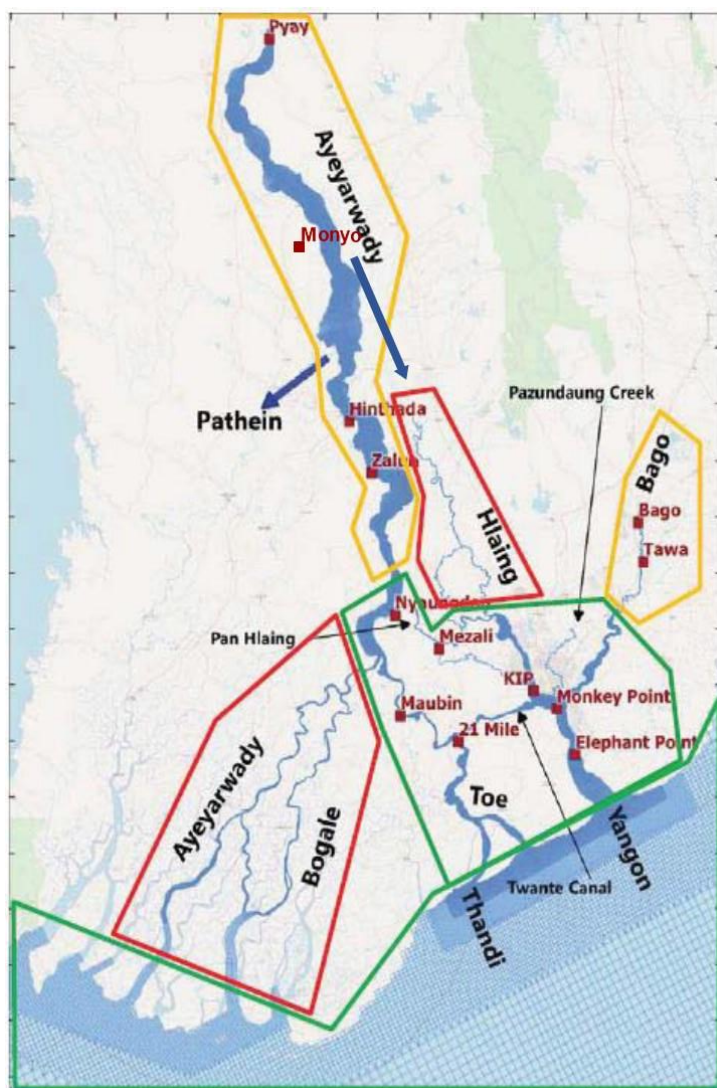


Figure 3: RWSS Project Model and Boundaries

2.1.3 RWSS Units

In order to assess the water security in the large project area, sub-regions are defined. Twenty so called “RWSS Units” are distinguished based on physical boundaries of the river system and land use (Figure 4). The following pragmatic steps are followed to create the RWSS Units with ArcGIS 10.7 software:

1. The project area is set to Yangon Region’s administrative boundary in the north and east and the Ayeyarwady River – Toe River and Pyapon River in the west. The coastline is the boundary of the project area in the south.
2. Within the project area, various elevated areas are present such as the Bago Yoma mountain range. These areas are identified based on SRTM data and used as natural boundaries with low-lying areas.
3. Identification of the main rivers which are part of the RWSS hydrodynamic model. By doing so, areas are identified that are either surrounded by rivers and/or the boundary of the project area.
4. Within the areas defined by step 3, rural and (future) urban areas are distinguished based on land use maps.

The RWSS Units are used to assess the water security for the four extreme events. For riverine and coastal flooding, the weakest point (lowest crest level in relation to the simulated water levels) is determined for every unit to determine the flood risk for that unit. These weakest points – also called “key locations” vary per unit depending on the extreme event that is analyzed. For the water scarcity events, the most downstream water intake points for irrigation are selected. A description of each unit is given in Table 1.

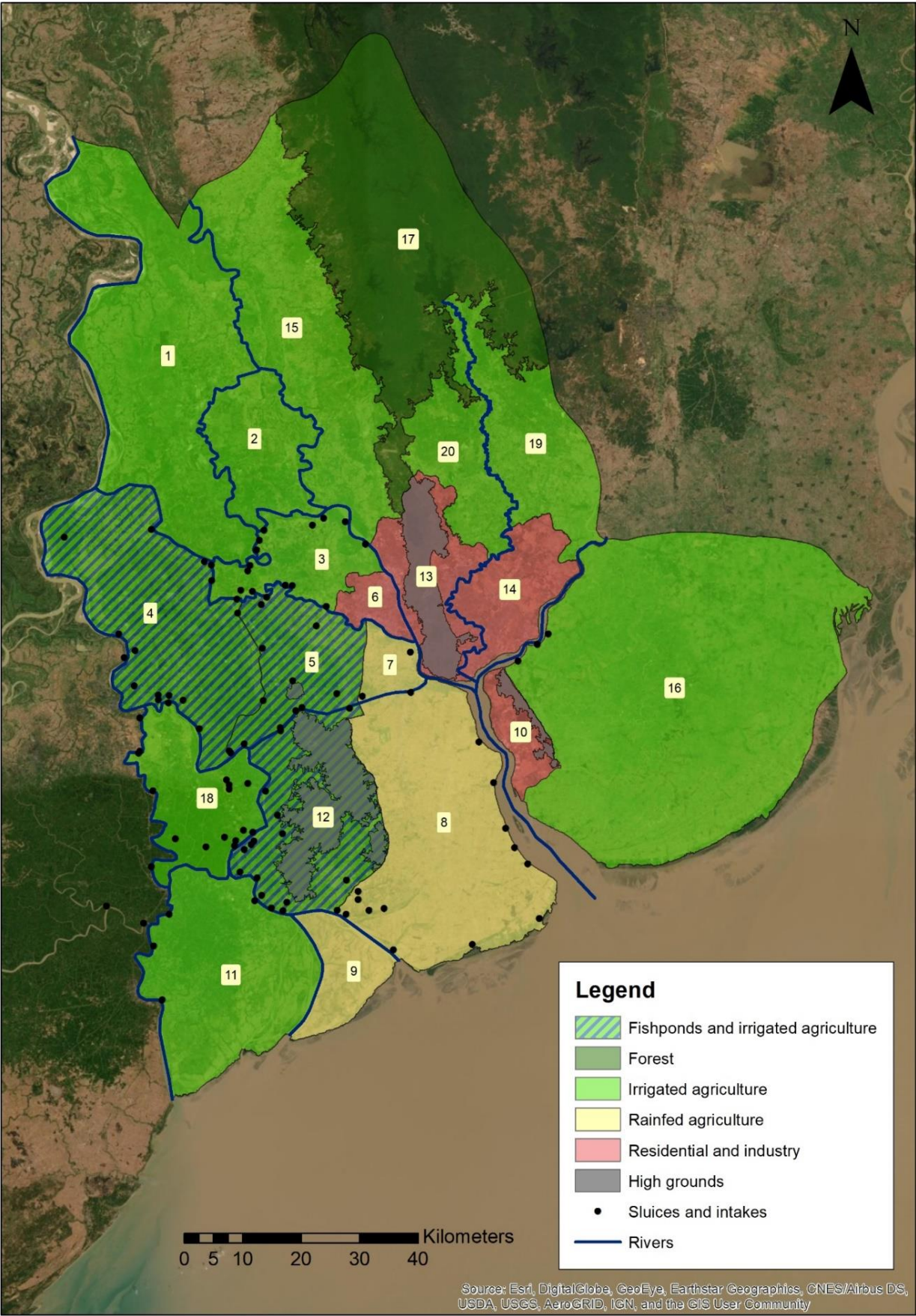


Figure 4: Map with RWSS Unit of the project area

Table 1: Setting, land use and description of the RWSS units

Unit	Setting	Main land use	Description
UNIT_01	Rural	Irrigated agriculture	
UNIT_02	Rural	Irrigated agriculture	
UNIT_03*	Rural	Irrigated agriculture	Urban development in UNIT_06 might continue into this area. Directly related to Pan Hlaing River development. The unit is part of focus area “Pan Hlaing Island” together with unit 6.
UNIT_04*	Rural	Fishponds and irrigated agriculture	Nyaungdon as major town in the north. Main land use in this area is fisheries. Boundary in the east is a small river on natural high grounds (channel deposits). The unit is part of focus area “Nyaungdon Island” together with units 5 and 7.
UNIT_05*	Rural	Fishponds and irrigated agriculture	Main land use in this area is fisheries. In the north the Pan Hlaing River is located, with potential future development. In the west, the boundary is a small river on natural high grounds (channel deposits). The unit is part of focus area “Nyaungdon Island” together with units 4 and 7.
UNIT_06*	Urban	Residential and industry	Hlaing Thar Yar and other industrial zones of Yangon City. The unit is part of focus area “Pan Hlaing Island” together with unit 3.
UNIT_07*	Urban development planned	Rainfed agriculture	Currently rainfed agriculture but in the future this area will be developed under the New Yangon City Phase 1 project. The unit is part of focus area “Nyaungdon Island” together with units 4 and 5.
UNIT_08*	Urban development planned	Rainfed agriculture	Currently rainfed agriculture but in the future this area will be developed under the New Yangon City Phase 2 project. This unit is together with unit 12 part of focus area “Yangon South”.
UNIT_09	Rural	Rainfed agriculture	
UNIT_10	Urban	Residential and industry	Thanlyin Area with industrial and ports developments
UNIT_11	Rural	Irrigated agriculture	
UNIT_12*	Rural	Fishponds and irrigated agriculture	Most of this unit is located on high grounds including Twante village. In the west, the land is used for irrigated agriculture and fisheries. This unit is together with unit 8 part of focus area “Yangon South”.
UNIT_13	Urban	Residential and industry	Urban Yangon (west of Pazundaung River). Most areas are located on higher grounds.
UNIT_14	Urban	Residential and industry	Urban Yangon (east of Pazundaung River).
UNIT_15	Rural	Irrigated agriculture	
UNIT_16	Rural	Irrigated agriculture	
UNIT_17	Higher grounds	Forest	Higher grounds with natural forests and reservoirs for Yangon city
UNIT_18	Rural	Irrigated agriculture	
UNIT_19	Rural	Irrigated agriculture	
UNIT_20	Rural	Irrigated agriculture	

**part of the RWSS focus area*

2.2 Fluvial Flooding Model

For the fluvial flooding model, scaled dynamic high flood waves are imposed as the inflow boundary conditions to the channel flow model and overland flow model.

2.2.1 Data availability

With respect to the fluvial flooding model, representative high flood waves with different recurrence periods were determined based on 50 years of available daily discharge time series data at Pyay (1966-2015) and 46 years of daily discharge time-series data at Bago (1966-2011) as depicted in Figure 5 and Figure 6 respectively. Please note that a climate trend is not considered. It is assumed, like in (RHDHV, 2019), that this time series is representative for the present climate.

The data for Pyay and Bago were obtained from DMH through RHDHV and provides daily discharge values. Discharges were derived from measured water levels using rating curves. These rating curves were derived from water level and discharge measurements covering low, medium and high flow conditions (i.e. a Q-H relationship). The data (discharge measurements) behind the establishment of the Q-H relationship was not available and could therefore not be verified. For the statistical analyzes it has been assumed that the discharge time series are validated and correct.

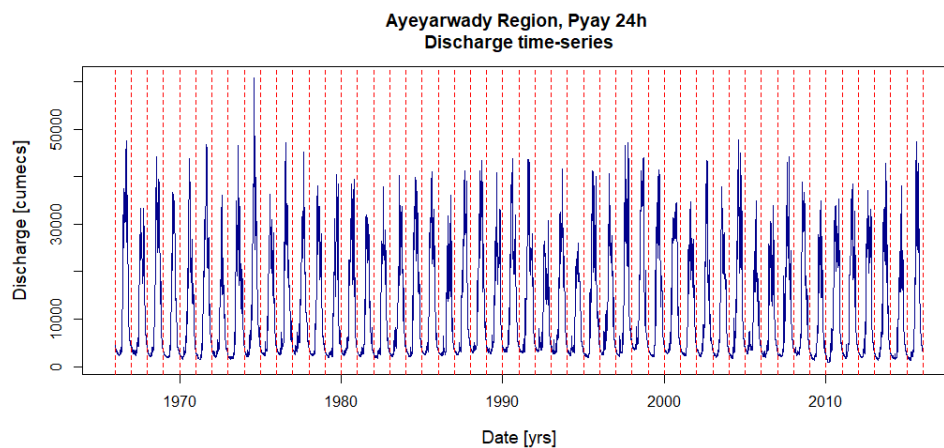


Figure 5: River discharge time-series data for Pyay (1966-2015).

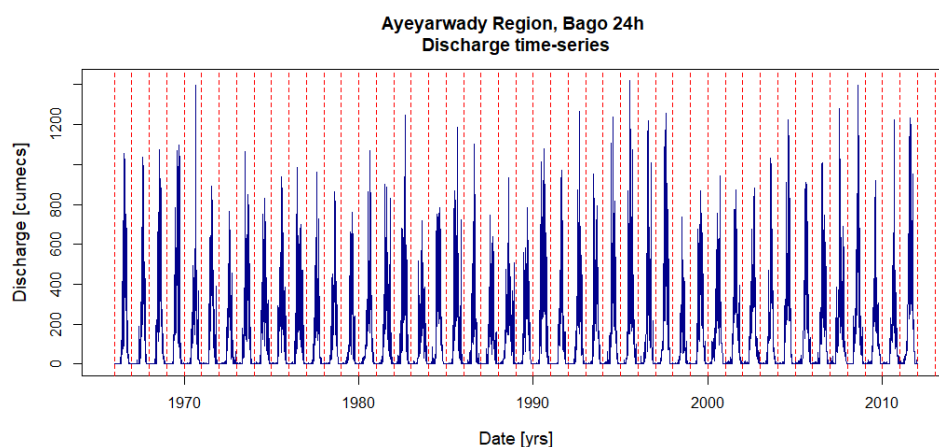


Figure 6: River discharge time-series data for Bago (1966-2011).

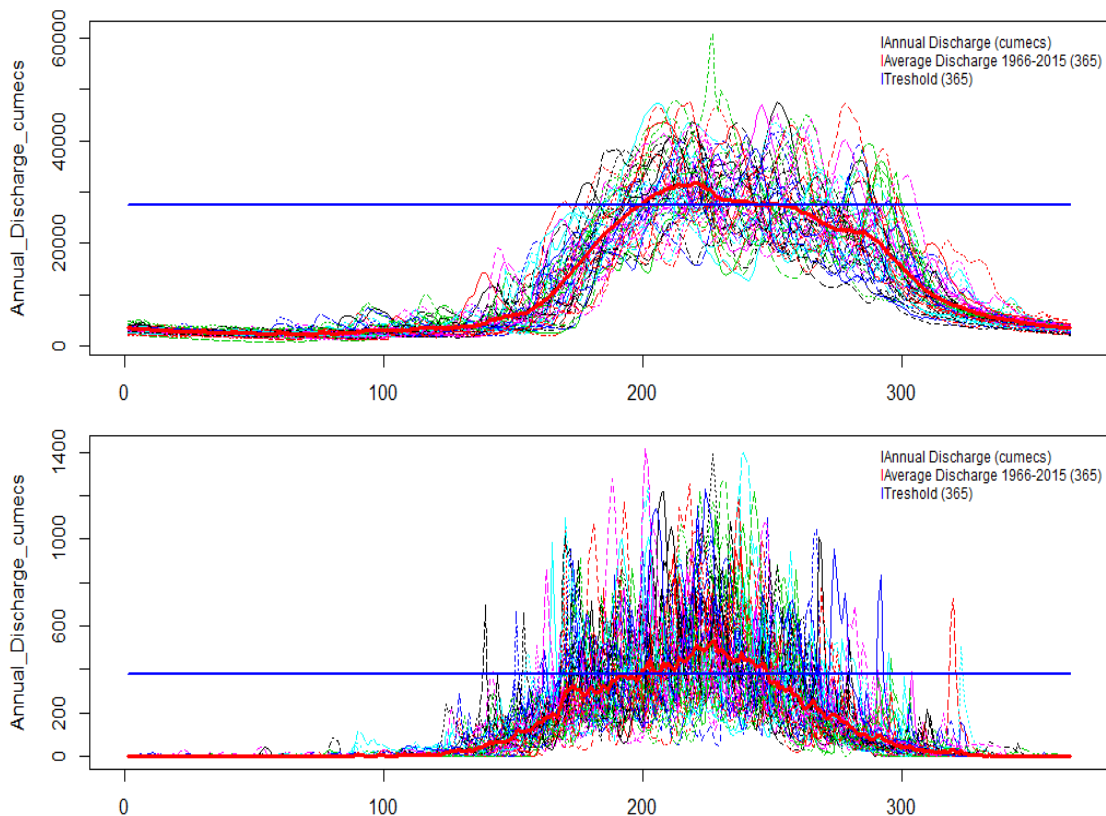


Figure 7: Annual Daily Discharges for Pyay (upper) and Bago (lower).

Based on the available time-series data for the inflow boundary at Pyay and Bago, statistical analyses have been carried out to assess return periods for maximum annual discharges. A representative shape of the flood waves was determined as Figure 7 indicates that there is quite some variation when comparing the annual discharge curves.

For two other key inflow locations, the bifurcation to Patheingyi River and the overflow at Monywa towards Upper Hlaing, data from DMH was available allowing the relation of these discharges to the measured upstream discharge at Pyay to be determined.

For one other key inflow locations, i.e. Pazundaung Creek, no time-series discharge data were available. Therefore, expert judgement was used in order to represent the likely inflow contributions for this inflow location.

2.2.2 Return period

For the riverine flooding extreme event, the river discharge return periods for the Pyay inflow locations was required so that the model output can be related to, and translated into, a recurrence interval for each of the predefined output key locations and/or RWSS units. Therefore, an extreme value analysis of annual maxima was carried out.

2.2.2.1 Return Period Pyay

The river discharge return periods for Pyay were derived from the 50-years of available time-series data using the annual maxima method with a Gringorton plotting position and a Gumbel fit. Figure 8 shows for each year the annual maximum and Figure 9 shows the obtained discharges for given return periods with a 95%-confidence interval. The obtained return periods and their discharges are presented in Table 2.

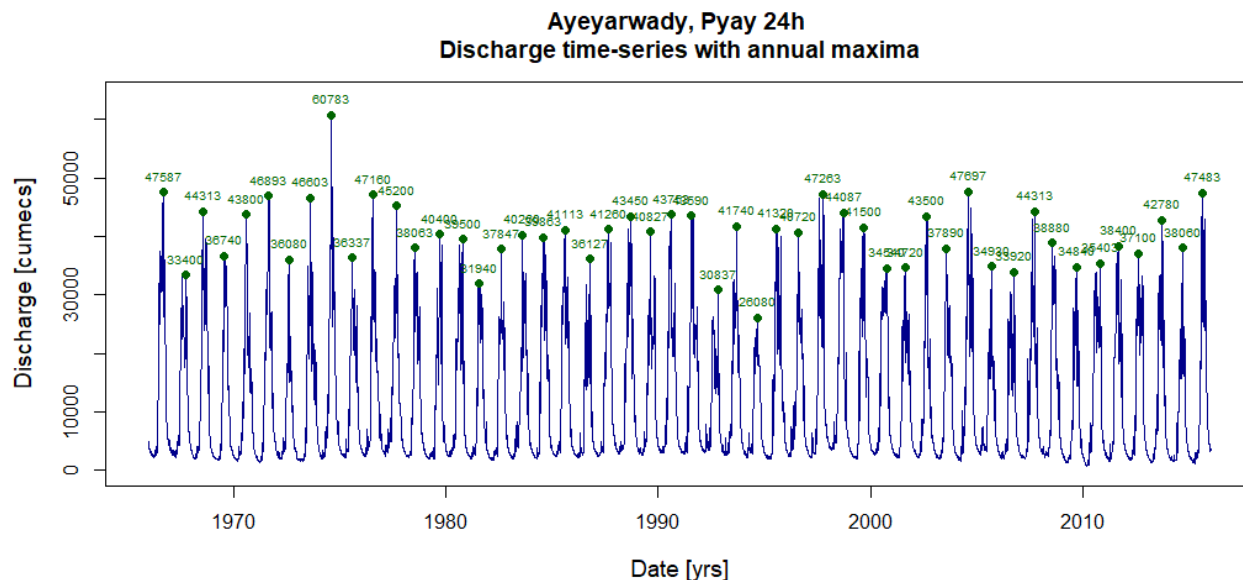


Figure 8: Annual Maxima time-series data for Pyay (1966-2015)

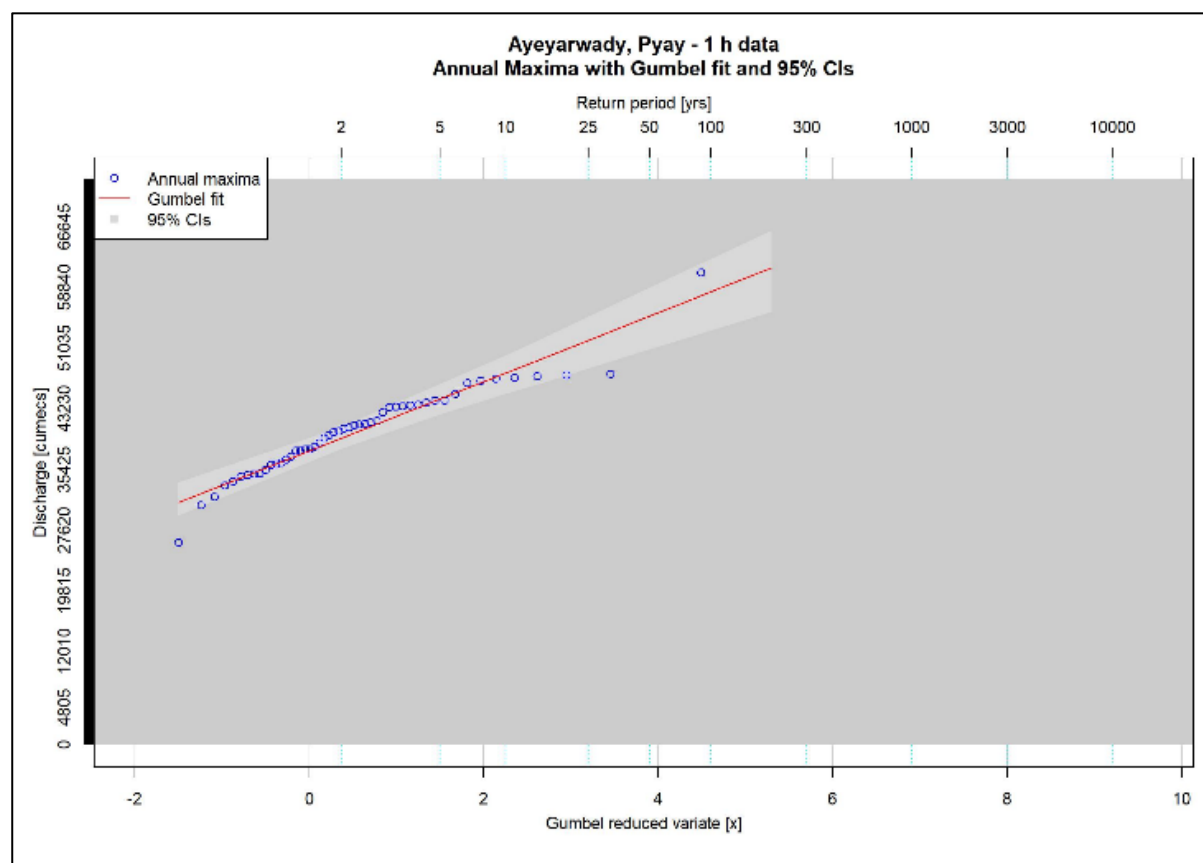


Figure 9: River Discharge Return Periods at Pyay obtained with the annual-maxima method and a Gumbel fit.

Table 2: Obtained discharges for given return periods at Pyay according to the Gumbel distribution.

Return period [years]	1	2	5	10	15	20	50	75	100	200
Discharge [m ³ /s]	31,166	39,481	44,522	47,860	49,743	52,077	55,206	57,024	58,311	61,405

The data presented in Table 2 were compared with findings obtained from RHDHV who established a Flood Hazard and Flood Risk model for Yangon City and obtained for this project flood tables for given return periods. Table 3 presents their findings for Pyay. The obtained results from the above analysis compared with the analysis executed by RHDHV show minor differences due to the longer time-series incorporated and due to a slightly different approach (use of Gringorton plotting position) applied in this model. Only for the more frequent events (i.e. a 1:1 return period), the RHDHV analysis showed a much lower discharge. It is possible that the applied Gumbel distribution and assumed plotting position did not provide a good fit at these lower discharges.

Table 3: Extreme value analysis of discharges at Pyay according to the Gumbel distribution (Data obtained from RHDHV, analysis based on data 1966-2010)

Return period [years]	1	10	25	100	200
Discharge [m ³ /s]	21,497	48,043	52,385	58,805	61,991

2.2.2.2 Return period Bago

The return period was derived from the 46-years of available time-series data using the annual maxima method with a Gringorton Plotting position and a Gumbel fit (Figure 10 and Figure 11). Table 4 presents the discharges obtained for given return periods from this analysis.

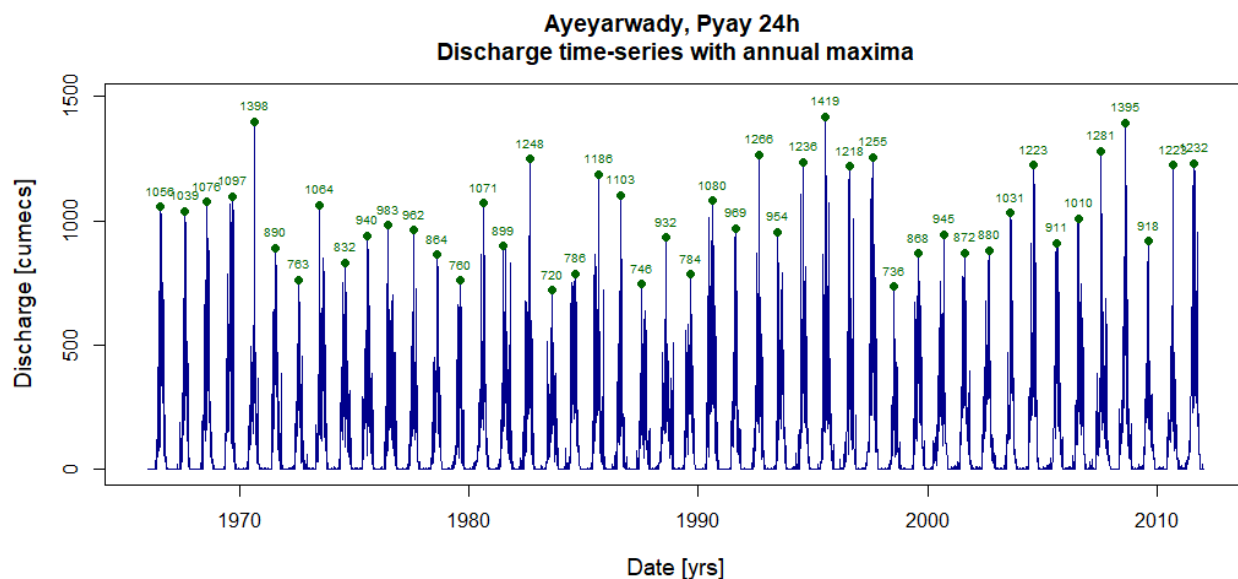


Figure 10: Annual Maxima time-series data for Pyay (1966-2011)

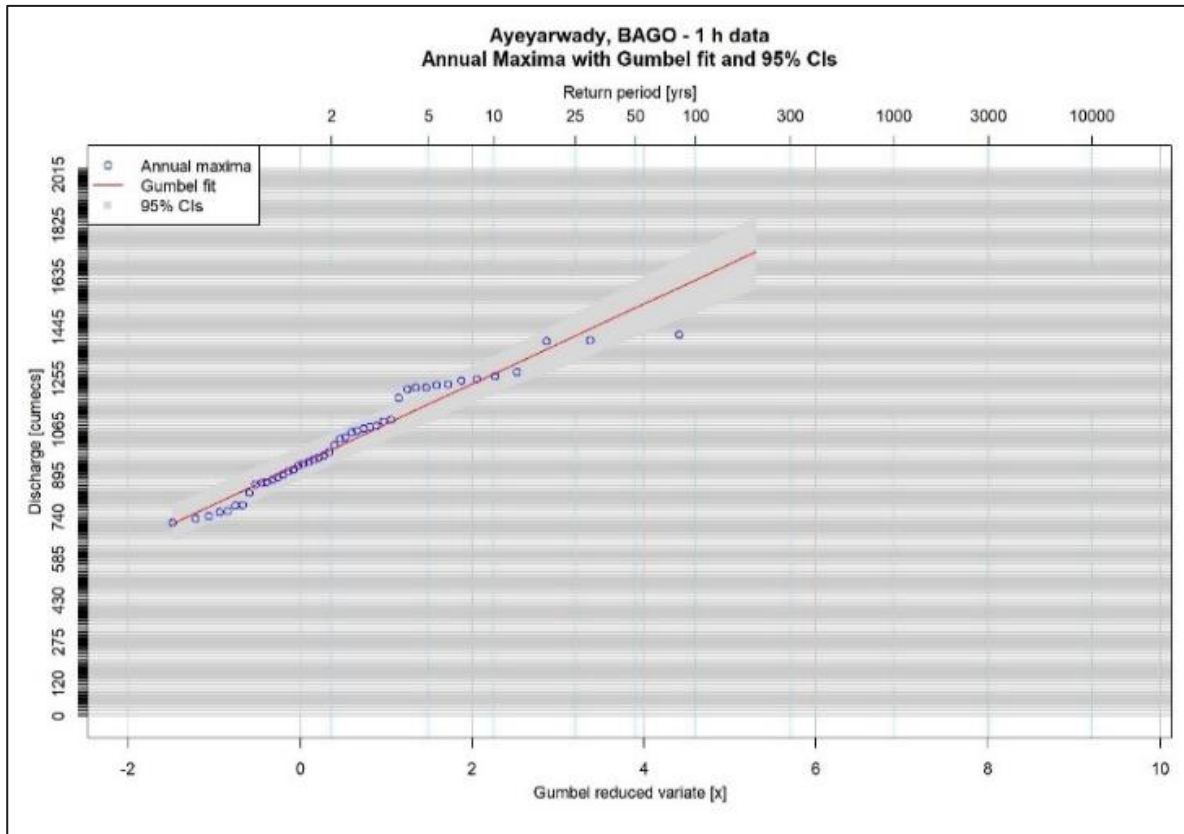


Figure 11: River Discharge Return Periods at Bago obtained with the annual-maxima method and a Gumbel fit.

Table 4: Obtained discharges for given return periods at Bago.

Return period [years]	1	2	5	10	15	20	50	75	100	200
Discharge [m ³ /s]	717	993	1,162	1,274	1,337	1,415	1,512	1,581	1,624	1,728

2.2.3 Flood wave at inflow boundary

2.2.3.1 Inflow boundary condition at Pyay

For Pyay three clusters of flood waves were compared from the data set, respectively representing annual maxima classes of 36,000, 40,000 and 47,000 m³/s on average. Each wave was shifted in time so that the peaks would overlay one another (i.e. the peak of each year occurred at $t=0$). Subsequently, the wave was restricted to a lower discharge level of 27,500 m³/s which was defined as the July-September average discharge at Pyay. From this, each cluster was compared, and an average wave-shape was derived.

By restricting the lower bounds of the flood wave to the average discharge (27,500 m³/s) and shifting the peaks so that they all occur at $t=0$, the following three average waves (red) were derived for the three different classes (i.e. 36,000; 40,000; and 47,000 m³/s):

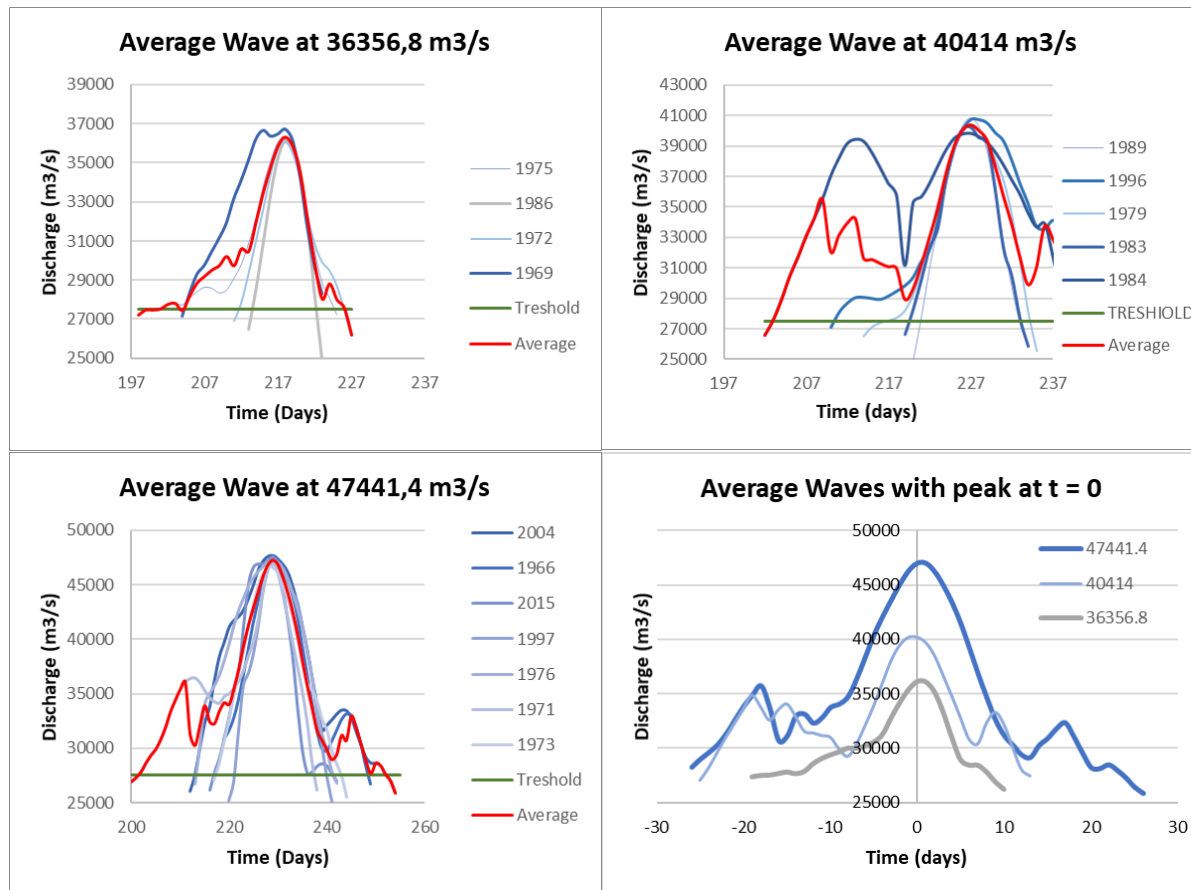


Figure 12: Overview of Pyay clustered discharges used to analyze the wave shape for different peak discharges. Bottom right presents the three averaged waves for the three classes with their peaks at $t=0$.

From Figure 12, it was concluded that for different annual maxima, the flood waves have a similar shape. From this observation, a wave shape was derived from the top-section of the averaged 47,000 m³/s wave so that the annual maxima can be fully captured by the function, i.e. the wave occurring from -8 to +8 (17 days). This wave and its representative shape function is presented in Figure 13 (left). This shape function was then multiplied with a factor so that the maximum of the function would peak at the determined return discharges. As the wave shape function does not describe the advancing/receding wave sections, an exponential time-step was introduced to describe the moments before and after the peak-wave occurs (Figure 13, right). Figure 14 shows that the constructed scaled discharge waves for different return periods have a good fit with the average measured wave on which they are based (i.e. 47,000 m³/s).

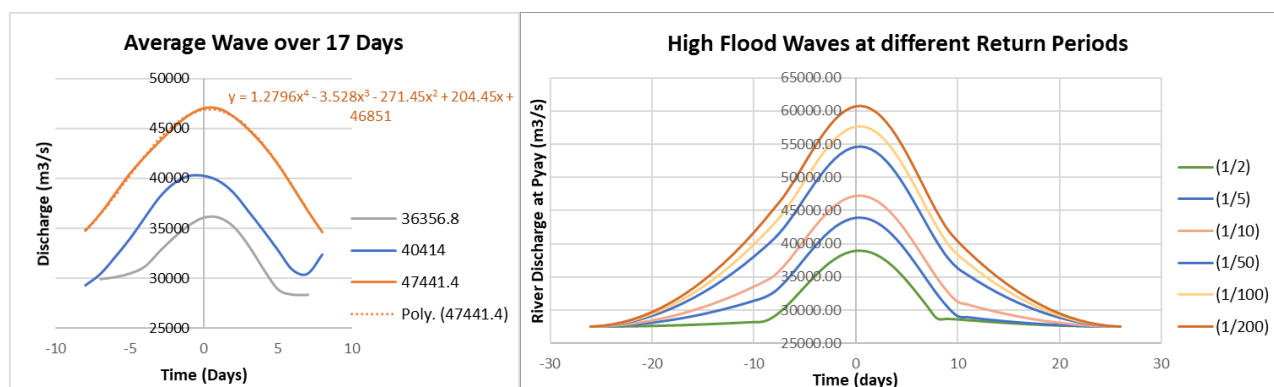


Figure 13: (left) the obtained polynomial peaks for the three classes of which 47,000 m³/s is used to determine the average shape of the Pyay wave; (right) the final scaled discharge waves for different return periods based on the average shape of the 47,000 m³/s wave.

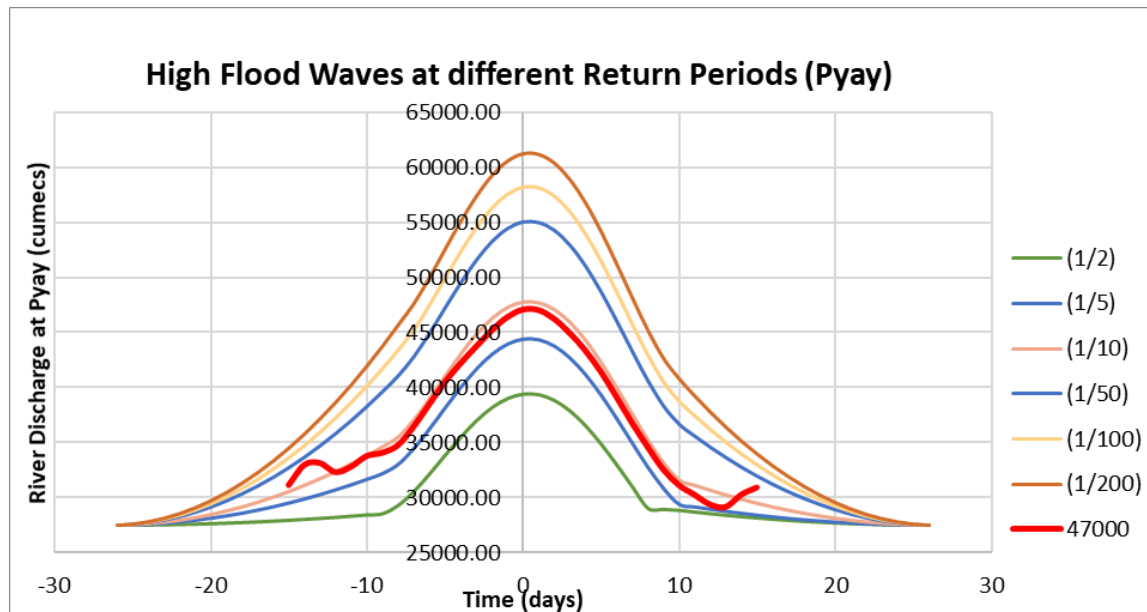


Figure 14: The scaled waves show a good fit with the averaged extreme discharge wave (47,000 m³/s) used to construct these discharge waves for Pyay.

2.2.3.2 Inflow boundary condition at Bago

For Bago three classes were compared, respectively representing annual maxima clusters of 900, 1200 and 1400 m³/s on average. Each wave was shifted in time so that the peaks would overlay one another (i.e. the peak of each year occurred at $t=0$). Subsequently, the waves were restricted to a lower level of 380 m³/s which was defined as the July-September average discharge at Bago. From this, each class was compared with one another, and an average wave was derived based on each of these three classes.

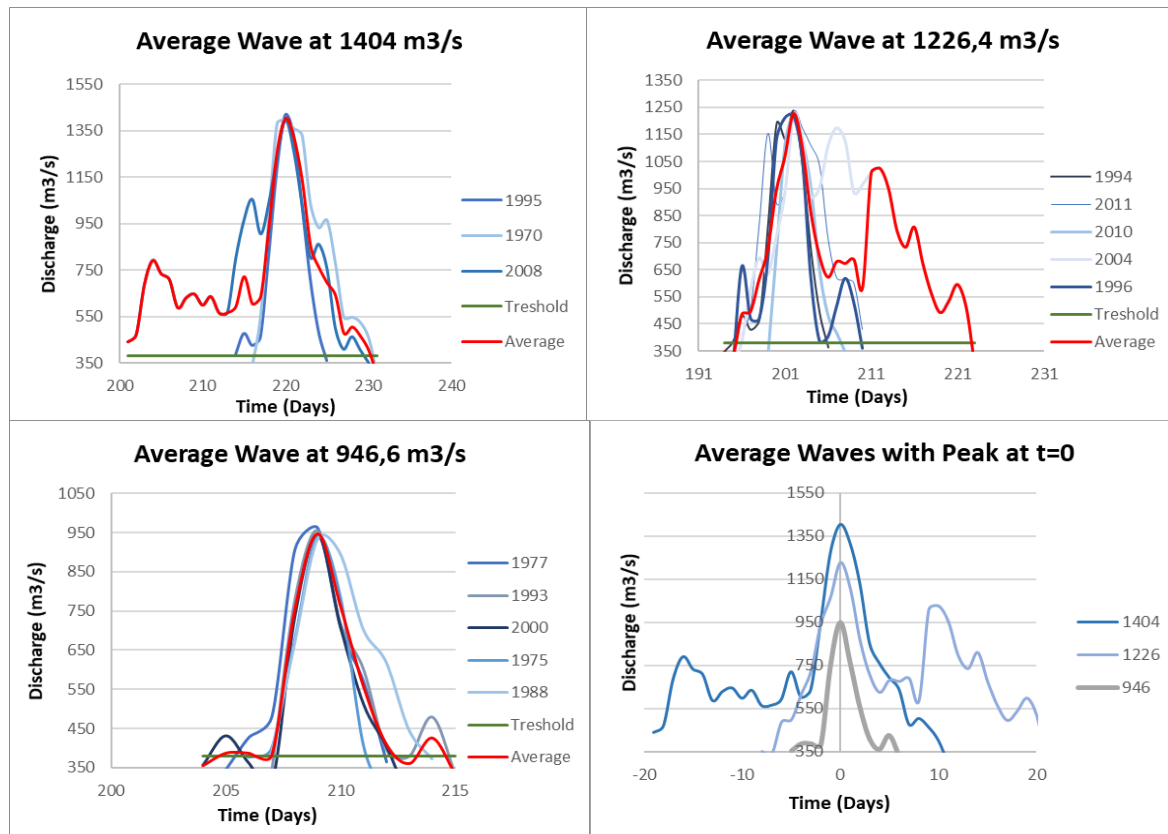


Figure 15: Overview of Bago clustered discharges used to analyze the wave shape for different peak discharges.

From Figure 15, it was concluded that for different annual maxima, the flood waves have a similar shape. From this observation, a 6th order polynomial was derived from the top-section of the 1404 m³/s wave so that the annual maxima can be fully captured by the function, i.e. the wave occurring from -3 to +3 (7 days). This wave and its 6th order polynomial function is presented in Figure 16 (left). The polynomial equation was then multiplied with a factor so that the maximum of the function would peak at the determined return discharges (Table 4).

As the polynomial function does not describe the advancing/receding wave dynamics, an exponential time-step was introduced to describe the moments before and after the peak-wave occurs. The duration for the exponential parts of the wave were based on the likely advancing/receding dynamics of the averaged 1404 m³/s wave, i.e. Figure 17 depicts that the discharge wave builds up slower than the period over which it recedes. Consequently, the exponential functions were adjusted so as to fully capture the observed differences as best as possible (Figure 16; right).

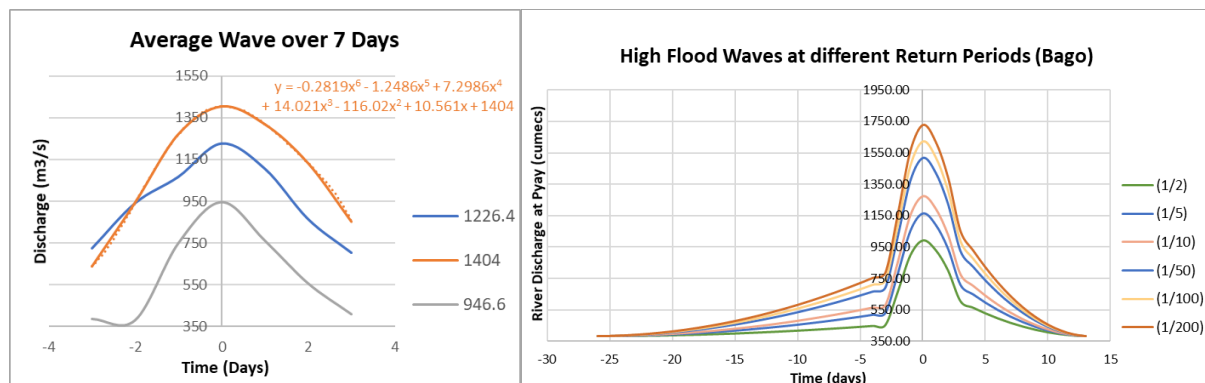


Figure 16: (left) the obtained polynomial peaks for the three classes of which 1404 m³/s is used to determine the average shape of the Bago wave; (right) the final scaled discharge waves for different return periods based on the average shape of the 1404 m³/s wave.

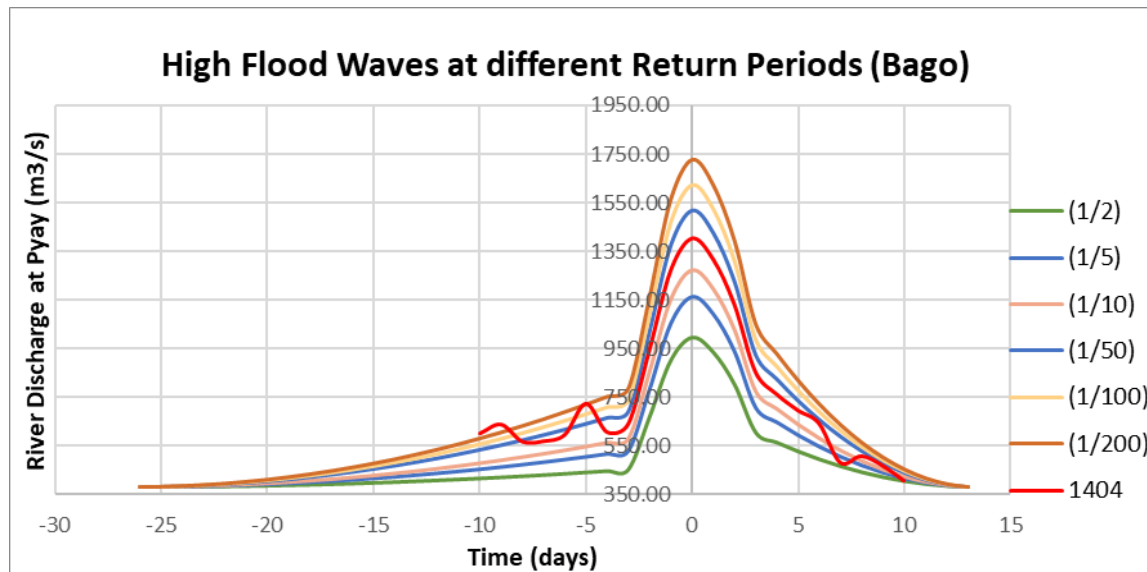


Figure 17: The scaled waves show a good fit with the averaged wave (1,404 m³/s) used to construct these discharge waves for Bago.

2.2.3.3 Inflow boundary condition at Hlaing

The Inflow at Hlaing in the model is manually forced into the model based on a Q-Q relationship between Pyay and Khamonseik using data from DMH. This forcing represents an overflow at Monyo towards Upper Hlaing, hence this forcing is only active above a certain local water level in the Ayeyarwady river and the associated river discharge. This can be observed in Table 5 where there is no overflow discharge up to 2500 m³/s. After that, the overflow increases from 4% to roughly 5.5% of the total discharge in the Ayeyarwady river. Above a discharge of approximately 40,000 m³/s in the Ayeyarwady, the increase in overflow towards the Upper Hlaing is only minimal. This is likely due to the limiting effect of the cross-sectional area of the Upper Hlaing river.

Table 5: Q-Q relation between Pyay and Upper Hlaing

Q Pyay	Q Upper Hlaing	Factor
500	0	0
2500	0	0
5000	200	0.04
10000	450	0.045
20000	1000	0.05
30000	1650	0.055
40000	2200	0.055
50000	2500	0.05
60000	2700	0.045
70000	2800	0.04

In addition to the overflow relation, a relation for groundwater flow towards the Upper Haling was established, based on the same Pyay – Khamonseik Q-Q relation. This relation is less sensitive to acute changes in river discharge and more sensitive to dry or wet periods. For simplicity, the groundwater discharge is still defined in relation to the discharge at Pyay. The result is shown in Table 6.

Table 6: Simplified groundwater discharge relation for the Upper Hlaing river, relative to Pyay

Q Pyay	Q Upper Hlaing
500	0
10000	500
70000	500

2.2.3.4 Inflow boundary condition at Pazundaung Creek

For high flow a constant discharge of 100 m³/s is forced at Pazundaung Creek. The discharge is further controlled at the Nga Moe Yeik sluice, resulting in a uniform flow direction downstream.

2.2.3.5 Extraction boundary conditions to Pathein River

In addition to the (internal) inflow boundaries, there exists a single extraction boundary schematizing the river flow at the bifurcation from the Ayeyarwady River to the Pathein River. This extraction is manually forced using a Q-Q relation based on the discharge time series at Pyay and Ngathainggaung (data DMH). The relation is shown in Table 7.

Table 7: Q-Q relation based on Pyay and Pathein River

Q Pyay	Q to Pathein	Factor
500	150	0.3
1000	200	0.2
5000	750	0.15
10000	1200	0.12
20000	2000	0.1
30000	2700	0.09
40000	3200	0.08
50000	3500	0.07
60000	3900	0.065
70000	4200	0.06

2.2.4 Lag between different inflow flood waves

In order to determine whether there is a correlation between the moment of peak discharge at Pyay and the moment of peak discharge at Bago, an analysis was carried out on the lag between the two peaks for the available 46 years of discharge data (1966-2011).

From the 10 highest annual peak discharges at Pyay (i.e. 1974; 2004; 1966; 2015; 1997; 1976; 1971; 1973; 1977; 1968 and 2007), only three years belong to the 10 highest observed waves at Bago, i.e. respectively 2007; 1997 and 2004. Based on these 10 years, it was noted that there is a lot of variability in lag, with some years at which the Bago peak arrives well ahead of the Pyay peak and other years in which the process is reversed. Therefore, it was assumed to look at the two highest peak discharge years at Pyay and determine when the peak arrives at Bago for these years. Based on the observation that during the two highest peak discharge years at Pyay, i.e. 1974 and 2004, (Figure 18) the peak at Pyay arrived at least 4 days before the peak at Bago, a lag of 3 days between Pyay and Bago was selected (Table 8). As under such a lag the peak discharges of both rivers arrive around the same time at their point of confluence in the delta, this assumption provides a conservative estimate of the flood levels.

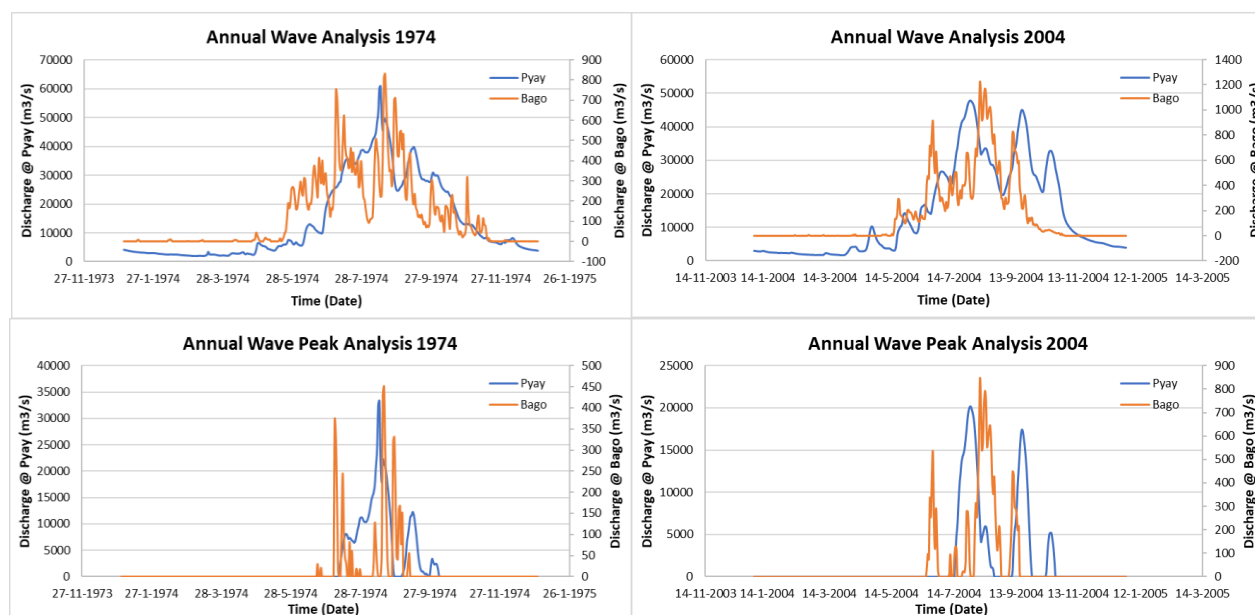


Figure 18: Lag observed for the two highest discharge years at Pyay between the Pyay and Bago wave developments.

Table 8: The lag calculated between the discharge peak at Pyay and the discharge peak at Bago. A negative value indicates that the peak at Pyay arrives before the peak at Bago.

Annual Maxima obtained for 10 wettest discharge years at Pyay												Avg. delay	Std.
Year	1974	2004	1966	2015	1997	1976	1971	1973	1977	1968	2007		
Delay [days]	-4	-9	41	N/A	60	41	43	58	33	-3	77	33.7	28.2

2.2.5 Lag between inflow and tides

During the baseline assessment of this extreme event, the spring tide occurs simultaneously with the peak of the inflowing high-flood wave. In other words, the boundary forcing is adjusted in such a way that the peak of the discharge from both Pyay/Bago arrive at Yangon at the same time as spring tide occurs in Yangon River.

2.2.6 Model use

As this event relates to the analysis of possible flooding of inland areas, the overland flow model was used for the baseline assessment of the riverine flooding extreme event. Flooding at certain points can lead to a reduction in water level downstream. This process of flooding needs to be included in order to be able to accurately determine the level of water security in these downstream areas. In addition, the overland flow model is needed to assess the impact of measures that affect the flooding of areas.

2.3 Water Scarcity Model

For the water scarcity model, a stationary (low) inflow boundary condition is forced at each of the inflow locations and the model was combined with a representative spring tide.

2.3.1 Data Availability

As for the riverine flooding event, this model relies on the discharge data at the various inflow locations provided by DMH and extensively discussed in the previous chapter (2.2.1). For the extreme drought baseline study, an analysis of the low flows was carried out. The annual minimum daily discharges for Pyay are shown in Figure 19.

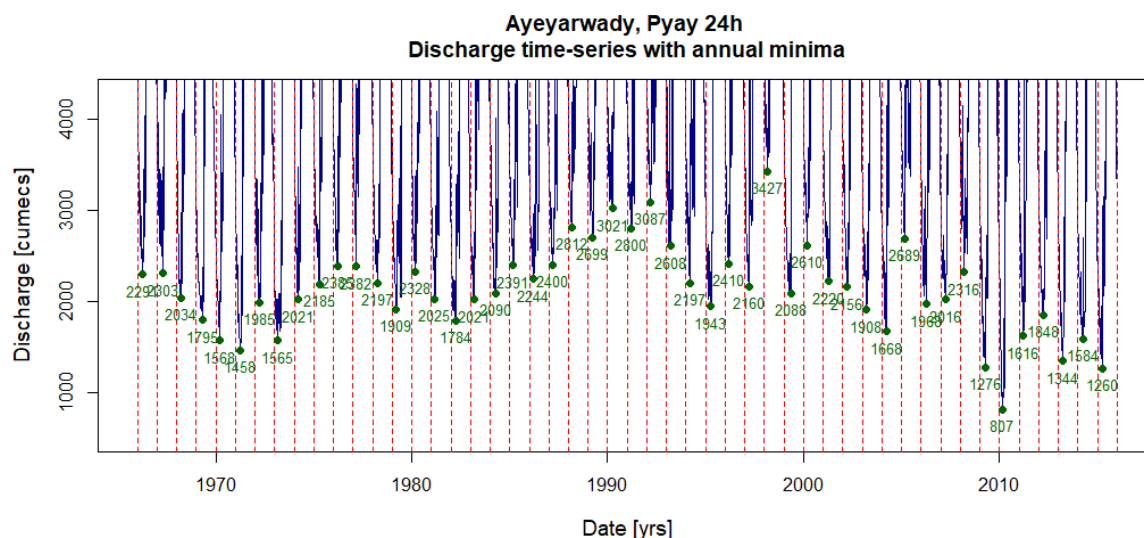


Figure 19: Annual Minima for the Pyay time-series data from 1966-2015.

2.3.2 Return Period

For the establishment of the relation between low discharge events and their return period a Weibull function is fitted to discharge events below a certain threshold. In addition, the return period also includes the length of the low discharge event, as longer low discharge events result in progressively more salt intrusion. The length of a low discharge event is characterized as the first moment the discharge drops below the threshold, until the threshold value times a factor of 1.4 is exceeded again (e.g. a discharge 40% above the considered threshold value). In this way low discharge events, where the system is not able to recover fully, are seen as a single (adjoined) event. A low discharge event is thus described as certain low discharge (m^3/s) in combination with a duration or persistency (days).

2.3.2.1 Return Period Pyay

The resulting return period for a range of low discharge events, defined by a discharge and a duration, is shown in Table 9. It can be observed that all events above $1500 \text{ m}^3/\text{s}$ are fairly frequent and only show a minor variation in return period as a result of the duration. Below $1500 \text{ m}^3/\text{s}$ the return period lengthens significantly, especially for durations of more than 25 days.

Table 9: Return period in years for a range of low discharge events (combination of a discharge and a duration)

Return Period [years]	≥ 15 days	≥ 25 days	≥ 35 days
< 2250 m ³ /s	1	1	1
< 2000 m ³ /s	2	2	2
< 1750 m ³ /s	2	3	4
< 1500 m ³ /s	4	5	7
< 1250 m ³ /s	7	12	24
< 1000 m ³ /s	13	37	150

2.3.2.2 Return Period Bago

Conducting an extreme value analysis for annual minima of the Bago time series showed negative values for larger return events (Table 10). As a consequence of this, it was preferred to relate the minimum inflow at Bago to the inflow at Pyay as Pyay is dominant input within the model, especially during low flows. Therefore, the Bago inflow for given return periods equaled 2% of the Pyay discharges (i.e. divided by 50) based on expert judgement.

Table 10: Extreme value analysis of minimum discharges at Bago according to the Gumbel distribution.

Return Period (Yrs)	Discharge Bago (m ³ /s) (Gumbel extreme value distribution)	Discharge Bago (m ³ /s) (Based on Pyay)
1	2.70	53
2	0.91	45
5	0.58	34
10	0.27	27
50	-0.13	18
100	-0.44	15

2.3.3 Inflow Boundary

2.3.3.1 Inflow Boundary Condition at Pyay and Bago

As both Pyay and Bago have available discharge data from which recurrence intervals were determined, for both stations stationary inflow discharges were imposed equaling the return periods as presented under 2.3.2.1 and 2.3.2.2.

2.3.3.2 Inflow Boundary Hlaing

An identical approach was adopted at this inflow boundary compared to the Riverine Flooding Model (refer to Section 2.2.3.3).

2.3.3.3 Inflow Boundary Pazundaung Creek

Due the lack of data on Pazundaung Creek time-series discharge data, expert judgement determined that the inflow at this boundary could be neglected ($Q = 0 \text{ m}^3/\text{s}$) due the minor contribution of this creek into the Delta. This assumption can be seen as very likely because during (extreme) dry periods, the minimal water level of 9.3 m+EGM08 necessary to provide flow though the Nga Moe Yeik sluice will not be reached.

2.3.3.4 Lag between Different Inflow Waves and Tides

For the low flow model, no lag was required as the inflow boundary is stationary.

2.3.4 Model use

For the Low Flow extreme event, the channel flow model is used for the baseline assessment as under low flow conditions no flooding and overtopping of the embankments occur.

In addition, the effect on the salinity intrusion is computed by combining the channel flow model results and the salinity intrusion simulation using the 3D salinity model.

2.4 Pluvial Flooding Model

2.4.1 Rainfall Data Availability

For the extreme rainfall boundary conditions two main sources were available. The first was compiled data from the Department of Meteorology and Hydrology (DMH) based on different rainfall gauges (Figure 20). These data were available for Hinthada, Labutta, Maubin, Nga Thaing Chaung, Pathein, Pharpon, Seikthar and Zalun for the period between 2005 and 2016.

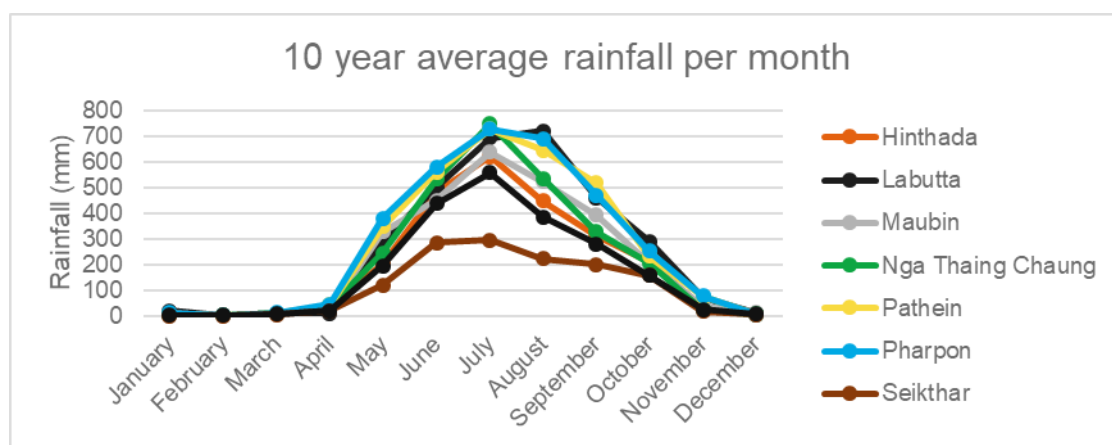


Figure 20: Average monthly rainfall between 2006-2015 for different gauging stations.

The second data set which was available is the ERA5 data set (C3S, 2017)¹. The data was available from 1979 until 2019 on a grid of 31km, 0.28125 degrees at 3-hour intervals. The average 3 hourly precipitation is shown in Figure 21 (left) and the extent of the important agricultural region in the low-lying polders near Yangon (Greater Yangon Region, GYR) are shown in Figure 21 (right).

¹ Copernicus Climate Change Service (C3S) (2017): ERA5: Fifth generation of ECMWF atmospheric reanalyses of the global climate . Copernicus Climate Change Service Climate Data Store (CDS), date of access. <https://cds.climate.copernicus.eu/cdsapp#!/home>

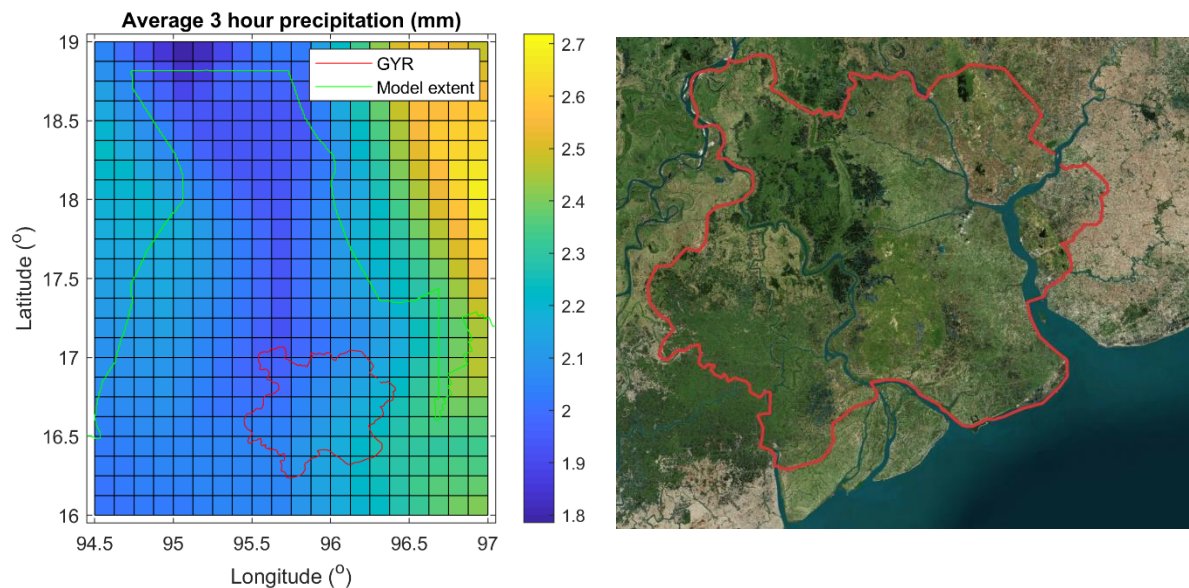


Figure 21: Average 3 hour precipitation from 1979 to 2019 for the Greater Yangon Region (GYR) and the full model extent or 'whole area' (left), and Greater Yangon Region (right)

The choice was made to use the ERA5 data set owing to the higher spatial and temporal resolution. Moreover, the rainfall from the ERA5 data was slightly higher than the DMH data leading to more conservative results.

2.4.2 Return period

The temporal resolution of the ERA5 rainfall data is 3-hourly. The first step in the rainfall analysis was to aggregate the time series to larger time steps in order to derive rainfall extremes for different durations. The two time series (GYR and 'whole area') were aggregated to durations of 3, 6, 12, 24, 48 and 72 hours. Subsequently, for each duration, two sets rainfall extremes were derived for extreme value analysis:

- Peaks-over-Threshold (PoT)
- Annual maxima

The PoT values were used to derive return values for return periods of 0.2 years (i.e. a frequency of 5 times per year) and 1 year, whereas the annual maxima were used to derive return values for return periods of 2, 5, 10, 25, 50, 100, 250, 500 and 1,000 years. In the PoT selection, the threshold was chosen in such a way that on average 10 peaks per year were selected, so 400 peaks in total over the 40-year period. A window of 7 days was applied in the peak selection to make sure that selected events were independent.

Figure 22 shows derived empirical return values based on the selected PoT values for the GYR-area. The empirical return values are based on the principle that the return period of the highest rainfall in a 40-year period is approximately 40 years, the return period of the second highest rainfall is approximately $40/2 = 20$ years, the return period of the third highest rainfall in a 40-year period is approximately $40/3 \approx 13$ years etc. The larger circles in this Figure highlight the estimated return values for the return periods of 0.2 years and 1 year. Figure 23 shows annual maxima (dots) and fitted extreme value distribution functions for the GYR-area. The Generalised Extreme Value distribution function (GEV) was used to fit the data. The fitted data functions describe the relation between return period and associated rainfall depth.

Table 11 and Table 12 show the resulting return values for the two areas. In general, return values for the GYR area are slightly higher than for the whole study area. This makes sense as the area-average extreme rainfall generally decreases with increasing area size.

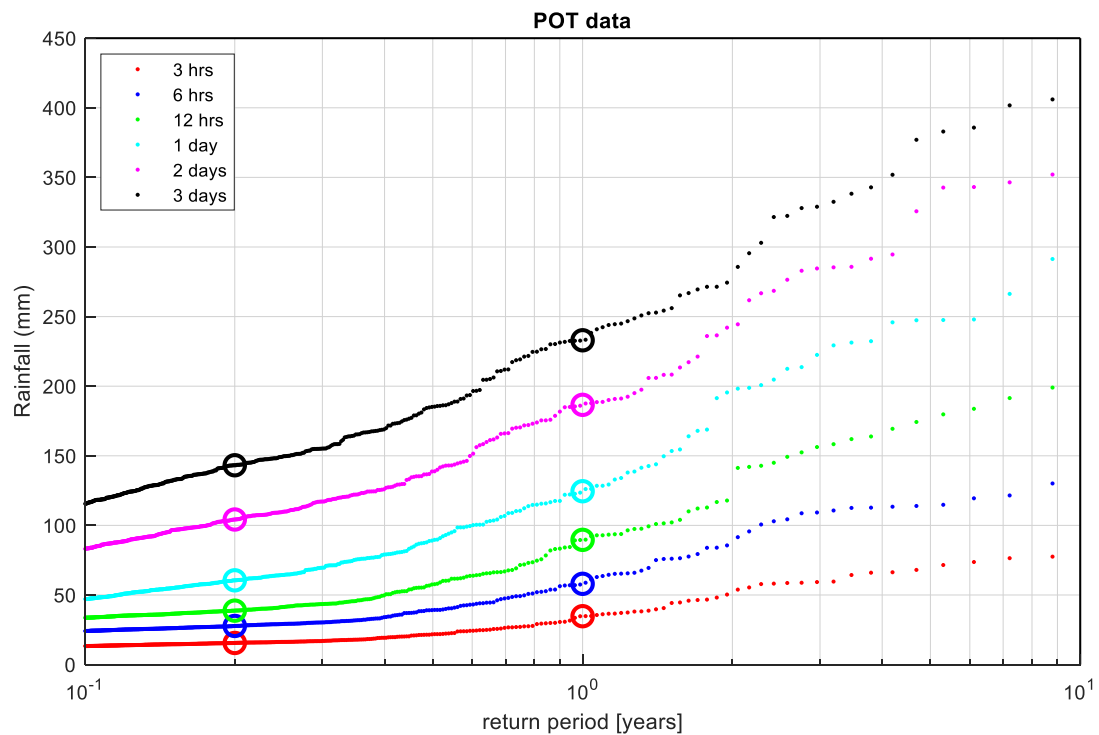


Figure 22: Empirical return values of rainfall for the for the GYR area for six different durations.

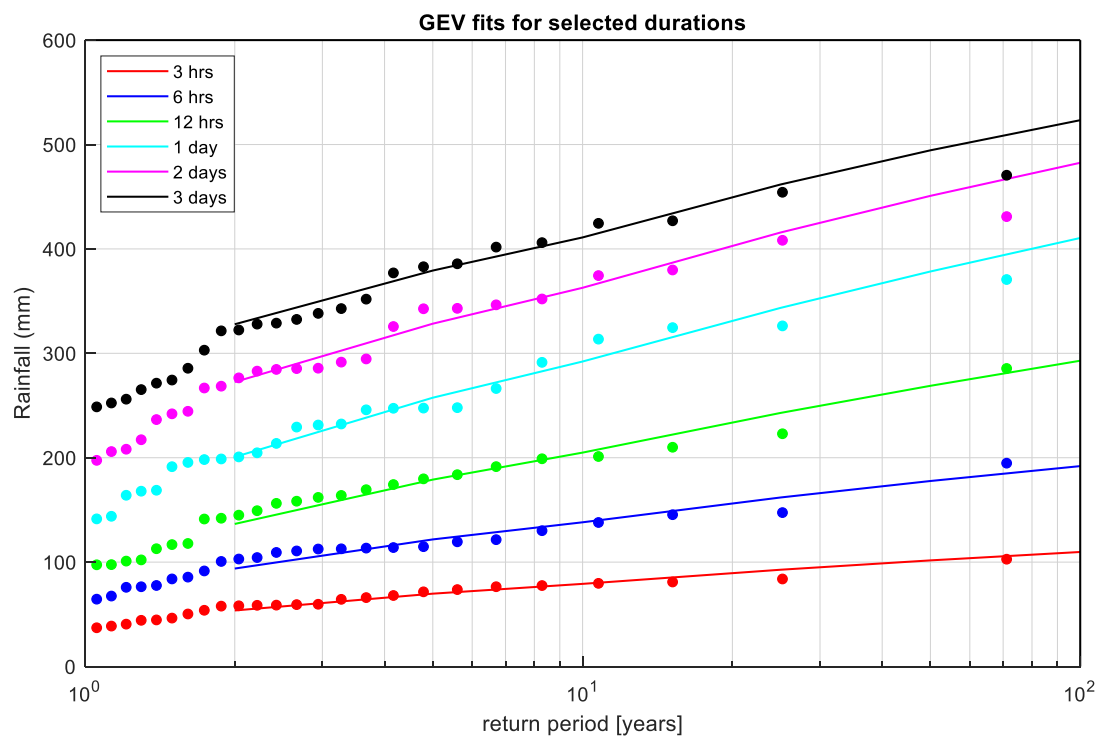


Figure 23: Annual maxima (dots) and fitted GEV distribution functions (lines) for the GYR area for six different durations

Table 11: Derived return values of rainfall (mm) for the GYR

Return period (years)	duration					
	3 hrs	6 hrs	12 hrs	1 day	2 days	3 days
0.2	15.5	27.8	38.8	60.5	104.2	143.2
1	34.8	58.0	89.6	124.6	186.6	233.0
2	53.7	93.8	136.6	200.7	272.5	327.8
5	69.8	121.7	179.0	257.5	328.4	379.3
10	79.2	138.1	204.9	292.1	362.8	411.0
25	92.7	161.9	242.9	343.5	415.7	461.7
50	101.7	177.7	268.9	378.4	450.8	494.4
100	109.7	192.0	292.9	410.5	482.5	523.3
250	119.2	208.8	322.1	449.2	519.9	556.5
500	125.6	220.2	342.4	475.9	545.1	578.3
1000	131.4	230.6	361.3	500.8	568.1	597.7

Table 12: Derived return values of rainfall (mm) for the whole area

Return period (years)	duration					
	3 hrs	6 hrs	12 hrs	1 day	2 days	3 days
0.2	14.6	26.0	37.1	60.8	105.9	147.7
1	30.8	54.8	79.7	124.9	185.7	233.3
2	39.7	70.0	103.4	162.0	230.6	283.8
5	53.0	94.2	136.8	208.1	284.2	335.4
10	62.2	110.8	158.9	237.0	320.0	369.5
25	75.2	134.3	189.3	275.8	370.4	417.9
50	84.9	152.1	211.3	302.6	406.5	451.7
100	94.6	169.8	232.6	327.7	441.2	483.5
250	107.5	193.5	260.1	358.5	485.4	523.0
500	117.3	211.5	280.3	380.2	517.6	551.1
1000	127.2	229.7	300.1	400.7	548.9	577.7

2.4.3 Boundary conditions pluvial flooding

The return values of the previous section were used to derive design hyetographs as boundary conditions for the pluvial flooding analysis. To illustrate how this method works we derive as an example the design hyetograph for the whole area for the 10-year return period. For this return period, we find from Table 13 the following return values for different durations:

Table 13: Derived 10-year return values of rainfall (mm) for the whole area

3 hrs	6 hrs	12 hrs	1 day	2 days	3 days
62.2	110.8	158.9	237.0	320.0	369.5

The design hyetograph covers the entire period of the longest considered duration, so 3 days (72 hours). In the alternating block method, the most intense rainfall occurs in the middle of the 72-hour period. We know from Table 13 that in three hours' time we expect a maximum of 62.2 mm, which is 20.7 mm/hour. Therefore, we choose a rainfall intensity of 20.7 mm/hour in the hours 35, 36 and 37 of the -hour hyetograph. According to Table 13 we can have a maximum of 110.8 mm in a period of six hours. Since we already have 62.2 mm

in the three hours in the middle of the hyetograph, we will have an additional $110.8 - 62.2 = 48.6$ mm in the three remaining hours of the six-hour period in the middle of the hyetograph. This means we have $48.6/3 = 16.2$ mm/hour rainfall in these three hours. Therefore, the hours 34, 38 and 39 of the design hyetograph each have 16.2 mm rainfall. According to Table 13, we can have a maximum of 158.9 mm in a period of twelve hours. Since we already have 110.8 mm in the six hours in the middle of the hyetograph, we will have an additional $158.9 - 110.8 = 48.1$ mm in the six remaining hours of the twelve-hour period in the middle of the hyetograph. This means we have $48.1/6 = 8.0$ mm/hour rainfall in these six hours. Therefore, the hours 31, 32, 33, 40, 41 and 42 of the design hyetograph each have 8.0 mm rainfall. In this manner we compose the entire hyetograph.

The benefit of this method is that all return values of Table 13 are included in a single design hyetograph. In other words, the highest 3-hour rainfall in the design hyetograph is equal to 62.2 mm, the highest 6-hour rainfall in the design hyetograph is equal to 110.8 mm etc., so all in line with Table 13. For other return periods we apply the same method and as such we compose design hyetographs for all relevant return periods. Figure 24 shows a few examples of the derived hyetographs for the GYR area. Similar hyetographs were derived for the whole project area.

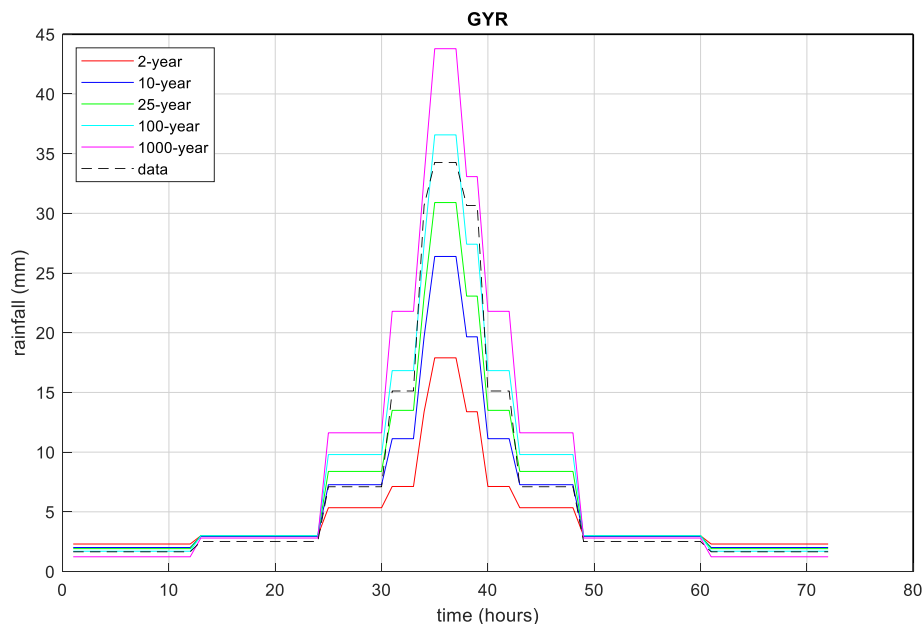


Figure 24: Design hyetographs for the GYR area for different return periods. For comparison, also a hyetograph is added that is associated with maximum observed rainfall depths for different durations over the entire observation period.

For the river discharge at Pyay, a constant discharge of $27,500 \text{ m}^3/\text{s}$ is assumed. This discharge is representative for a yearly average for the wet season. Forcing a larger discharge would result in an overly conservative scenario because while extreme pluvial events often result in peak fluvial events, there exists a certain delay where the associated fluvial event follows the pluvial event after a few days to weeks.

2.4.4 Drainage

While the overland flow model is certainly complex, it is still fairly large scale. One of the consequences is that small scale free-flow drainage (e.g. small waterways, sluices, outlets, culverts) that still represent a significant part of the drainage within the study area during heavy rainfall, are not automatically included. In order to come to representative pluvial inundation values (extent and depth) per rainfall event, a number of extractions representative for the abovementioned drainages was included in the model. These extractions are located at their associated geographic location. At these locations a discharge is extracted representing the tide-averaged drainage capacity during a pluvial event with a specific return period. The extractions as a function of the severity of the pluvial event are based on the SOBEK model (RHDHV, 2019).

2.4.5 Model use

For the simulation of the pluvial events, the overland flow model is applied. This model includes the catchment area for the RWSS study domain.

2.5 Coastal Flooding Model

2.5.1 Description

Coastal flooding, such as during cyclone Nargis in 2008, can have a tremendous impact on the people who live and work in the Ayeyarwady Delta. The combination of a storm surge, high tide during spring tide and extreme rainfall, results in extreme water levels in the downstream area of the delta. This event, while occurring less frequently than an isolated extreme rainfall event, represents extreme flooding and therefore the highest probability of a disaster in the southern part of the Yangon Region.

2.5.2 Methodology

It is relatively difficult to statistically analyze the severity of cyclones, relative to their return period. There exist many variables such as the cyclone track, landfall location, time of landfall, peak pressure drop and peak gust wind speeds that determine the experienced severity and its consequences. It is therefore opted to adopt a real-life cyclone event for the simulated coastal flooding event. In recent history, cyclone Nargis (2008) sticks out as most severe, especially considering its consequences in the Myanmar region. At its peak, cyclone Nargis was a category 4 tropical cyclone with 3-minute sustained windspeeds of up to 165 km/h and 1-minute sustained wind speeds as high as 215 km/h. The air pressure dropped to 962 mPa within its eye. The landfall in Myanmar occurred on May 2nd, 2008.

2.5.3 Return period

Based on 13 years of observation at Elephant Point covering 32 coastal surge events, a statistical analysis was performed in (RHDHV, 2019). Comparing this to the simulated peak surge during Nargis (approximately 1.45 m), it was concluded that Nargis can be considered a one in hundred years coastal surge event (e.g. a return period of 100 years, 1:100).

A study-specific method to generate a range of cyclone events with different return periods is adopted. By means of scaling the (peak) wind velocity and pressure drop within the eye of the cyclone, synthetic cyclone events are generated. The cyclone extent and track is kept constant; identical to the characteristics of Nargis (2008).

In order to scale the wind and pressure, a statistical analysis was performed using the cyclone characteristics of the Indian Ocean from 1842 to 2019 (NHC Data Archive, NOAA, 2019). It was found that Nargis, viewed only from a wind velocity and pressure drop perspective, can be considered as only mildly extreme. Its (peak) wind velocity is part of the 25% most severe known events and the pressure drop is part of the third most severe known events. Based on the figure below Nargis ranks in the RP005 to RP010 range based on its peak velocity (167 km/h) and its eye pressure (962 mBar). The experienced severity of Nargis was mostly due to its track being very unfavorable. It moved over the coastal regions of Labutta and Bogale and subsequently, over Yangon itself. Because of its counter-clockwise orientation, the cyclone front caused continuous severe surges and coastal wave attack along its track. These effects were amplified within river mouths and tidal inlets.

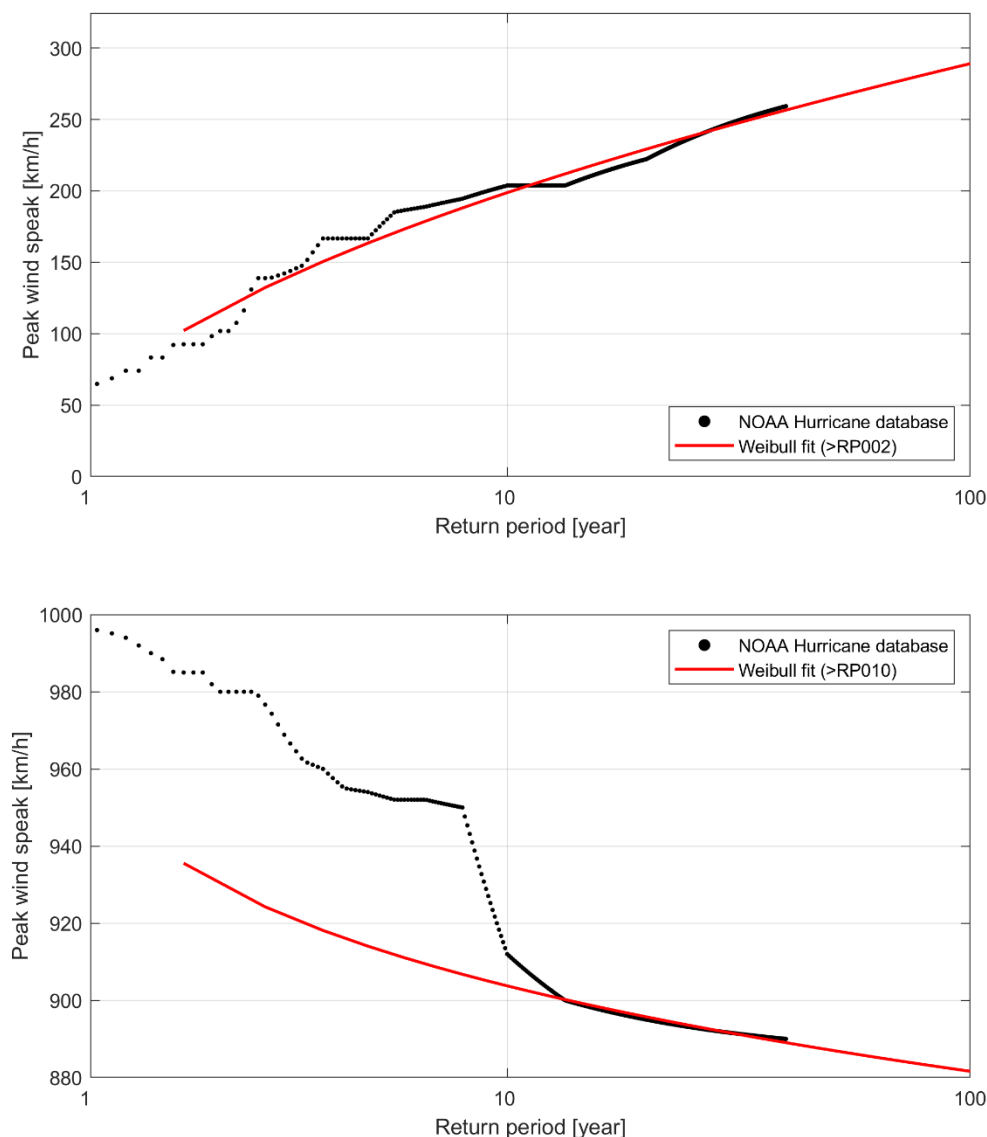


Figure 25: Cyclone characteristics for the Indian Ocean. Upper frame: 3-min wind velocity. Lower frame: cyclone eye pressure (fitted from RP010 onwards to favor fit accuracy for extremes).

Using a Peak Over Threshold and Weibull-based Extreme Value Distribution, the cyclone characteristics were analyzed. An exceedance fit-function was computed for both the wind velocity and the pressure drop using the cyclone characteristics of cyclones originating in the Indian Ocean (see figure above). Based on the surge-based return period of once per 100 years for Nargis found in (RHDHV, 2019), a range of synthetic cyclone events were generated scaled to different return periods. Table 14 includes the peak wind velocity and peak pressure drop per considered return period. As mentioned above, the cyclone track, spatial extent, relative build-up and relative decay have been kept identical to the associated characteristics of Nargis, 2008.

Table 14: Synthetic cyclone events with different return periods

Return Period [1 / X years]	Wind velocity [km/h]	Pressure [mBar]
1:25	102	995
1:50	121	987
1:100 (Nargis, 2008)	167	962
1:200	195	940
1:500	222	924
1:1000	235	914

For the river discharge at Pyay, a constant discharge of 4,500 m³/s is assumed. This discharge is representative for the months in which most cyclones occur.

2.5.4 Boundary Conditions Cyclone Model

The synthetic cyclones with the properties as presented above are fully recreated in the model, using a spider-web forcing with spatially and temporally varying wind velocity and air pressure, based on the Holland et al. (2010) model. The full period of the cyclone, 27 April 2008 – 3 May 2008, excluding hydrodynamic spin-up, has been simulated.

The actual river discharge and tidal conditions that were present at the time, have been forced on the upstream and downstream boundaries, respectively. At the moment of land-fall, the tidal conditions were nearing springtide conditions, which can be considered conservative regarding its cumulative effect.

2.5.5 Model use

Comparable to the model use for the riverine flooding simulations; the overland flow model is used for the baseline assessment of the coastal flooding extreme event.

3 METHODOLOGY OF BASELINE ASSESSMENT

A description of the applied methodology to determine the level of water security using the model results is outlined for each type of extreme event in their respective sections below. The methodology includes the description of:

- Event specific boundary forcing (see also Section 2);
- Return periods considered;
- The model(s) used;
- Interpretation and application of results at key locations;
- Derivation of water security levels.

3.1 Riverine Flooding

An overview of the applied external boundary forcing is given in Table 15. On the upstream river boundaries, a discharge wave is forced representative for the return period considered. On the coastal boundary a spring-neap tidal forcing is applied.

Table 15: Overview of the external boundary forcing for the fluvial event

Boundary	Forcing
Upstream river: Pyay	Discharge wave (varies with return period)
Upstream river: Bago	Discharge wave (varies with return period)
Upstream river: Pazundaung Creek	Constant representative discharge (100 m ³ /s)
Coastal boundary	Spring-neap tidal cycles
Freshwater extraction(s)	None
Wind and atmospheric pressure	None
Precipitation	None
Drainage	Natural drainage only
Salinity	None

The fluvial flooding is considered for the return periods of 1/2, 1/5, 1/10, 1/50, 1/100 and 1/200 years. This is outlined in more detail in Section 2.2.3. The resulting high-water discharge waves for Pyay are shown in Figure 26.

In light of minimizing the computational effort, all high discharge waves are initially simulated using the channel flow model. This model only considers the flow within the channels and therefore runs a lot faster. However, in case of fluvial flooding, the overflow and the resulting reduction in riverine water level is not considered by this model, effectively underestimating the water security level of the downstream area(s) by a certain degree. This underestimation is quantified separately by simulating only the relevant return period(s) using the more computationally demanding overland flow model. This model does include the abovementioned process of overtopping of the dikes and embankments and inundating the land behind them.

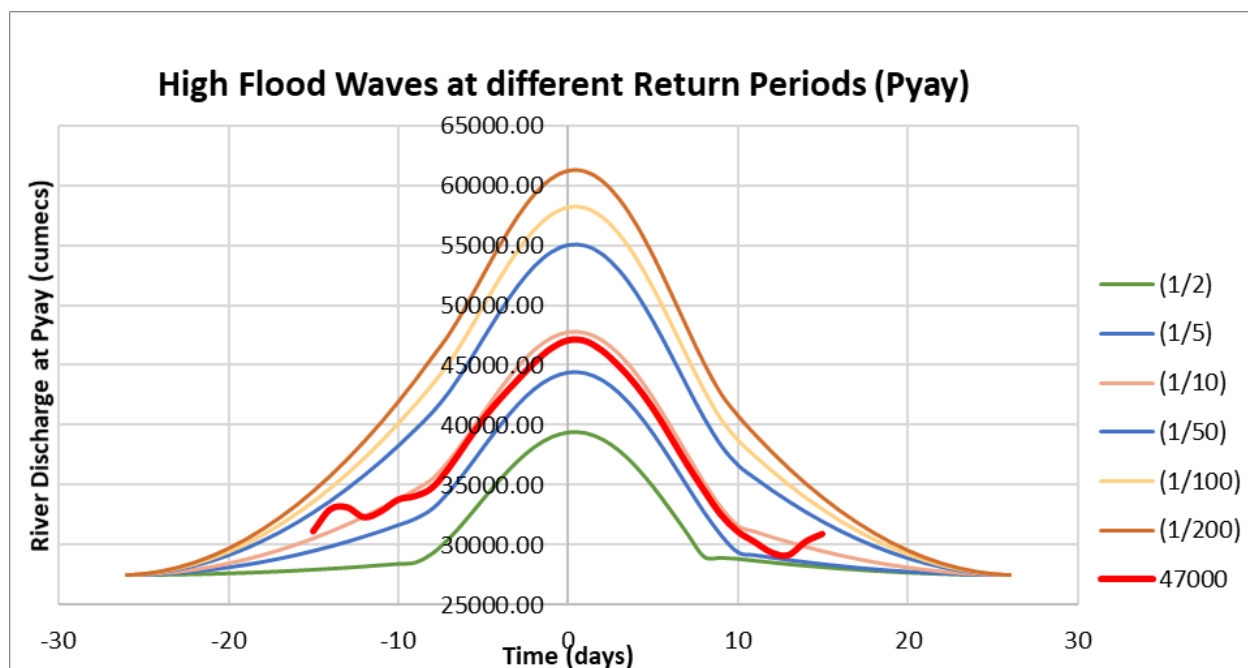


Figure 26: High water discharge waves with varying return periods forced at Pyay to assess the fluvial water security

For each individual dike section the dike heights are compared with the computed maximum water level along the considered dike section per return period. Based on this, it is possible to identify the 'weakest link' per section. This is the location where fluvial flooding occurs first or, in case no flooding occurs during the 1/200 scenario, the location with the smallest remaining margin.

Subsequently, the water security level is determined per dike section. Three different results can be distinguished:

- Overflow is computed at one or more locations along the considered dike section during the mildest event (i.e. the 1/2 year event); the dike section has a fluvial safety level of $>1/2$ (more frequent than once every 2 years) with the location of the largest exceedance as weakest link.
- Overflow is first computed at a certain location for a return period between 1/2 and 1/200 years; the exact fluvial safety level for the considered dike section is determined by means of interpolation using a Weibull distribution fit function.
- No overflow is computed along the considered dike section during the most extreme event (i.e. the 1/200 year event); the dike section has a fluvial safety level of $<1/200$ (less frequent than once every 200 years) with the location of the smallest remaining margin as weakest link.

3.2 Water scarcity and salt intrusion

An overview of the applied external boundary forcing is given in Table 16. On the upstream river boundaries a constant low discharge is forced representative for the return period considered. On the coastal boundary a spring-neap tidal forcing is applied. The locations where irrigation practices are currently taking place were determined. The freshwater irrigation demand for early February is forced, representative for the yearly peak extraction rate. In addition, the freshwater extractions for (re)filling of the aquaculture ponds is accounted for. Lastly, a salinity of 30 ppt is forced on the coastal boundaries.

Table 16: Overview of the external boundary forcing for the water scarcity event

Boundary	Forcing
Upstream river: Pyay	Constant discharge (varies with return period)
Upstream river: Bago	Constant discharge (varies with return period)
Upstream river: Pazundaung Creek	Constant representative discharge (0 m ³ /s)
Coastal boundary	Spring-neap tidal cycles
Freshwater extraction(s)	Peak freshwater extractions for irrigation and aquaculture
Wind and atmospheric pressure	None
Precipitation	None
Drainage	Natural drainage only
Salinity	30 ppt on coastal boundaries

The modelling effort for this event is twofold. Firstly, the low water discharge distribution is computed for a persistent low water discharge situation between 2250 and 1000 m³/s using the channel flow model. These particular low water discharges in combination with a duration represent certain return periods. This is outlined in more detail in Section 2.3.3. Secondly, the salinity model is run for a limited amount of stationary low discharges in order to limit the total computational effort. Based on the results of the salinity model, the intrusion length (i.e. location of the salinity front of 0.5 ppt at the bottom) can be related to a discharge and duration combination. Subsequently, the associated return period can be computed.

Per river branch, the most downstream situated water intake/inlet will function as key location for the consideration of the return period for salinity intrusion.

In addition to the simulation of freshwater scarcity and salinity intrusion, this particular event can also be used to assess the navigability at certain pre-defined bottlenecks. The minimal water levels can be used to assess navigability at certain key locations. As the current model bathymetry is the result of manual interpolation of cross-sectional data and might not accurately represent the course of the waterway (thalweg), it is recommended to find key locations in the RWSS where navigation problems are most common. At these key locations, the water depth should be determined with additional measurements, to ascertain the exact local bottom profile. In combination with the simulated minimal water level, using the guidelines for the interpretation of the model results, the local minimal water depth can then be determined. This indicator can then be used to assess the (impact on) navigability. In addition, this can be related to a return period. This analysis could not be carried out at this moment, as the main navigation bottlenecks and required detailed river bed geometry are not available yet.

3.3 Pluvial Flooding

An overview of the applied external boundary forcing is given in Table 17. On the upstream river boundaries a constant discharge is forced representative for a mean high river discharge. On the coastal boundary a spring-neap tidal forcing is applied. Precipitation is forced with a spatial and temporal variation, representative for the return period considered. Evaporation and infiltration are accounted for. The large scale catchment behavior of the area is simulated in the model. In addition, a schematization of the large-scale drainage (i.e. significant drainage by means of water systems and through sluices not included in the current model because of limitations as a result of the model detail) is now included as well.

Table 17: Overview of the external boundary forcing for the pluvial event

Boundary	Forcing
Upstream river: Pyay	Constant representative discharge (27,500 m ³ /s)
Upstream river: Bago	Constant representative discharge (450 m ³ /s)
Upstream river: Pazundaung Creek	Constant representative discharge (100 m ³ /s)
Coastal boundary	Spring-neap tidal cycles
Freshwater extraction(s)	None
Wind and atmospheric pressure	None
Precipitation	Spatially forced (varies with return period), including evaporation and infiltration
Drainage	Natural drainage and schematized large-scale drainage
Salinity	None

The pluvial flooding scenarios are modelled using the overland flow model. This model includes all catchment areas relevant to the RWSS project area. Spatial results are used to determine (local) inundation extent and (maximum) inundation depths. An area is considered to be inundated at a depth of 'knee-deep'

(e.g. 0.6 m) or more. Subsequently, inundation extent and inundation depth can be computed per sub-area as a function of return period. Finally, a RWSS unit is considered to be no longer eligible for socio-economic activities when 10% or more of the area is inundated with a minimum depth of 0.3 (urban areas) or 0.6 m (rural areas). Using this criterium, an estimate for the level of water security can be made per unit.

3.4 Coastal Flooding

An overview of the applied external boundary forcing is given in Table 18. On the upstream river boundaries a constant discharge is forced representative for a mean river discharge during the cyclone season. The cyclone is fully recreated in the model, using a spider-web forcing with spatially and temporally varying wind velocity and air pressure, based on the Holland model, (Holland et al., 2010). The cyclone severity is scaled using the wind velocity and the pressure drop in the eye, representative for the return period considered. The cyclone track is kept identical to that of Nargis, 2008 (refer to Section 2.5.3). On the coastal boundary a spring-neap tidal forcing is applied. The cyclone passes Yangon City at the moment of spring tide, for a conservative estimate for the total water set-up. A value of 0.5 to 1.0 m is added to the total water level, representative for the wind-wave action during the passage of the cyclone (Fritz et al., 2009). A fixed value of 0.5 m was added to the water level signal on the coastal boundary, representing the average increase in water level due to waves in the coastal zone in the delta. On top of this another 0.5 m was added to the computed water levels throughout the GYR to account for peak wave heights, for instance at the dikes. This results in a total of 1.0 m in the coastal zone, 0.5 – 1.0 m in the transition zone within the delta and 0.5 m in the upstream zone to represent the wave action during a cyclone. With this approach for the wave correction, both the inundation patterns and the calculated water levels in the delta for the 1/100 year scenario are similar to observed characteristics during Nargis.

Table 18: Overview of the external boundary forcing for the coastal (cyclone) event

Boundary	Forcing
Upstream river: Pyay	Constant representative discharge (4,500 m ³ /s)
Upstream river: Bago	Constant representative discharge (25 m ³ /s)
Upstream river: Pazundaung Creek	Constant representative discharge (5 m ³ /s)
Coastal boundary	Spring-neap tidal cycles
Freshwater extraction(s)	None
Wind and atmospheric pressure	Spatially varying (varies with return period)
Precipitation	None
Drainage	Natural drainage
Salinity	None

The coastal (cyclone) flooding is considered for the return periods of 1/25, 1/50, 1/100, and 1/200 years.

The methodology for modelling and assessment of the coastal water security is comparable to the fluvial water security analysis. As flooding of inland areas is expected during (the more severe) cyclone scenarios, it is required to apply the overland flow model.

For each individual dike section the dike heights are compared with the computed water level along the considered dike section per return period. Based on this, it is possible to identify the 'weakest link' per

section. This is the location where fluvial flooding occurs first or, in case no flooding occurs during the 1/200 scenario, the location with the smallest remaining margin.

Subsequently, the water security level is determined per dike section. Three different results can be distinguished:

- Overflow is computed at one or more locations along the considered dike section during the mildest event (i.e. the 1/25 year event); the dike section has a coastal safety level of $>1/25$ (more frequent than once every 25 years) with the location of the largest exceedance as weakest link.
- Overflow is first computed at a certain location for a return period between 1/25 and 1/200 years; the exact coastal safety level for the considered dike section is determined by means of interpolation using a Weibull distribution fit function.
- No overflow is computed along the considered dike section during the most extreme event (i.e. the 1/200 year event); the dike section has a coastal safety level of $<1/200$ (less frequent than once every 200 years) with the location of the smallest remaining margin as weakest link.

4 RESULTS BASELINE ASSESSMENT

4.1 Fluvial Flooding

For a range of high river discharges (e.g. discharges related to return periods of 2, 5, 10, 25, 50, 100 and 200 years) the peak water levels have been simulated throughout the study area. For each individual dike section the dike heights are compared with the computed water level along the considered dike section per return period. Subsequently, the water security level can be determined per dike section. Three different results can be distinguished:

- Overflow is computed at one or more locations along the considered dike section during the mildest event (i.e. the once per 2 year event); the return period for the dike section is smaller than two years, which is expressed with $<1:2$, with the location of the largest exceedance as weakest link.
- Overflow is first computed at a certain location for a return period between 1 per 2 and 1 per 200 years; the exact fluvial safety level for the considered dike section is determined by means of interpolation using a Weibull distribution fit function.
- No overflow is computed along the considered dike section during the most extreme event (i.e. the 1 per 200-year event); the dike section has a fluvial safety level of $>1:200$ with the location of the smallest remaining margin as weakest link.

Figure 27 gives an overview of the fluvial water security level per dike section. The location of the weakest link per dike section is marked along the section. Please note that these markings do not necessarily indicate flooding but instead show the location with the smallest margin between the peak water level and the dike height. The legend on the right of the figure shows the fluvial water security per dike section expressed in the frequency of fluvial flooding. What can be observed is that there is a large variation in the level of water security. Especially, the dike sections with the lower numbers (i.e. 01 through 05 and 12) show a water security level of around 1:10 and lower. This means that overtopping due to fluvial flooding is likely to occur once per ten years or more frequent, on average. Most other dike sections show a fluvial water security level of $>1:50$ or higher. One exception is section 07, which is computed to have a safety level of 1:14.

When looking at the locations of the 'weakest link' it can be observed that many of those are clustered in the eastern section of the Kokowa River and at both ends of the Twante Canal. Figure 28 and Figure 29 show the weak sections along Units 01 and 03 during a 1:10 fluvial event, respectively. During this event, multiple dike stretches of significant length are already shown to be overtopping (indicated by the red colour) and adjacent sections show a remaining margin of <1 m. These stretches are focused along the Kokowa river, mainly to the east of Mezali.

Figure 30 shows the weak sections along the Twante Canal, covering multiple Units. It can be observed that fluvial flooding is predicted during the 1:10 fluvial event, especially along the western half of the Twante Canal (Units 5 d 12). Most of this section is shown in red, indicating overtopping. Although the eastern half (Units 7 and 8) shows significantly less dike stretches where overtopping can be expected in such an event, the remaining margin is less than 1 m for most of the dike sections.

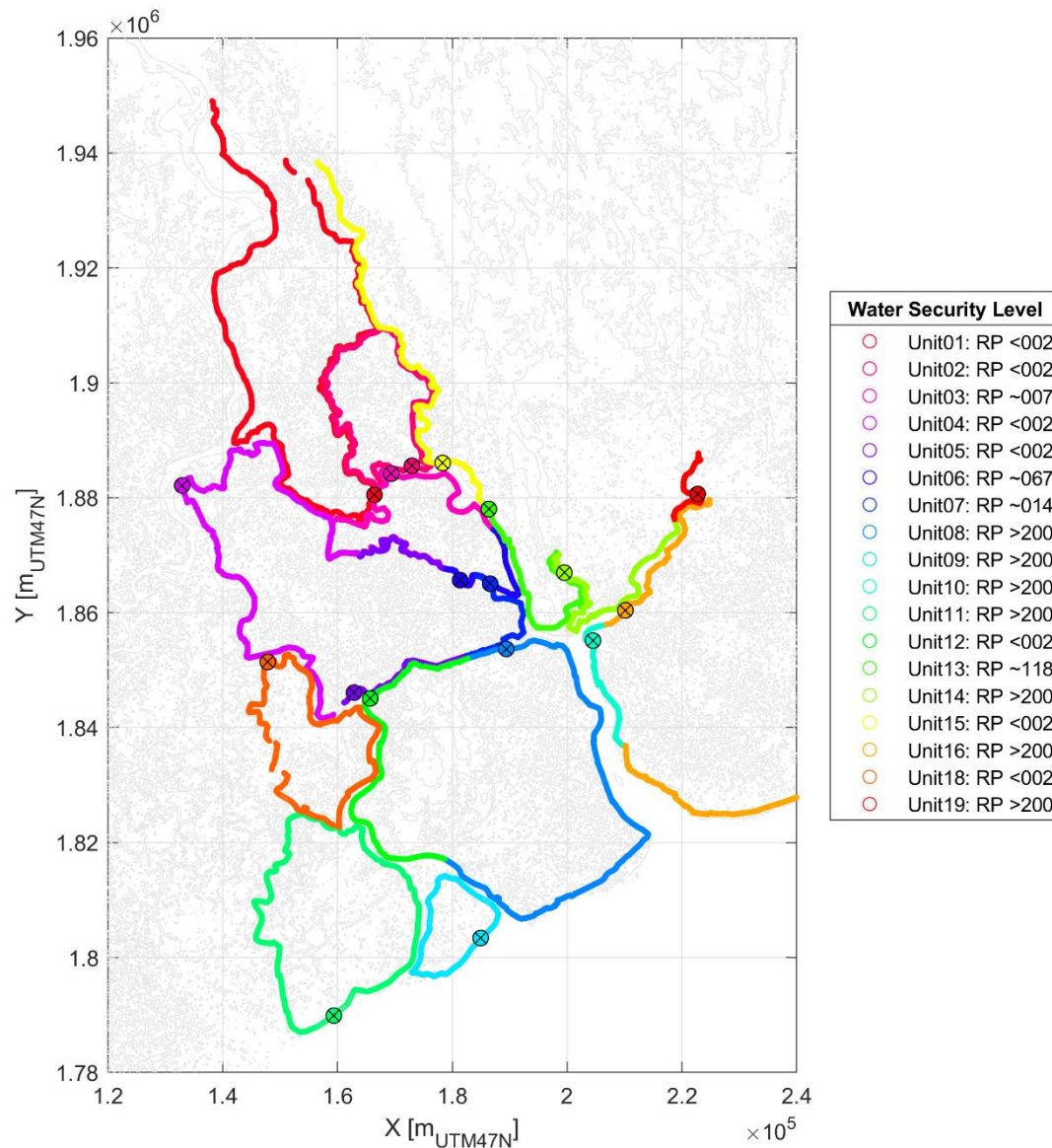


Figure 27: Overview of the fluvial water security level per dike section. The location of the weakest link per dike section is marked along the section.

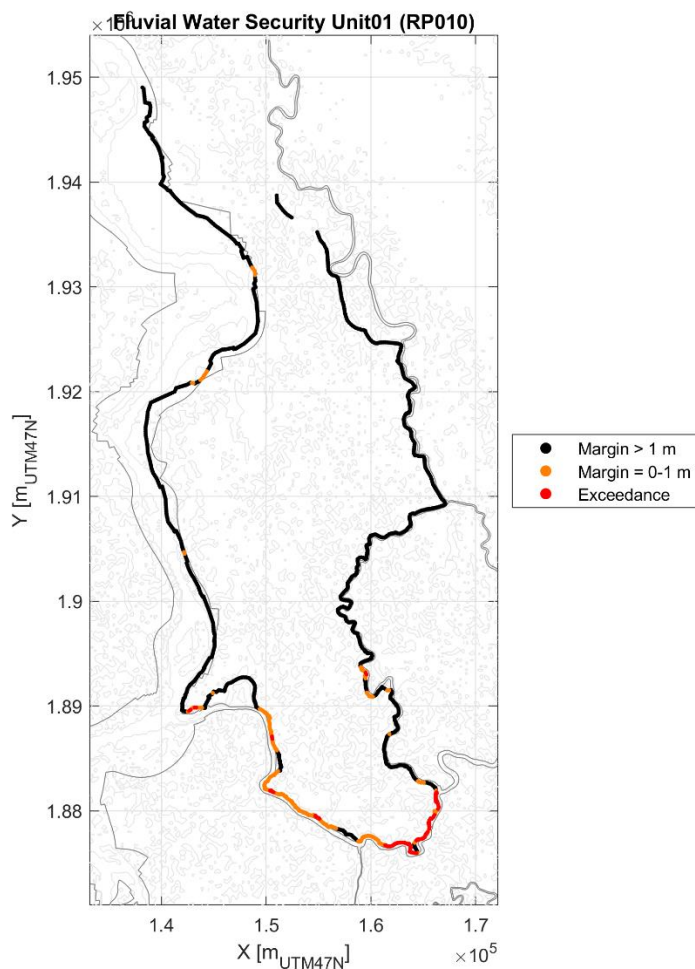


Figure 28: Identification of weak section(s) along Unit01 during a 1:10 fluvial event

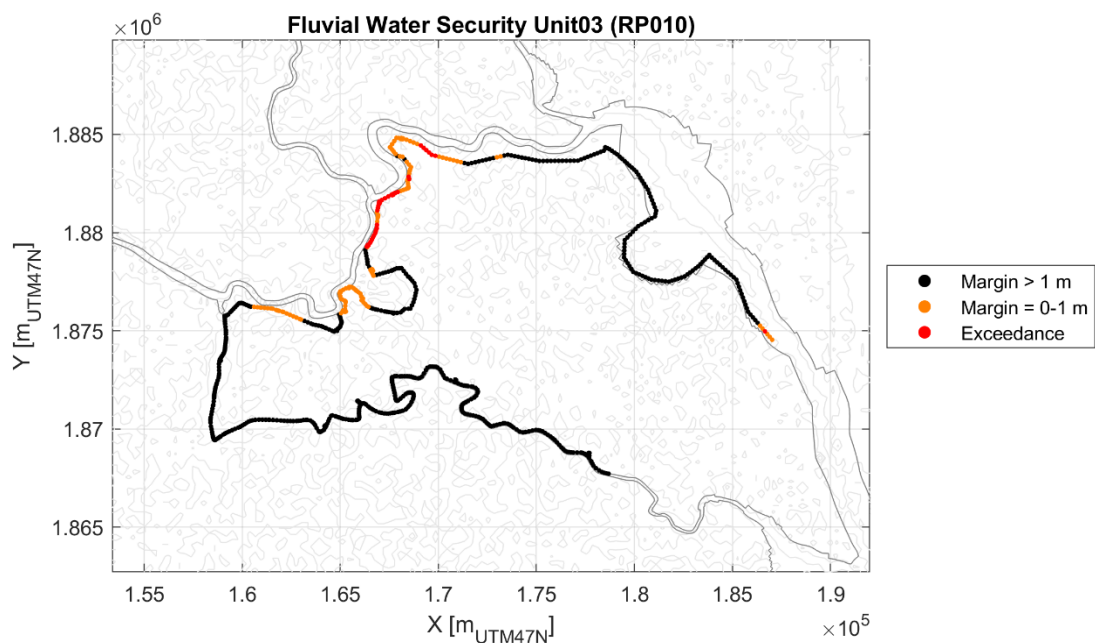


Figure 29: Identification of weak section(s) along Unit03 during a 1:10 fluvial event

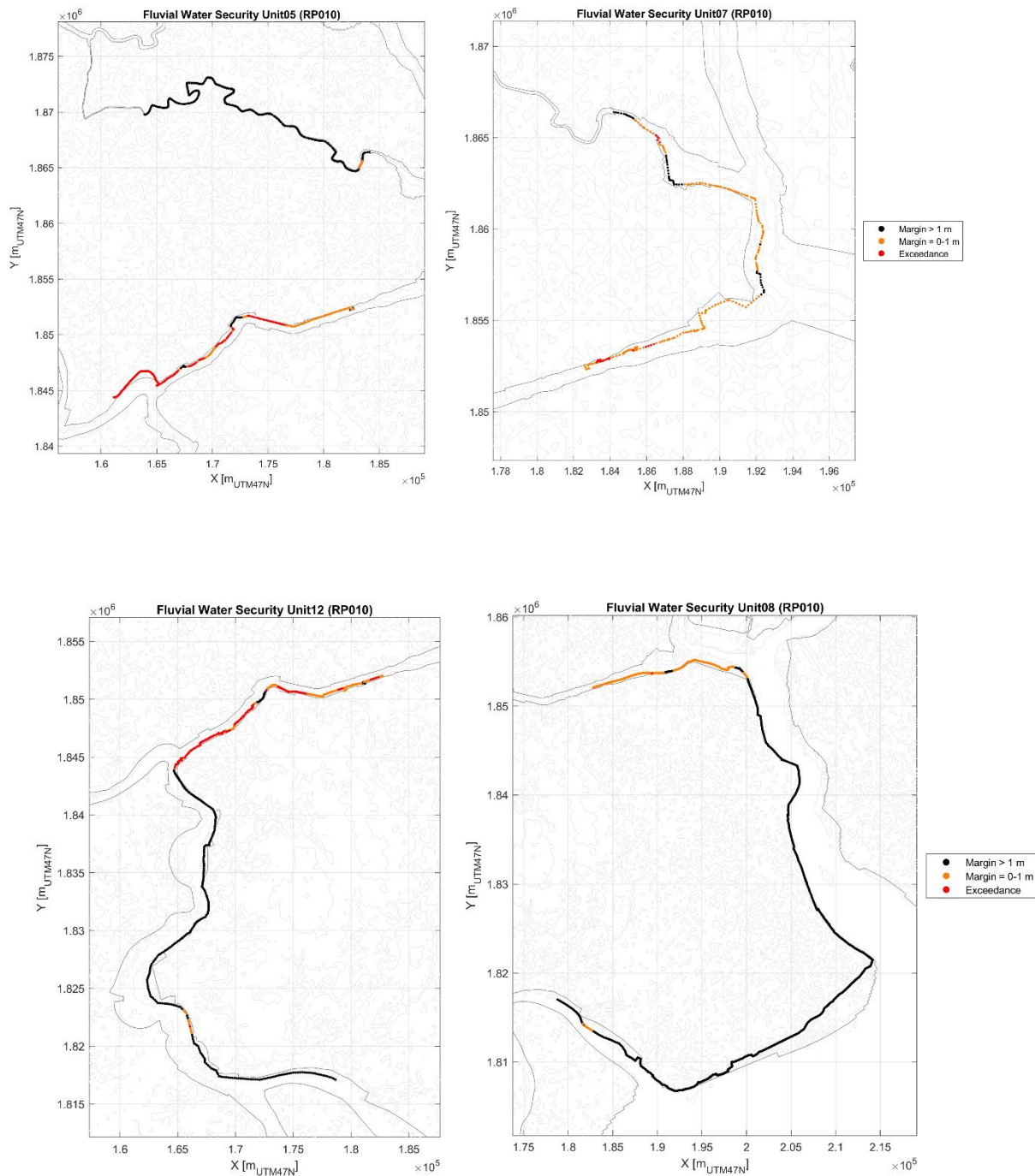


Figure 30: Identification of weak sections along the Twante Canal during a 1:10 fluvial event. Including Unit05 (upper left), Unit07 (upper right), Unit12 (lower left) and Unit08 (lower right).

4.2 Water scarcity and salt intrusion

First, the impact of (peak) freshwater extractions is simulated using the channel flow model. Freshwater extractions for all known irrigation use and aquaculture is accounted for. Future scenarios might also include additional extractions for urban and industrial use as well as an increase of existing extractions. Currently, the peak freshwater extraction is computed to be approximately 250 m³/s, occurring during the first half of February.

Table 19 shows the river discharges in the system for a representative low river discharge at Pyay (2,250 m³/s) for a situation without extractions and with peak freshwater extractions. The impact of the extractions is limited to the region south of Nyaungdon. Moreover, the observed impact in the relevant river sections is relatively small at a decrease of 30-40 m³/s, roughly 12-16% of the combined extraction discharge in the entire Yangon Region. The relatively small impact is due to the fact that most extractions are located further downstream and/or more to the west and therefore have negligible impact on the discharge through the considered river sections. The increase at Mezali is a result of the extractions along the Pan Hlaing river. Because this river is closed off by a Cofferdam in the east, filling of this river can only occur via the Mezali Sluice.

Table 19: Tide averaged discharges with and without peak extraction discharges (2,250 m³/s at Pyay)

Location	Discharge (no extractions) [m ³ /s]	Discharge (peak extractions) [m ³ /s]	Difference [m ³ /s]
Pyay	2250	2250	0
Nyaungdon (upstream)	1970	1970	0
Nyaungdon (downstream)	1560	1560	0
Nyaungdon (side)	410	410	0
Mezali (south)	0	15	+15
Maubin (Toe river)	510	480	-30
Hlaing river	390	360	-30
Kokowa (east)	445	405	-40

Secondly, the salt intrusion into the Yangon delta over time is simulated for multiple continuously low river discharges using the 3D salinity model. This section presents the evaluation of the upstream salt intrusion along the two main river branches moving into the Yangon Delta:

1. The Yangon River into Hlaing River into Kokowa/Upper Haling River branch;
2. The Toe River.

The salt intrusion is evaluated along the length axis of these river sections, starting at the Hlaing River mouth and Toe River mouth, respectively and following an upstream orientation. The maximum intrusion length of the salt along the axes of these rivers is computed as a function of return period. Please note that for the evaluation of the salt intrusion along the first of the two river sections, a fixed length of 25 km is added to the computed intrusion length to account for model inaccuracies (Arcadis, 2019).

The salinity intrusion over time was computed for three discharges at Pyay; 750 m³/s, 1250 m³/s and 2250 m³/s, which can be considered as an extremely low, a very low and a mean low discharge, respectively. In combination with the computed discharge distributions for the once per 2, 5, 10, 50, 100 and 200 year low discharges, including peak freshwater extractions, the intrusion length was computed along both river axes as a function of the return period. For interpolation between return periods, a Weibull extreme value fit was applied.

Figure 31 and Figure 32 show the location of the salt front at the moment of maximum intrusion as a function of return period for both considered river branches. It is shown as a function based on a Weibull fit through the model results. It can be observed that the model results represent different fixed return periods along the graphs. This is the result of the fixed discharges forced at Pyay that don't necessarily scale linearly to the discharges in the Kokowa and Toe Rivers, the effective discharge that present the counterforce for the intrusion. A result of a non-linear discharge distribution throughout the Yangon Delta as well as a non-uniform spreading of the current fresh-water demands.

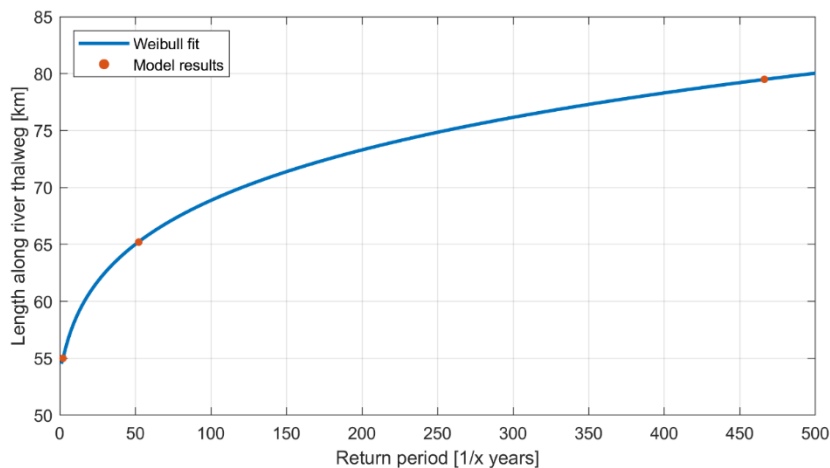


Figure 31: Location of the salt front into the Hlaing River and into Kokowa River as a function of return period

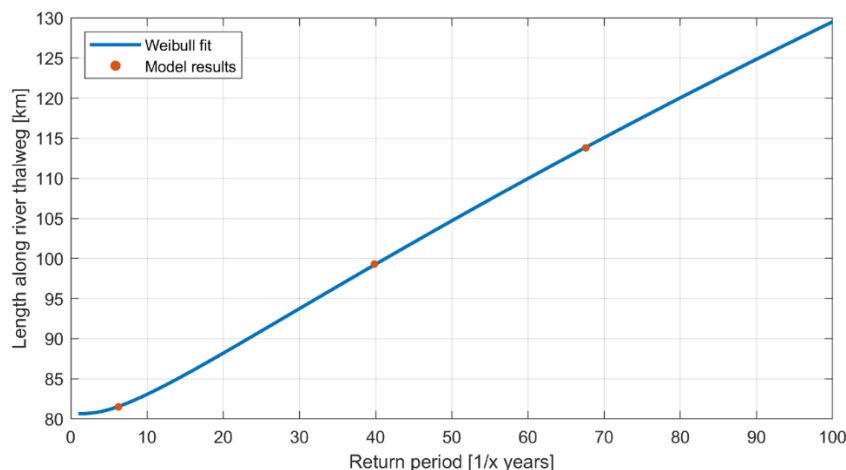


Figure 32: Location of the salt front into the Toe River as a function of return period

When looking at the results, it is important to note that, presently, the 'once per year' location for both river sections is approximately 55 and 81 km (upstream from the mouth), respectively. What this means is that the salt front reaches this point yearly resulting in a return period of once per year or more frequent for all key locations at this point or further downstream. For these locations, the salt intrusion could instead be expressed in days per year. This was not included during this phase of the study. The reason for the discrepancy in intrusion distance for both rivers is likely due to the Toe River also being connected to the Yangon River via the Twante Canal, roughly at km 65, importing salt water during flood tide.

Secondly, it can be observed that the shape of both function is different. This is likely due to the gradually decreasing shape for the first river branch. The cross-sectional area reduces significantly from Hlaing River into the Kokowa river. This means that the further the salt front reaches, the more effective a freshwater discharge can push it back. For the Toe River, the cross-sectional area is fairly constant, resulting in a more linear fit relation.

Finally, when looking at the two key locations situated upstream of the baseline intrusion length, we can find that:

- The key location at Katwe, roughly 67 km upstream from the Hlaing River mouth, is reached by the salt front once per 72 years, on average.
- The key location near Maubin, roughly 84 km upstream from the Toe River mouth, is reached the salt front once per 12 years, on average.

- For all other key locations, situated further downstream, the return period is once per year or more frequent

The results are summarized in Figure 33.

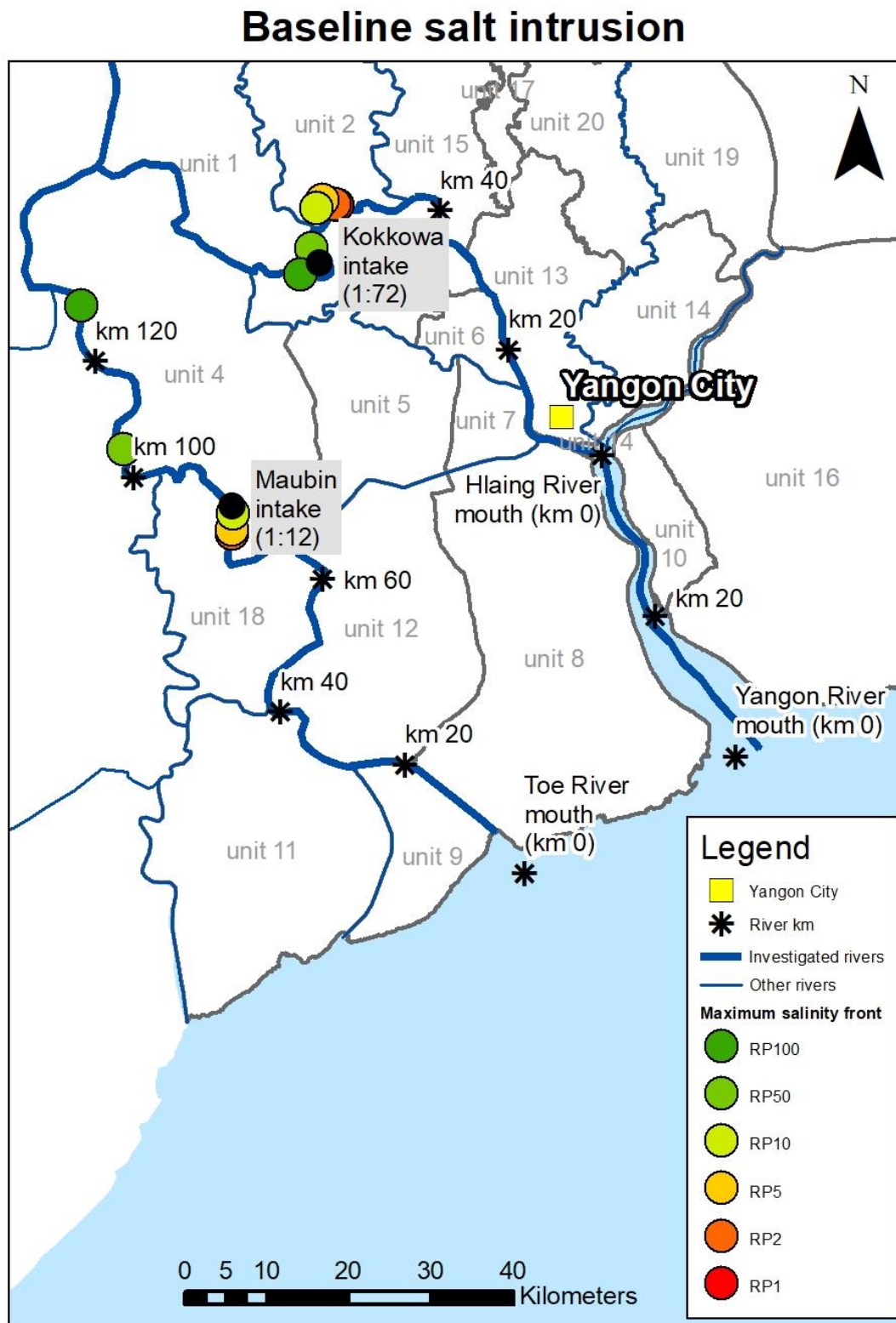


Figure 33: Estimated return periods for salt intrusions at key locations

4.3 Pluvial Flooding

The pluvial flooding is evaluated using the spatial inundation (depth and extent) per RWSS unit. For each return period, the total inundation extent is evaluated, accounting for the respective drainage capacity per unit. Of the 82 known drainage locations 77 can be allocated to a RWSS unit. An overview is given in Table 20. It can be observed that the *known* drainage locations are fairly concentrated in a select number of units. A tide-averaged drainage capacity per return period is accounted for. It should be noted that this capacity is dependent on the (average) hydraulic head and could be reduced as a result of storm set-up. This is not accounted for in this analysis. In addition, the predominant setting per unit is used to determine the threshold for the inundation depth. It is assumed that above this threshold, 0.3 m for urban and 0.6 m for rural, the socio-economic functioning of this area is severely limited and/or evacuating becomes a necessity.

Table 20: RWSS unit properties related to pluvial flooding.

RWSS Unit	Area [km ²]	Active drain points [-]	Setting [-]	Threshold [m]
Unit01	1275	0	Rural	0.6
Unit02	341	0	Rural	0.6
Unit03	290	14	Rural	0.6
Unit04	887	12	Rural	0.6
Unit05	370	8	Rural	0.6
Unit06	90	0	Urban	0.3
Unit07	97	2	Urban development planned	0.6
Unit08	1076	15	Urban development planned	0.6
Unit09	201	0	Rural	0.6
Unit10	132	0	Urban	0.3
Unit11	765	4	Rural	0.6
Unit12	624	10	Rural	0.6
Unit13	361	0	Urban	0.3
Unit14	289	0	Urban	0.3
Unit15	955	0	Rural	0.6
Unit16	2386	3	Rural	0.6
Unit17	1487	0	Higher grounds	0.6
Unit18	396	9	Rural	0.6
Unit19	481	0	Rural	0.6
Unit20	337	0	Rural	0.6

The peak inundation properties are simulated per RWSS unit. It should be noted that the RWSS model, in its current iteration, only includes the large scale (>1km) topographical rainfall run-off, accounting for known drainage. Anything with a smaller physical scale is not included. This means that small waterways, streams,

creeks, ditches and the like that would realistically impact the distribution of water within the unit to some extent are not considered. In addition, small levees, dikes, heightened roads and the like that would limit the distribution are also not included following the same logic. This means that one should only interpret the simulated inundation on a large scale and apply the results and conclusions of this analysis accordingly. The possible shortcomings of this approach have been researched by modelling the pluvial inundation using a more detailed model covering Unit08, with the larger RWSS model providing its hydrodynamic boundaries. This additional study is discussed in chapter 7 of this appendix.

The inundation map of RWSS unit03 for pluvial events with a different return period is shown in Figure 34 and Figure 35 per example. For the once per year rainfall event, the peak inundation depth is limited to 0.1-0.5 m for roughly 25% of the unit area. The inundation depth for the remainder of the area is <0.1 m. In case of an 1:1000 pluvial event, the inundation is more severe. Roughly 80% of the area shows an inundation of >0.1 m, with 20% above 0.5 m, but mostly limited to 1 m. It can be observed that, for unit03, the larger inundation depths tend to be concentrated close to the location of the dikes surrounding the unit.

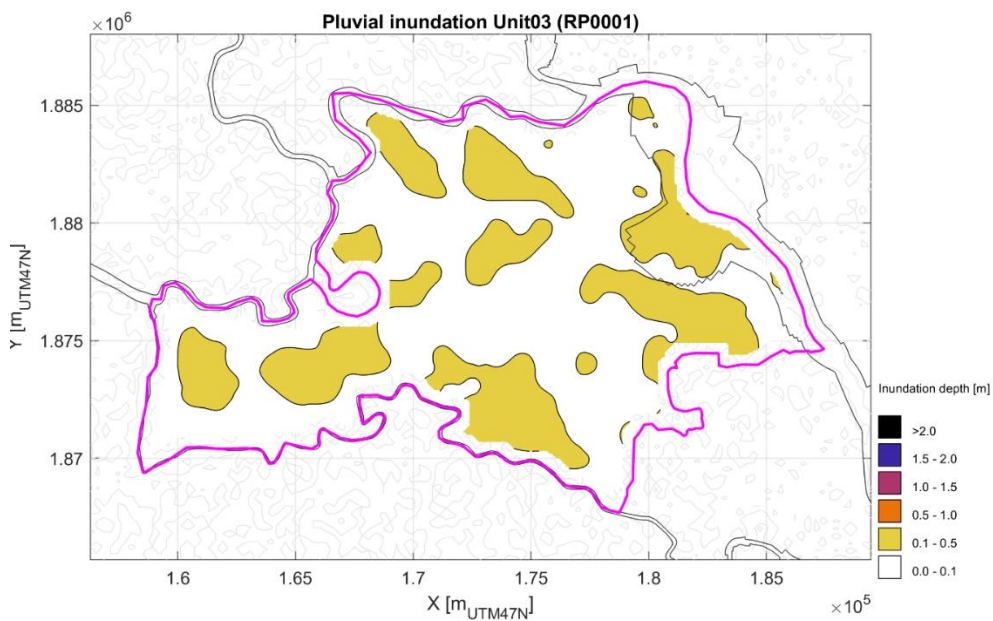


Figure 34: Peak pluvial inundation pattern for RWSS unit03 as a result of a 1:1 pluvial event.

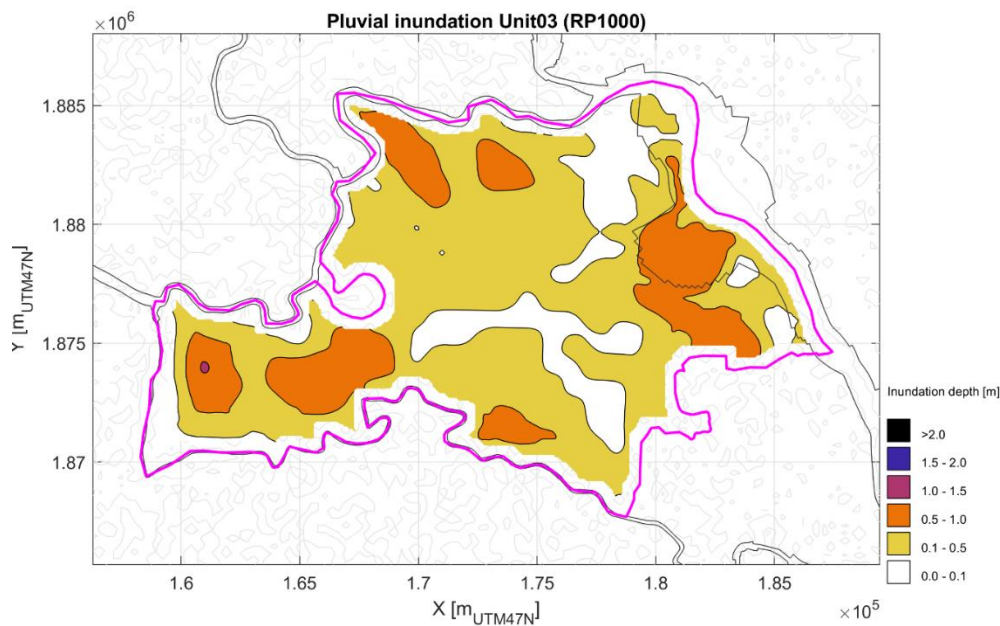


Figure 35: Peak pluvial inundation pattern for RWSS unit03 as a result of a 1:1000 pluvial event.

When evaluating the units using their respective values for the peak inundation depth; >0.3 m (urban) and >0.6 m rural), the extent of pluvial inundation can be evaluated per return period, expressed as a percentage of unit area or in km² per unit area. The results are collected in Table 21 and Table 22.

The following can be observed:

- No significant inundation is estimated during the pluvial event occurring 5 times a year.
- When assuming that an inundation extent of more than 10% of the respective unit area can be considered to result in a limitation of the social and/or economic functioning of an area, all but one area still function during a once per two year event.
- Per the same criterium, Unit 05 through 09, 11, 12, 17 and 18 are shown to be functioning even during a 1:1000 event.
- In contrast, the northern units 01 and 02, as well as the areas more to the east, units 14, 16 and 19 are especially sensitive to pluvial flooding.

Table 21: Percentage of RWSS unit area with an inundation above the threshold value per return period.

RWSS Unit	0.2	1	2	5	10	25	50	100	250	500	1000
Unit01	0%	1%	6%	8%	10%	14%	17%	19%	22%	23%	25%
Unit02	0%	2%	6%	9%	10%	14%	16%	19%	23%	25%	27%
Unit03	0%	0%	0%	1%	1%	1%	2%	4%	7%	10%	11%
Unit04	0%	0%	1%	3%	3%	5%	6%	8%	11%	13%	15%
Unit05	0%	0%	0%	0%	0%	1%	2%	2%	3%	4%	5%
Unit06	0%	1%	5%	6%	6%	6%	7%	8%	9%	9%	10%
Unit07	0%	0%	1%	1%	1%	2%	3%	4%	5%	6%	5%
Unit08	0%	0%	0%	1%	2%	2%	3%	4%	6%	7%	7%
Unit09	0%	0%	0%	0%	0%	0%	0%	1%	1%	1%	2%
Unit10	0%	3%	6%	8%	8%	10%	10%	10%	11%	12%	13%
Unit11	0%	0%	2%	4%	5%	6%	7%	7%	7%	8%	9%
Unit12	0%	0%	1%	1%	2%	2%	2%	3%	3%	4%	4%
Unit13	0%	3%	7%	10%	10%	11%	13%	13%	14%	15%	15%
Unit14	0%	4%	14%	18%	20%	26%	31%	35%	39%	41%	44%

Unit15	0%	4%	9%	11%	13%	16%	17%	20%	21%	23%	24%
Unit16	0%	1%	10%	14%	18%	21%	23%	26%	29%	30%	31%
Unit17	0%	2%	4%	6%	6%	7%	8%	8%	9%	9%	9%
Unit18	0%	0%	0%	1%	1%	3%	5%	6%	8%	9%	9%
Unit19	0%	2%	8%	15%	18%	24%	28%	32%	36%	38%	40%
Unit20	0%	2%	6%	8%	10%	15%	17%	19%	21%	23%	25%

Table 22: RWSS unit area [in km²] with an inundation depth above the threshold value per return period.

RWSS Unit	0.2	1	2	5	10	25	50	100	250	500	1000
Unit01	0	15	78	104	126	173	214	247	282	296	315
Unit02	0	5	20	30	35	47	55	66	78	86	92
Unit03	0	0	1	2	2	4	6	11	22	28	31
Unit04	0	0	11	22	30	47	55	71	94	117	132
Unit05	0	0	0	0	0	4	6	9	12	17	19
Unit06	0	1	4	5	5	6	7	7	8	9	9
Unit07	0	0	1	1	1	2	3	4	5	5	5
Unit08	0	0	3	11	18	25	36	44	61	77	76
Unit09	0	0	0	0	0	0	0	2	3	3	4
Unit10	0	4	8	10	11	13	13	14	15	16	17
Unit11	0	0	14	28	37	46	50	54	57	63	66
Unit12	0	0	7	9	12	13	15	17	20	23	25
Unit13	0	9	26	34	36	41	46	48	51	53	54
Unit14	0	12	40	53	59	77	91	101	112	120	126
Unit15	0	43	88	110	126	148	166	188	204	216	228
Unit16	0	27	231	345	421	503	551	623	682	709	744
Unit17	0	31	66	86	96	106	113	122	128	130	134
Unit18	0	0	1	4	6	12	21	24	30	37	37
Unit19	0	8	39	72	87	116	133	154	173	183	190
Unit20	0	5	20	27	33	52	57	64	71	79	85

Finally, as a sensitivity analysis, the level of water security was computed for multiple criteria for the inundation extent within the units. Table 23 shows an overview of the computed return periods for pluvial inundation per unit when an extent of 5, 10 and 20% of the unit area is adopted as the spatial criterium. It shows that the water security level for pluvial flooding is quite sensitive for the choice of threshold value for area inundated deeper than 0.3 or 0.6 m.

Table 23: Pluvial water security level for multiple inundation extent criteria

RWSS Unit	WS [1/x year] (5% area)	WS [1/x year] (10% area)	WS [1/x year] (20% area)
Unit01	1	10	135
Unit02	1	9	128
Unit03	144	613	1000
Unit04	22	213	1000
Unit05	947	1000	1000
Unit06	3	1000	1000
Unit07	206	1000	1000
Unit08	186	1000	1000
Unit09	1000	1000	1000
Unit10	1	44	1000
Unit11	11	1000	1000
Unit12	1000	1000	1000
Unit13	1	9	1000
Unit14	1	1	9
Unit15	1	3	127
Unit16	1	2	20
Unit17	3	1000	1000
Unit18	46	1000	1000
Unit19	1	2	14
Unit20	1	10	178

4.4 Coastal Flooding

The modelling of the passage of cyclone Nargis (2008) over Yangon from west to east on the 2nd and 3rd of May 2008, results in a significant water level increase. The water level increases due to the combination of the pressure drop and a wind-induced water level set-up. Figure 36 shows the characteristics of cyclone Nargis as simulated by the model. The left frame shows the air pressure and the right frame shows the wind velocity and direction. As can be observed, the eye passes right over Yangon, resulting in a local increase in water level due to the pressure drop. In addition, when the cyclone is moving towards Yangon, the wind is directed into and along the Yangon River resulting in a further increase in water level.

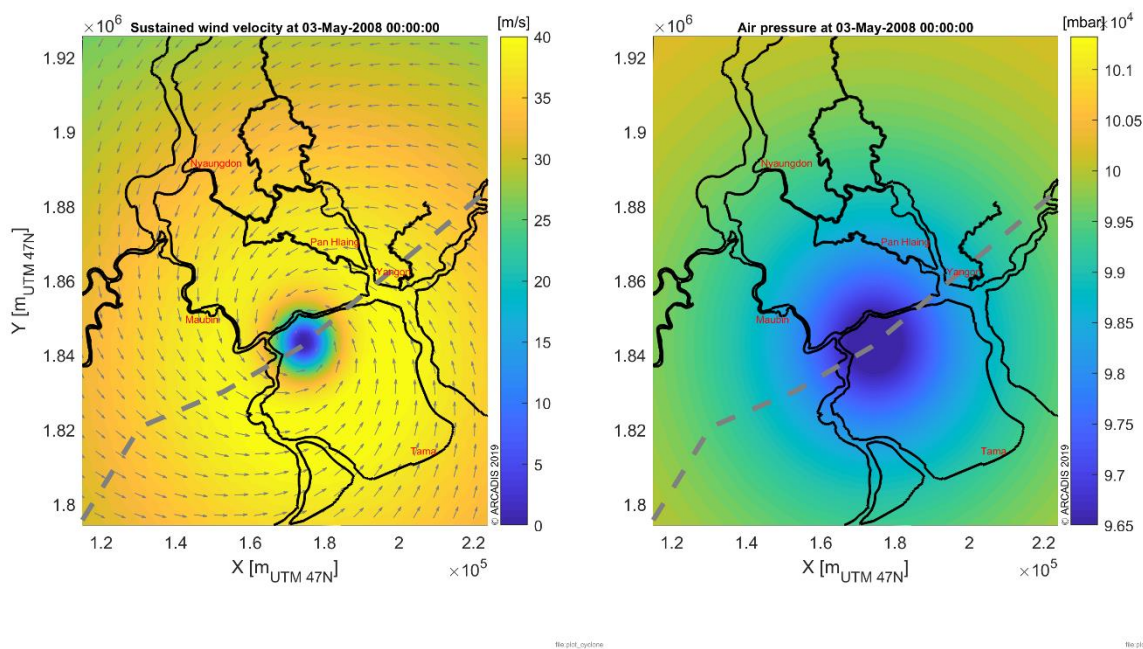


Figure 36: Simulated characteristics of cyclone Nargis during its passage over Yangon, the cyclone track is indicated with the dashed grey line.

As described in Section 2.5, the cyclone Nargis was scaled to represent cyclone events that occur every 25, 50, 100 and 200 years, on average. This was done by scaling the wind velocity and pressure drop, while keeping the cyclone track identical to Nargis. Going from south to north along the Yangon River towards Yangon City, Figure 37, Figure 38 and Figure 39 present the water level fluctuation at Elephant Point, Monkey Point and Htantabin, respectively. The blue graphs show the baseline water level signal (identical hydrodynamic conditions, but no wind forcing) and the other graphs show the water level with cyclone forcing. As is the case with the tidal signal, the impact of the cyclone is amplified when moving into the delta, mainly due to funneling. The simulated peak water levels not only increase with increased wind forcing, but also when moving into the Yangon delta.

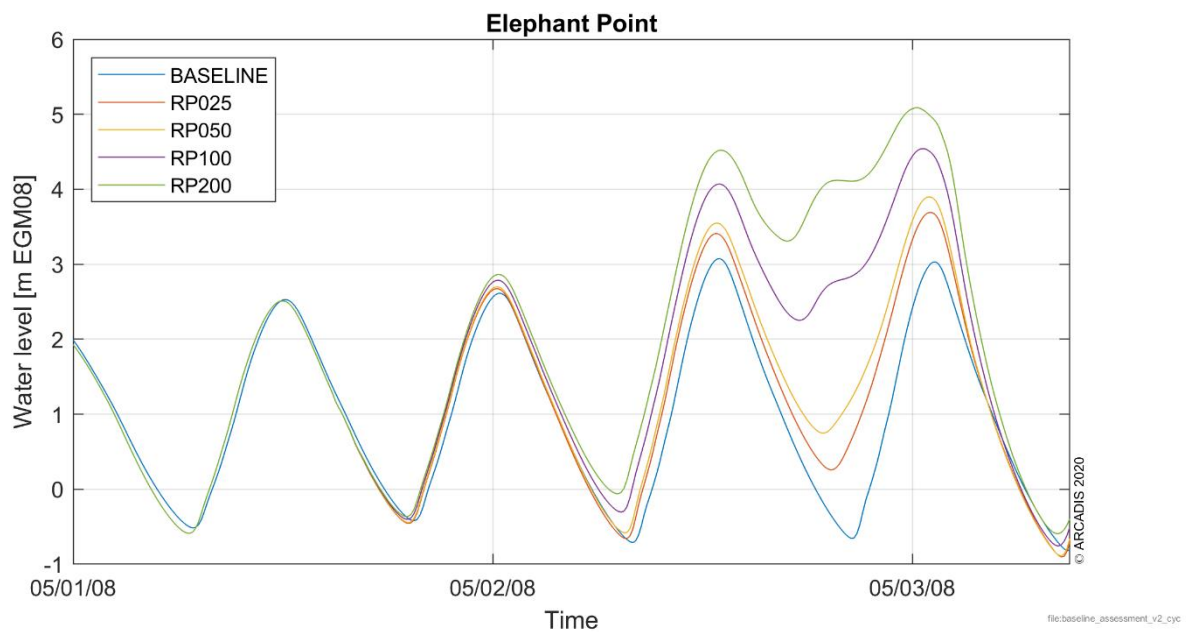


Figure 37: Simulated water level time series at Elephant Point

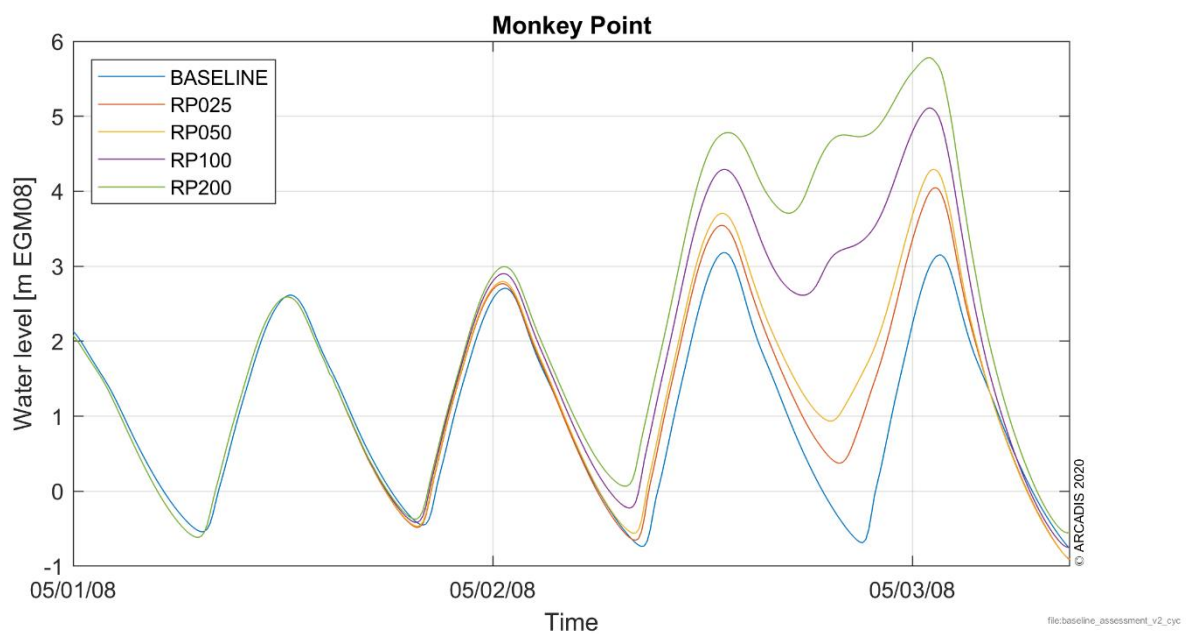


Figure 38: Simulated water level time series at Monkey Point

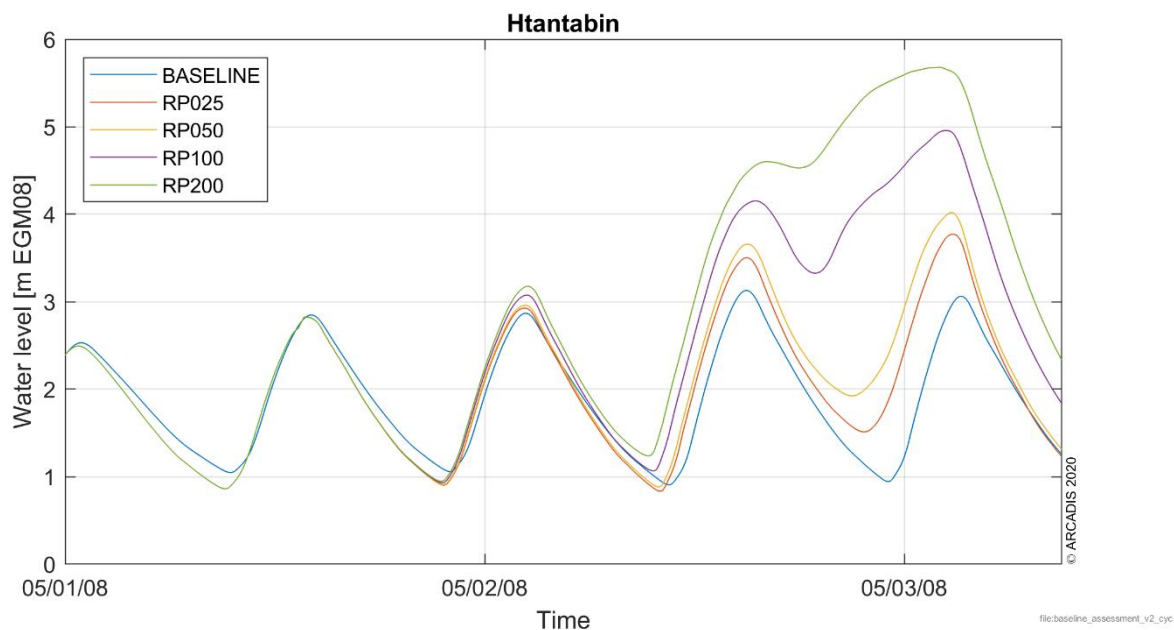


Figure 39: Simulated water level time series at Htantabin

Subsequently, the computed peak water level during the passage of the cyclone is compared to the local dike heights to get an indication of the level of coastal water security. To large degree comparable to the analysis for the fluvial water security. Three different results can be distinguished:

- Overflow is computed at one or more locations along the considered dike section during the mildest event (i.e. the once per 2 year event); the dike section has a fluvial safety level of $<1:2$ with the location of the largest exceedance as weakest link.
- Overflow is first computed at a certain location for a return period between 1 per 2 and 1 per 200 years; the exact fluvial safety level for the considered dike section is determined by means of interpolation using a Weibull distribution fit function.
- No overflow is computed along the considered dike section during the most extreme event (i.e. the 1 per 200 year event); the dike section has a fluvial safety level of $>1:200$ with the location of the smallest remaining margin as weakest link.

Figure 40 gives an overview of the coastal water security level per dike section. The location of the weakest link per dike section is marked along the section. Please note that these markings do not necessarily indicate flooding but instead show the location with the smallest margin between the peak water level and the dike height. The legend on the right of the figure shows the coastal water security per dike section expressed in the frequency of coastal flooding. It is important to note that Nargis (2008) is considered to be representative for a 1:100 year storm condition. Effectively, this means that all dike sections that have a computed level of safety of 1:100 or less, are predicted to have been overtopped at one or more locations along the dike section.

What can be observed is that there is (again) a large variation in the level of water security. Generally, the coastal dike sections present the lowest safety level, which is to be expected as coastal flooding conditions tend to gradually decrease in severity further into the delta. It can also be noted that a large number of 'weakest points' are located in the mouth of the Hlaing River, directly to the west and northwest of Yangon City (indicated with the red circle in the figure). This is most likely related to the funneling effect of any local water level increase. The same was observed for the local tidal amplitude, but the effect is also present during a water level increase as a result of storm surge set-up.

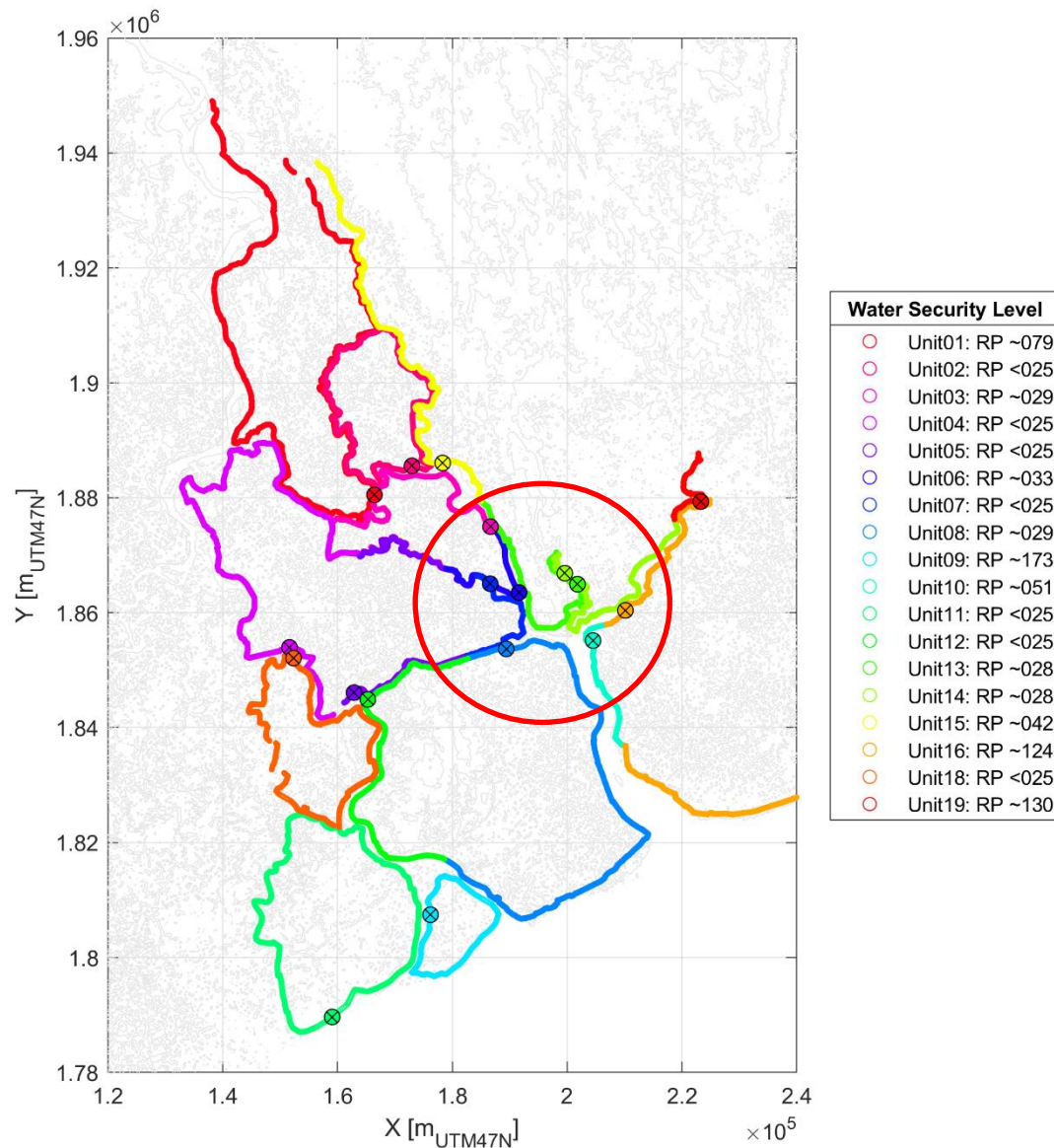


Figure 40: Overview of the coastal water security level per dike section. The location of the weakest link per dike section is marked along the section.

5 IMPACT ASSESSMENT OF CLIMATE CHANGE AND UPSTREAM DEVELOPMENTS

5.1 Approach

To assess the impact of climate change and future upstream developments, the hydrodynamic models from the Baseline Water Security are modified to include the expected changes induced by climate change representative for 2040. The following baseline situations are defined:

- Riverine flooding: high river discharge in combination with spring tide.
- Freshwater scarcity: low river discharge in combination with spring tide.
- Coastal flooding: storm conditions (e.g. cyclone) with average river discharge.
- Pluvial flooding: extreme rainfall with average river discharge.

In order to get a better understanding of how climate change and future upstream developments will impact the baseline situation, the 2040 climate change scenario and upstream developments (for current climate) are simulated and presented.

In order to assess the impact of climate change and future upstream developments (dams) on the water security for GYR, the model settings and boundary conditions are accordingly adjusted based on the baseline simulations settings (Chapter 2 and 3). Using the same methodology of determining the weakest links per unit and the corresponding return period allows to make comparisons with the return periods from the baseline assessment. The change in return period is the regional effect caused by the various climate change processes (i.e. rainfall intensity, river discharge, sea level rise) or the upstream developments (i.e. dams, reservoirs, hydropower, etc.).

5.2 Climate change

5.2.1 Description

Following literature and expert judgement, climate change will have an impact on the project area. Events such as sea level rise, more intense/frequent precipitation events, increased Himalayan snow melt rates and other processes are expected to alter the present processes within the Ayeyarwady delta influencing the water security for Greater Yangon Region in the future. Below a description of the major changes is discussed and the impact of these on the model boundary conditions is presented.

5.2.1.1 Wet season river discharge

Horton (2016) states that river discharges will increase with 2-12% in the coming period until 2040, see Table 24 below. Therefore, it is envisioned to adopt an increase of 7% on average to the flood discharges in the year 2040 during the wet season.

Table 24: Projected change in mean precipitation (%) in the 2011 – 2040 period compared to the 1980 – 2005 average in eight major regions and for the nation of Myanmar (Source: Horton, 2016)

Town/city	Annual		Hot Season (MARCH TO MAY)		Wet Season (JUNE TO OCTOBER)		Cool Season (NOVEMBER TO FEBRUARY)	
	Low Estimate	High Estimate	Low Estimate	High Estimate	Low Estimate	High Estimate	Low Estimate	High Estimate
Myanmar (All Regions)	+1%	+11%	-11%	+12%	+2%	+12%	-23%	+11%
Ayeyarwady Delta	-1%	+11%	-13%	+18%	0%	+10%	-27%	+13%
Central Dry Zone	+2%	+11%	-14%	+13%	+3%	+12%	-32%	+9%
Northern Hilly	+2%	+13%	-10%	+14%	+3%	+16%	-19%	+8%
Rakhine Coastal	0%	+9%	-17%	+14%	+2%	+10%	-30%	+8%
Eastern Hilly	0%	+10%	-11%	+11%	+2%	+12%	-25%	+9%
Southern Coastal	-1%	+8%	-10%	+8%	-2%	+9%	-11%	+18%
Yangon Deltaic	0%	+12%	-12%	+19%	+1%	+11%	-29%	+14%
Southern Interior	+1%	+11%	-11%	+11%	+1%	+13%	-28%	+14%

5.2.1.2 Dry season river discharge

Horton (2016) presents in Table 24 also the low and high estimates of change in precipitation for the hot (dry) season. The table does not show a clear increase or decrease during this hot season. On average, for Myanmar the change for low flows is around 0% (medium of low and high estimate: -11% and +12%). In addition, no indication is given on the duration of low flows. On the other hand, Horton (2016) describes: “Perhaps most importantly for planning in the water-resource management sector, recent trends and future projections both indicate increasing variability characterised by intensifying fluctuations between dry and wet periods and more frequent extreme weather events. It is critical for the water resources sector to engage other stakeholders in managing this increasing variability. Water resource managers can work with other regions to secure additional drinking water sources for Yangon – this should help to address increasing scarcity during the dry season. They should also plan for increased flooding with the disaster risk reduction sector and, similarly, work with farmers to implement both flood defenses and water-efficiency measures.”

There is a general consensus on an expected increase in frequency and magnitude of extreme events (floods and droughts) in the future. Therefore an average of low and high estimates is considered too conservative. Consequently, RWSS proposes to adopt a 5% reduction of the low flow discharges in the year 2040 representative for dry season flows.

5.2.1.3 Sea level rise

The projected sea level rise is presented in Horton (2016). Table 25: presents the sea level rise for the 25th and 75th percentile representative for the middle-range projections. In the 2080-2089 time period the projected sea level rise varies between 37cm and 83cm with the potential for a level up to 122 cm in the highest range of projections for this time period.

Table 25: Middle range projections of sea level rise above 2000 – 2004 base periods levels in Myanmar (cm).

	2020-2029	2050-2059	2080-2089
SLR above 2000-2004 period	5-13 cm	20-41 cm	37-83 cm

Using the numbers of Horton (2016) and averaging the sea level rise rates, RWSS adopts a sea level rise of 20 cm on average representative for 2040.

5.2.1.4 Cyclones

In the Myanmar Climate Change Strategy and Action Plan (MCCSAP) 2016–2030 from MoNREC (2016), the following is stated based on observations regarding future cyclone events:

“Higher intensity and frequency of cyclones and strong winds. From 1887 to 2015, 1304 tropical storms formed in the Bay of Bengal; 80 (6.7 per cent) reached Myanmar’s coastline (Study of Cyclonic Storms which crossed Myanmar Coasts 1877 to 2015). Cyclones Mala (2006), Nargis (2008) and Giri (2010) were the most severe and damaging cyclones Myanmar has experienced.”

Following this statement, and the insights provided by Horton (2016) who states that “The IPCC has stated that research on future changes in the frequency, intensity and duration of tropical cyclones as a result of climate change is inconclusive (IPCC, 2012).”; and “While predicted cyclone changes over the 21st-century are uncertain, the already-high human vulnerability to cyclones is likely to increase given population growth and rapid development. Furthermore, sea level rises alone will allow storm surges from cyclones of the same magnitude to reach further inland (Wong et al. et al., 2014; IPCC, 2014). An increase in the land area inundated by tropical cyclones will result in more damage to communities, infrastructure and ecosystems that were not previously in the flood zone. Building resilience will thus require planning for coastal inundation and impacts farther inland.”, RWSS proposes not to alter wind nor pressure boundary conditions but incorporates solely a 20cm increase of sea level representative for 2040.

5.2.1.5 Precipitation

Table 24 of Horton (2016) shows a range for changes in precipitation during the wet season from +1 to +11% representative for the Yangon Deltaic Region. Consequently, the RWSS model adopted for the extreme precipitation events an increase of 6% in precipitation intensity.

5.2.2 Model Boundary Condition Adjustments

In summary, Table 26 presents an overview of how each of the affected RWSS model boundary conditions is altered in order to account for climate change, representing a 2040 scenario.

Table 26: Schematization of climate change scenarios in the model boundaries

Parameter	Change in 2040
River flood discharge	+7%
River low discharge	-5%
Sea level rise	+20 cm
Cyclones	0% intensity, sea level rise +20 cm
Precipitation	+6% extreme events

5.2.3 Results

The sections below give a brief summary of the computed impact of the climate change scenario per threat. These results should be viewed in comparison to the baseline results which were presented in Section 4.

5.2.3.1 Riverine Flooding

The impact of the considered climate change scenario with respect to riverine flooding is summarized in Table 27. An increase of 7% in peak river discharge results in an increase in flooding frequency, mainly in the units that were already shown to be sensitive to this threat. Especially units 03, 06, 07, 08 and 13 show a significant decrease in water security level.

Table 27: Return period for fluvial inundation per unit, baseline and climate change scenario

RWSS Unit	WS [1/x year] (baseline)	WS [1/x year] (climate change)
Unit01	<2	<2
Unit02	<2	<2
Unit03	7	<2
Unit04	<2	<2
Unit05	<2	<2
Unit06	67	39
Unit07	14	<2
Unit08	>200	15
Unit09	>200	>200
Unit10	>200	>200
Unit11	>200	176
Unit12	<2	<2
Unit13	118	35
Unit14	>200	>200
Unit15	<2	<2
Unit16	>200	>200
Unit18	<2	<2
Unit19	>200	>200

5.2.3.2 Water scarcity and salt intrusion

The effect on salt intrusion proves to be very noticeable. Both the decrease of 5% of freshwater discharge from upstream and the increased water level downstream as a result of SLR, displace the salt front upstream significantly during (extreme) dry conditions. Table 28 summarizes the result. Salt intrusion at Katwe will become more than 3 times more frequent. The intrusion at Maubin will even change from once every 12 years to once per year or more.

Table 28: Return period for salt intrusion at key-locations, baseline and climate change scenario

Key Locations	RP [1/years] (baseline)	RP [1/year] (climate change)
Katwe	72	21
Unit03	<1	<1
NYCD	<1	<1
Maubin	12	<1
21Mile	<1	<1
Udo	<1	<1
Dedaye	<1	<1
Pyapon	<1	<1

5.2.3.3 Pluvial flooding

An increase in precipitation of 6% during extreme events, with equal drainage capabilities, results in an increase in pluvial inundation for all units. A summary is given in Table 29. On average, the level of water security is roughly halved, meaning pluvial inundation is twice as likely. Units 06 and 10 are impacted more severely. On the other side, units 05, 07, 08, 09, 12 and 17 maintain a security level of once per 1000 years or more.

Table 29: Pluvial water security level, baseline and climate change scenario

RWSS Unit	WS [1/x year] (10% area) (baseline)	WS [1/x year] (10% area) (climate change)
Unit01	10	7
Unit02	9	6
Unit03	613	336
Unit04	213	138
Unit05	1000	1000
Unit06	1000	34
Unit07	1000	1000
Unit08	1000	1000
Unit09	1000	1000
Unit10	44	16

RWSS Unit	WS [1/x year] (10% area) (baseline)	WS [1/x year] (10% area) (climate change)
Unit11	1000	453
Unit12	1000	1000
Unit13	9	4
Unit14	1	1
Unit15	3	2
Unit16	2	1
Unit17	1000	1000
Unit18	1000	424
Unit19	2	2
Unit20	10	6

5.2.3.4 Coastal flooding

Finally, for coastal inundation, the impact of the SLR is simulated. An overview of the change in water security level expressed in the computed return period for coastal flooding is summarized in Table 30. Without exception, all units show a decrease in water security level. Most units show an increase in flooding frequency of 15-25%. However, the units along the Hlaing River often show an increase in frequency of more than 25%, further indicating the sensitivity to the local funneling effect of the storm surge.

Table 30: Return period for coastal inundation per unit, baseline and climate change scenario

RWSS Unit	WS [1/x year] (baseline)	WS [1/x year] (climate change)
Unit01	79	70
Unit02	<25	<25
Unit03	29	<25
Unit04	<25	<25
Unit05	<25	<25
Unit06	33	<25
Unit07	<25	<25
Unit08	29	<25
Unit09	173	158
Unit10	51	40
Unit11	<25	<25
Unit12	<25	<25
Unit13	28	<25
Unit14	28	<25
Unit15	42	33
Unit16	124	108
Unit18	<25	<25
Unit19	130	118

5.3 Future upstream developments

5.3.1 Description

Upstream dam development in the Ayeyarwady catchment may alter high and low flow conditions in the delta. The Basin Exploratory Scoping Study (BESS) of the Future Ayeyarwady basin explored storylines to offer plausible and (moderately) provocative images of alternative long-term futures in the Ayeyarwady catchment (Foran et al., 2019). It compares a baseline (2016) with a future (2055) scenario. In BESS a scenario of 21 hydropower dams, additional to 13 operational dams in 2016 (baseline), has been analyzed in a future dam-only scenario (i.e. 4A in Figure 41). This scenario comprised 27 billion m³ of storage volume. As the operation rules of the dams were not known, and based on information in IFC (2018), BESS assumed that each reservoir is operated as storage-backed dams. These fill during the course of the wet season. During the dry season consequently, they operate with a uniform daily water release, in order to reach a specified drawdown level. These assumed operating rules maximize the impact of hydropower operations on the seasonal hydrograph.

BESS (Foran et al, 2019) applied a hydrological model originally developed to support the SOBA surface water resources baseline assessment (eWater, 2018) to assess the impact of dam development. The model was run with 36 years of historic climate data (1981–2016). The choice of model baseline was determined by the availability of inputs and observed calibration data sets.

Figure 42 shows modelled and observed monthly discharge, and the associated percentage deviations from the baseline scenario. During low flow periods, the difference between observed data and the baseline model scenario ranges from -20 to -40%. These results showed that the confidence in the model is lower for low flows and thus caution is needed in drawing conclusions about low flow impacts if they are being compared with observations. Instead, comparing modelled scenarios effects relative to Baseline scenario are more informative.

Project Name	Capacity (MW)	Design ¹	Storage-backed ²	Vol ² (MCM)	Base-line (MW)	1AC, 4A (MW)	1BC, BD (MW)	2D, 2E (MW)	3E (MW)
Dapein (Tarpein) I	240	RoR		22	240	Y	Y	Y	Y
Kinda	56	S	Y	1078	56	Y	Y	Y	Y
Kyeon Kyeewa	74	S		571	74	Y	Y	Y	Y
Mone	75	S	Y	832	75	Y	Y	Y	Y
Myogyi	24	S	Y	443	24	Y	Y	Y	Y
Na Bang	180				180	Y	Y	Y	Y
Sedawgyi	25	S	Y	448	25	Y	Y	Y	Y
Shweli I	600				600	Y	Y	Y	Y
Thapanzeik 2	30	S	Y	3552	30	Y	Y	Y	Y
Yazagyo	4				4	Y	Y	Y	Y
Yeywa	790	S	Y	2630	790	Y	Y	Y	Y
Zawgyi 2	12	S		639	12	Y	Y	Y	Y
Chibwe Nge	99	RoR		1	99				
Total Baseline				10,216	2,209	2,209	2,209	2,209	2,209
Chibwe	3400	RoR	Y	1910		3400	Y		
Dapein (Tarpein) II	140	RoR		55		140		Y	Y
Deedoke	66	RoR		13		66	Y	Y	Y
Dum Ban (Tum Baing)	130	S	Y	34		130	Y		
Gawlan	120	RoR		1		120	Y		
Khaunglanphu	2700	S	Y	3100		2700	Y		
Laiza	3000	S	Y	11780		3000	Y		
Manipur	400	S	Y	1643		400			
Nam Li	165	RoR		2		165	Y		
Nam Paw	20	S		52		20		Y	Y
Nam Tabak I	141	RoR		15		141		Y	
Nam Tabak II	144					144		Y	
Nam Tu	100					100		Y	
Phizaw (Pisa)	2000	RoR		535		2000	Y		
Renan (Yenam)	1200	S	Y	1183		1200	Y		
Shweli II	520	RoR	Y	72		520		Y	Y
Shweli III	1060	S	Y	5464		1060		Y	
Tongxinqiao	340	RoR		5		340	Y		
Wutsok	1800	RoR	Y	605		1800	Y		
Yeywa Middle	700	S	Y	454		700		Y	Y
Yeywa Upper	280	S	Y	341		280		Y	
Total Plan				27,264 ³		18,426	14,921	2,111	1,446
Total				37,480 ³		20,635	17,130	4,320	3,655

[Source: Authors, based on IFC (2018a)] Notes: Grey highlighting denotes constructed plant. (1) 'Storage-backed' refers to configured in BESS scenarios to fill during wet season, then operated such that a specified drawdown level is not reached before end of dry season. (2) Volume refers to total reservoir storage. (3) Applies to Scenario 1AC and 4A.

Figure 41: Table showing the specific Hydropower projects included in the BESS Baseline (above the Total Baseline row) and the projects included in Scenario 4A (Below the Total Baseline row) [Source: Foran et al, 2019].

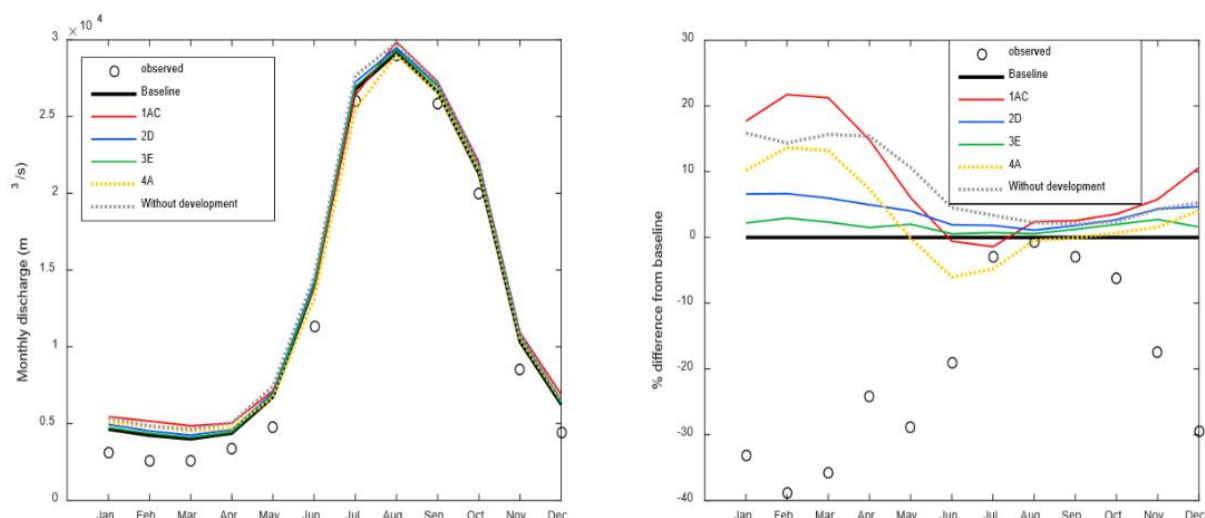


Figure 42: Seasonal discharge in the lower Ayeyarwady: modelled scenarios vs. observations. Average monthly discharge in the lower Ayeyarwady showing flow at Pyay for each month comparing modelled scenarios and observations (left) and the percentage difference in monthly flows from the Baseline scenario (right) [Source: Foran et al., 2019]

5.3.2 Model Boundary Condition Adjustments

The comparison between the Baseline scenario and ‘maximal’ hydropower development (Scenario 4A) is given in Figure 42 (yellow dashed line). It shows an increase in the low flow period January-April of about +10% in discharge. During the wet season (August-September) the impact on flood discharges is negligible.

These results are as expected based on the operation rules for hydro-power generation. In the wet season the reservoirs will be completely filled. This leaves no flood storage in these months.

5.3.3 Results

The impact on these changes on the water security is neutral for flooding and positive for salt intrusion. The expected impact on the water quality for the different intake stations is given in Table 31. For the intakes at Katwe and Maubin, salt intrusion becomes >40% less frequent as a result of the retention capacity upstream. However, the base location of the salt front is still located upstream of all other key-locations, so the frequency of salt intrusion at these intakes remains once per year or more frequent.

Table 31: Return period for salt intrusion at key-locations

Key Locations	RP [1/years] (present)	RP [1/year] has (retention)
Katwe	72	106
Unit03	<1	<1
NYCD	<1	<1
Maubin	12	17
21Mile	<1	<1
Udo	<1	<1
Dedaye	<1	<1
Pyapon	<1	<1

6 IMPACT ASSESSMENT OF FUTURE INTERVENTIONS

A long-list of future development plans has been made with input from key-stakeholders during workshops and meetings. Every development plan from this long-list has either 1) a direct impact on the regional water system or 2) will enable future developments that changes the water needs and/or safety standards and thresholds. As an example: when closing a complete channel with a sluiceway, the flows are expected to distribute differently through the other channels in the delta resulting in a regional impact which can be assessed with the hydrodynamic model. The second category of future developments enable economic and population growth in a specific area, such as a bridge towards a remote area. When this is implemented, a larger water supply demand and higher threshold values for flooding are expected. From all future development plans that have been collected from the stakeholders, only four are expected to have a regional impact on the water system. These so-called interventions are:

- Pan Hlaing Sluice including enlarged water extraction (IWUMD);
- Twante Canal improvement project (DIWR);
- New water extraction points in the Kokowa River and the Toe River (YCDC); and
- Flood protection for New Yangon City (New Yangon City Development Company).

The effects of these interventions have been assessed during the previous phase of the Regional Water Security Study: IADS-B [IADS-B, 2019]. Since then, the methodology and presentation of the modelling results are changed with representation in return periods of flooding for the defined units. This chapter describes the assessment of the regional impact on the water system, and how this changes the return periods for the (relevant) extreme events from the baseline situation.

6.1 Approach

To assess the impact of the selected interventions, the hydrodynamic models from the Baseline Water Security are modified to include the new intervention. The following baseline situations are defined:

- Riverine flooding: high river discharge in combination with spring tide.
- Freshwater scarcity: low river discharge in combination with spring tide.
- Coastal flooding: storm conditions (e.g. cyclone) with average river discharge.
- Pluvial flooding: extreme rainfall with average river discharge.

For each of the intervention it is determined which of these baseline situations is most likely to be affected. Table 32 gives an overview of the assessed extreme events per intervention.

In order to assess the impact of the interventions, the same model settings and boundary conditions are used for the simulations as for the baseline simulations (Chapter 2 and 3). Using the same methodology of determining the weakest links per unit and the corresponding return period allows to make comparisons with the return periods from the baseline assessment. The change in return period represents the regional effect caused by the intervention.

Table 32: Modelled extreme events per intervention

Intervention	Riverine flooding	Water scarcity and salt intrusion	Coastal flooding	Pluvial flooding
Pan Hlaing Sluice	Yes	No	Yes	No
Twante Canal improvement project	Yes	Yes	Yes	No
New water extraction Kokowa River and Toe River	No	Yes	No	No
New Yangon City	Yes	No	Yes	No

6.2 Pan Hlaing Sluice

6.2.1 Description

The 80-kilometer-long Pan Hlaing River connects the Kokowa River in the west with the Yangon River in the east. Over time the section of the Pan Hlaing River east of Mezali has experienced significant sedimentation and decreasing discharge capacity. Today, most of the river discharge (>95%) that enters the Pan Hlaing River at Nyaungdon, flows into the Kokowa River, the Hlaing River, the Yangon River and ultimately into the ocean. The abandonment of the middle and lower section of the Pan Hlaing River jeopardized its important role to irrigate and drain the surrounding agricultural lands.

In the next years and decades, the area on the east side of the Pan Hlaing river (near Yangon City) will be used for new industrial and residential areas. The realization of a new sluice on the east side of the Pan Hlaing river is expected on short term to conclude the Pan Hlaing River Rehabilitation Project which commenced in 2014. With the new Pan Hlaing sluice implemented at the downstream side, and the existing Mezali2 sluice on its upstream side, it becomes easier to control the water challenges of this part of the Pan Hlaing river basin. These challenges include sufficient clean and freshwater for irrigation in the dry season and drainage of local precipitation in the wet season. Other benefits are the significant reduction of saltwater and suspended sediment inflow and improved flood resilience for the planned New Yangon City (NYDC). Because the new sluice will have a separate ship lock, vessels will be able to reach the sand depots and industrial sites that are located 'behind' the sluice.

Another target of the Pan Hlaing River Rehabilitation Project is to increase the water intake from the Kokowa River. This extra water will be used for more irrigation water supply, but also for industrial and domestic use.

As the final design of the Pan Hlaing Sluice is not yet ready, the modeling has been based on the available specifications from existing reports. This section describes the effect of a closed sluiceway on the Yangon side of the Pan Hlaing river in combination with increased water intake from the river.



Figure 43: Location of the proposed Pan Hlaing Sluice and the existing Mezali Sluice 2 (source: Pan Hlaing River Rehabilitation Masterplan)

Closing off the Pan Hlaing river mouth will likely influence the tidal conditions on the Yangon and Hlaing rivers. As the water input from the Yangon River into the Pan Hlaing river is eliminated when the sluice is closed, the tidal flow is expected to propagate further upstream into the Yangon River. This can increase saltwater intrusion in the Hlaing River, which may be further increased by additional water extraction from the Kokowa River further upstream.

The discharge feeding the Yangon River from the Pan Hlaing River during dry season will disappear with the construction of the sluice. Currently, a cofferdam is built every dry season to prevent saltwater to enter the Pan Hlaing River. This closes the hydraulic connection between the Yangon River and the Pan Hlaing River. Therefore, the most significant impact is expected during wet season when in the current situation the link between these two rivers is (often) open.

6.2.2 Schematization in model

The Pan Hlaing Sluice measure is modeled with a “thin dam” which impedes all flow. To assess the maximum effects of the sluiceway on the flows and water levels surrounding the Pan Hlaing River, it is assumed that the sluiceway is fully closed during the extreme events. During the previous phase of the project (RWSS IADS-B) it has been concluded that the additional water extraction of 100 MGD from the Pan Hlaing River has very limited regional impact. Therefore, only the extreme events coastal flooding and riverine flooding are simulated with this intervention.

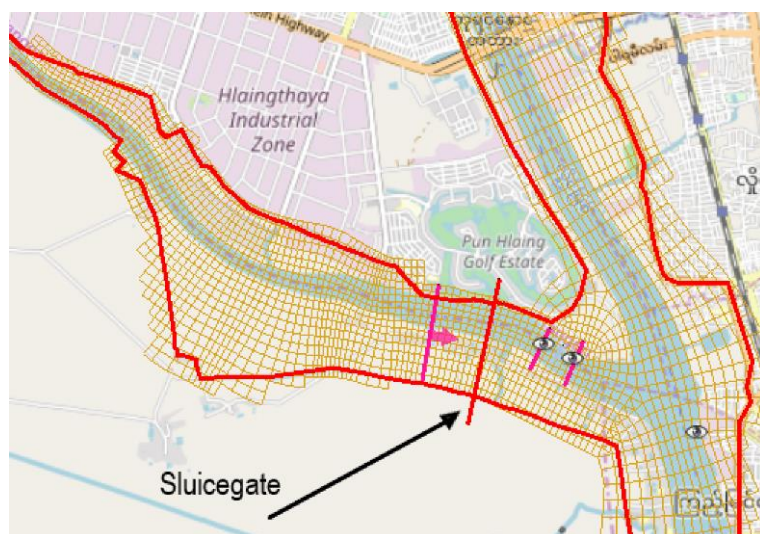


Figure 44: schematization of a “thin dam” in the Delft3D FM model at the proposed location of the Pan Hlaing Sluice

6.2.3 Results

6.2.3.1 Riverine Flooding

The impact of the effective closure of the Pan Hlaing canal as a result of the construction of the sluice with respect to riverine flooding is summarized in Table 33. It can be observed that the units directly adjacent to Pan Hlaing, units 03, 06 and 07, have an increased level of water security as a result of the closure. As no discharge can pass through Pan Hlaing, more water remains in the Kokowa river leading to higher water levels locally. No negative effect is visible because units 01 and 02 were already at a level of <1:2.

Table 33: Return period for fluvial inundation per unit, baseline and Pan Hlaing sluice intervention

RWSS Unit	WS [1/x year] (baseline)	WS [1/x year] (Pan Hlaing Sluice intervention)
Unit01	<2	<2
Unit02	<2	<2
Unit03	7	7
Unit04	<2	<2
Unit05	<2	<2
Unit06	67	41
Unit07	14	16
Unit08	>200	134

RWSS Unit	WS [1/x year] (baseline)	WS [1/x year] (Pan Hlaing Sluice intervention)
Unit09	>200	>200
Unit10	>200	>200
Unit11	>200	>200
Unit12	<2	<2
Unit13	118	118
Unit14	>200	>200
Unit15	<2	<2
Unit16	>200	>200
Unit18	<2	<2
Unit19	>200	>200

6.2.3.2 Coastal Flooding

The impact on coastal flooding is relatively small. The closure of the Pan Hlaing canal only blocks a relatively small waterway with a relatively small increase of the funneling of the storm surge as a result. The impact is summarized in Table 34. Although fairly small, the impact is predominantly negative. The funneling of the surge into the Haling River is increased very locally with a lower water security level as a result. Only Unit03 sees a minor improvement to its security level.

Table 34: Return period for coastal inundation per unit, baseline and Pan Hlaing sluice scenario

RWSS Unit	WS [1/x year] (baseline)	WS [1/x year] (Pan Hlaing sluice intervention)
Unit01	79	78
Unit02	<25	<25
Unit03	29	31
Unit04	<25	<25
Unit05	<25	<25
Unit06	33	32
Unit07	<25	<25
Unit08	29	28
Unit09	173	173
Unit10	51	51
Unit11	<25	<25
Unit12	<25	<25
Unit13	28	28
Unit14	28	28
Unit15	42	42
Unit16	124	124
Unit18	<25	<25
Unit19	130	130

6.3 Twante Canal improvement project

6.3.1 Description

The Twante Canal is a crucial navigation channel that connects Yangon City with cities in the north of the country along the Ayeyarwady River. The channel links the Yangon River and the Toe River and has a total length of 34 km. Since its completion in 1883, no additional system interventions such as sluices have been built. Hence, the strong tidal flows are still present in the current situation but sedimentation in the channel is relatively slow compared to the Pan Hlaing River.

DWIR is responsible for navigation on the Twante Canal. Besides the crucial service as navigation channel, the channel also forms a threat to nearby rural communities as floods occur regularly near Dala Township. Yangon South Region, which is located north of the Twante Canal and south of the Pan Hlaing River, is expected to expand significantly with industry and residential areas. Regular flooding will then not be acceptable anymore and therefore DWIR has explored opportunities to increase flood resiliency of the surrounding area of the Twante Canal with the Twante Canal Improvement Project. The first phase of this project consists of the dredging works and improvements of the embankments along the channel. Regional impact of such works is expected to be limited and are therefore not simulated with the model. On a longer term, DWIR aims to build sluiceways at the Toe River side, the Yangon River side or both. Technical details are not available as this intervention is expected on the long-term. The effects on the water system as a result of construction of two sluiceways at the western side of the channel (Toe River) and the eastern side (Yangon River) are assessed for this study.

Closing the hydraulic link between the Toe River and the Yangon River is expected to have significant effect on tidal flows in both river branches. As the upstream water input for the Yangon River is very limited, it is expected to have more significant tidal effects as the area in which this tidal energy can dissipate becomes smaller. As the tidal currents along the coast propagate from east to west, the tidal flows move currently from the Yangon River into the Twante Canal and therefore contributes to the tidal flows in the Toe River in the west. Therefore, it is expected that the tidal flows in the Toe River will reduce to a certain extent.

6.3.2 Schematization in model

To assess the maximum effects of the two sluiceways on the flows in the Toe River and the Yangon River it is assumed that the sluiceways are fully closed. Some minor 'leakage' may occur at both sides caused by drainage and operation of the ship lock. This is not considered as a significant effect on the broader system. Therefore, two "thin dams" are included in the model at the potential locations of the sluiceways (Figure 45). The exact location is unknown and therefore the assumption is made that sluiceways will be located near the Toe River and the Yangon River at a place where the Twante Canal is relatively narrow and consists of a single canal. The resulting locations in the model are shown below.

The regional effects of this intervention are assessed for the extreme events coastal flooding, fluvial flooding and water scarcity.

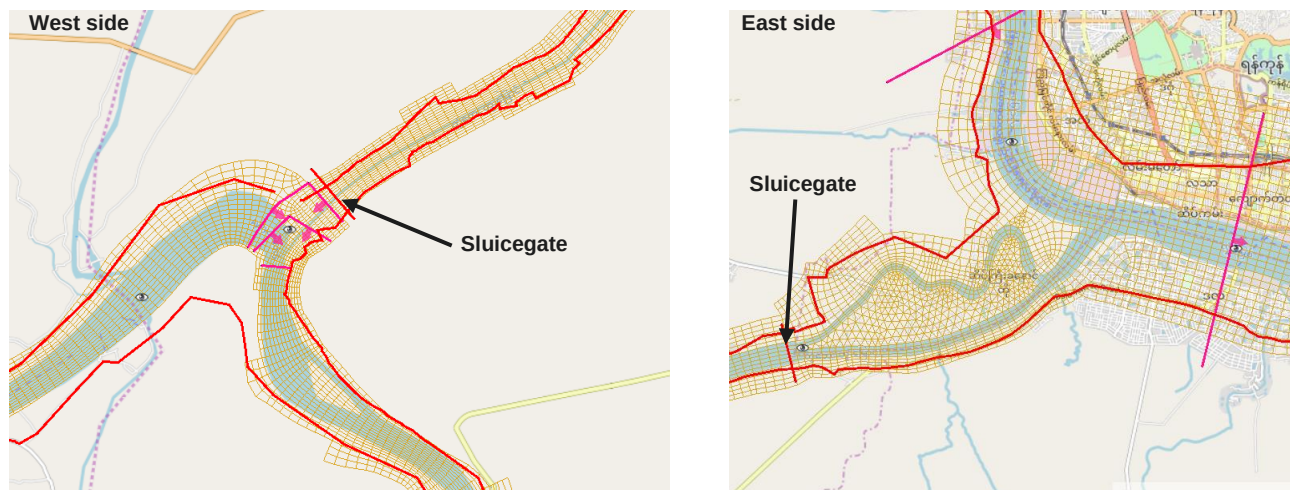


Figure 45: schematization of Twante Canal sluices in the Delft3D FM model

6.3.3 Results

6.3.3.1 Riverine Flooding

The impact of the effective closure of the Twante Canal as a result of the construction of the sluices at both ends with respect to riverine flooding, is summarized in Table 35. In general, the level of water security is neutral or impacted negatively. Especially the flood safety level in Units 06, 07 and 08 decreases. The simulations show that the dikes around Unit 5 and 12 along the Toe River are relatively low. Despite the sluice at the western side of the Twante Canal water will enter the units when overtopping these low dikes. This water cannot leave the Twante Canal at the eastern side, because of the sluice at that side. This means an increase in water level in the Twante Canal, having a negative impact on the flood safety. The results can be improved when construction of the sluices will be combined with heightening of the dikes along Toe River.

Table 35: Return period for fluvial inundation per unit, baseline and Twante Canal improvement intervention

RWSS Unit	WS [1/x year] (baseline)	WS [1/x year] (Twante Canal improvement intervention)
Unit01	<2	<2
Unit02	<2	<2
Unit03	7	7
Unit04	<2	<2
Unit05	<2	<2
Unit06	67	53
Unit07	14	8
Unit08	>200	13
Unit09	>200	>200
Unit10	>200	>200
Unit11	>200	>200
Unit12	<2	<2
Unit13	118	121
Unit14	>200	>200
Unit15	<2	<2
Unit16	>200	>200
Unit18	<2	<2
Unit19	>200	>200

6.3.3.2 Water scarcity and salt intrusion

The closure of the Twante Canal is shown to result in a larger tidal amplitude into the Hlaing and Upper Hlaing rivers, due to the increased funneling of the tidal forcing. As a result, the salt load also increases and with that, the salt intrusion. Consequently, the frequency of salt intrusion at Katwe is doubled, going from once per 72 to once per 34 years. For Maubin, the intervention is less impactful. The closure results in a blockage of saltwater coming from Yangon River through the Twante Canal. The freshwater discharge can now hold back the salt front along the Toe River relatively more effective. However, the discharge distribution is slightly different with a small decrease through the Toe River. Cumulatively, this results in small increase of the computed frequency of salt intrusion at this intake location (from once per 12 to once per 11 years).

Table 36: Return period for salt intrusion at key-locations, baseline and Twante Canal improvement intervention

Key Locations	RP [1/years] (present)	RP [1/year] (Twante Canal)
Katwe	72	34
Unit03	<1	<1
NYCD	<1	<1
Maubin	12	11
21Mile	<1	<1
Udo	<1	<1
Dedaye	<1	<1
Pyapon	<1	<1

6.3.3.3 Coastal Flooding

Again, a negative impact is observed when evaluating the effect of the Twante Canal improvement on the coastal water security level. The storm surge is funneled into the Hlaing River and moves further upstream compared to the baseline. This results in higher peak water levels.

Table 37: Return period for coastal inundation per unit, baseline and Twante Canal improvement scenario

RWSS Unit	WS [1/x year] (baseline)	WS [1/x year] (Twante Canal improvement intervention)
Unit01	79	77
Unit02	<25	<25
Unit03	29	<25
Unit04	<25	<25
Unit05	<25	<25
Unit06	33	31
Unit07	<25	<25
Unit08	29	<25
Unit09	173	173
Unit10	51	50
Unit11	<25	<25
Unit12	<25	<25
Unit13	28	<25
Unit14	28	<25
Unit15	42	41
Unit16	124	122
Unit18	<25	<25
Unit19	130	129

6.4 New Yangon City Development

6.4.1 Description

Yangon City has expanded in the past decade towards the western side of the city with large industrial and residential zones such as Hlaing Thar Yar. This expansion will continue in the future with new plans already in development, such as the two-phase New Yangon City Development plan. New Yangon City Phase 1 is located south of the Pan Hlaing River and north of the Twante Canal and covers an area of 90 km². Within this area, new industrial zones and residential areas will be build. Phase 2 of the plan covers a much larger area (600 km²) between the southern bank of the Twante Canal and the coastline in the south. As Phase 2 is only in consideration, the focus on the assessment of this intervention is on the regional impacts on water system caused by Phase 1.

Phase 1 of the New Yangon City development will be the protection against flooding with embankments surrounding the area. The construction of these embankments is an intervention of the river system as it prevents overland flow in the area, which currently would happen when the water level in the river would rise significantly. Therefore, the effects on this intervention on the water levels in the Yangon River are investigated and explained in this section.

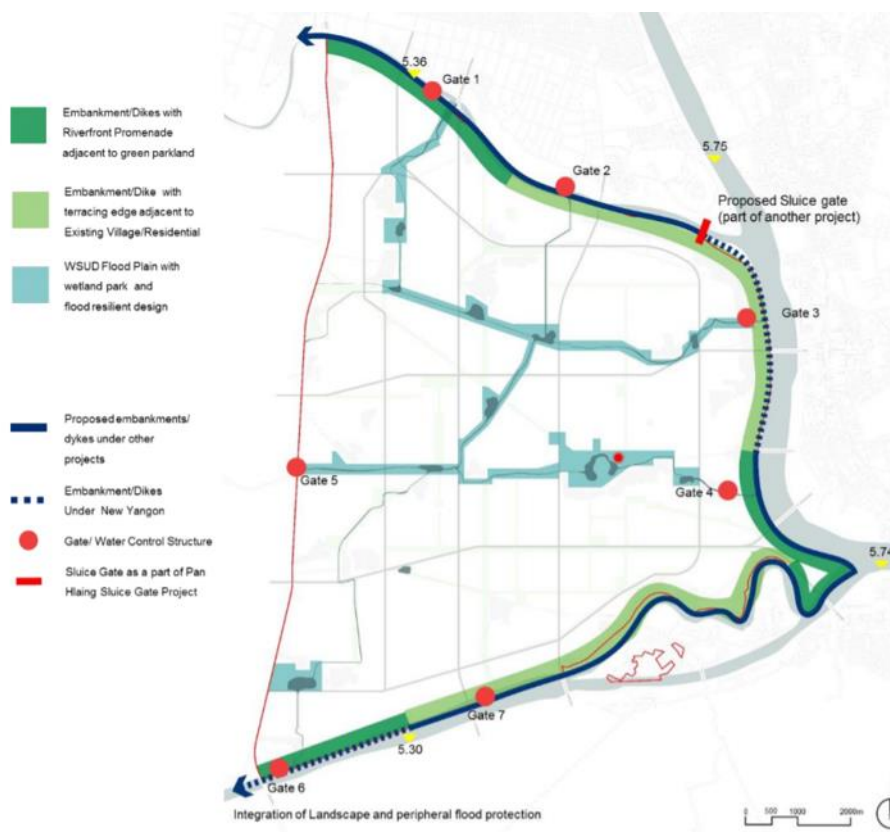


Figure 46: proposed embankments along the New Yangon City project area

As the area is currently prone to flooding, it functions as retention zone as no flood protection is in place. When the new flood protection will be built, no more water can be stored in this area resulting in higher water levels on the Yangon River during flood events as the water can only stay in the river. This can potentially increase the flood risk for other areas such as Yangon City.

6.4.2 Schematization in model

To assess the impact of the flood protection of New Yangon City Phase 1 at other locations, the regional effects of this intervention are assessed for the extreme event coastal flooding only. Figure 47 shows how the intervention is schematized in the model as a “thin dam” that surrounds the entire New Yangon City Phase 1 area. This implicitly assumes that the new dikes will be high enough to resist the storm surge that is

simulated and therefore overbank flow will not occur. Furthermore, for this simulation it is assumed that the proposed Pan Hlaing Sluice is not constructed (yet), but it is likely that both interventions would be developed and build within the same moment of time. However, as the period of occurrence is assumed to be April – May, the cofferdam is present in the model.



Figure 47: schematization of the flood protection area of New Yangon City

6.4.3 Results

6.4.3.1 Coastal Flooding

The impact of flood protection of New Yangon City Development is relatively small. The effective reduction of flooding area that is available during coastal flooding, leads to a small peak water level increase in the Yangon and Hlaing rivers as well as upstream. However, this effect is spread out over a large area and only results in a minor decrease in the level of water security.

Table 38: Return period for coastal inundation per unit, baseline and New Yangon City flood protection (Unit07)

RWSS Unit	WS [1/x year] (baseline)	WS [1/x year] (New Yangon City intervention)
Unit01	79	78
Unit02	<25	<25
Unit03	29	28
Unit04	<25	<25
Unit05	<25	<25
Unit06	33	31
Unit07	<25	>200
Unit08	29	28
Unit09	173	173
Unit10	51	51
Unit11	<25	<25
Unit12	<25	<25
Unit13	28	28
Unit14	28	28
Unit15	42	42
Unit16	124	123
Unit18	<25	<25
Unit19	130	131

6.5 New water extraction Kokowa and Toe Rivers

6.5.1 Description

Yangon City Development Committee (YCDC) is planning to implement Water Treatment Plants (WTP) for water supply to the Yangon City, using different water resources (rainfall and river). Japan International Cooperation Agency (JICA) provided a "Preparatory Survey for Greater Yangon Water Supply Improvement Project" to YCDC. It suggests using water resources of Kokowa River and Toe River for a potential water supply network. JICA recommended that the implementation of Kokowa WTP and Toe WTP should be done in multiple stages to avoid financial overburden. It was also suggested that Toe WTP project can be postponed overcoming budget limitations.

The overall capacity of the Kokowa water intake will be between 140 and 180 MGD (approximately equal to 7,4 m³/s – 9,5 m³/s) based on the amount of water that can be obtained from Pan Hlaing River for 2040. JICA suggested the project implementation stages as follows:

- a. Kokowa Stage 1: 60 MGD (2025), currently in development stage;
- b. Kokowa Stage 2: +40 MGD (total 100 MGD);
- c. Kokowa Stage 3: +40 MGD (total 140 MGD);
- d. Kokowa Stage 4: +40 MGD (total 180 MGD) depending on the capacity of Pan Hlaing Water Treatment Plant.

For the Toe River WTP, the intake capacity will be 70 MGD (3,7 m³/s) according to the revised JICA report from 2017. The project owner is YCDC and it's proposed to be financed by Union Government budget and partly by a JICA ODA loan. However, a final decision on funding and the location of the water intake is not confirmed yet as the Kokowa water intake is planned to be build first. The locations and the capacity of the water supply system in 2025 and 2040 are shown below.

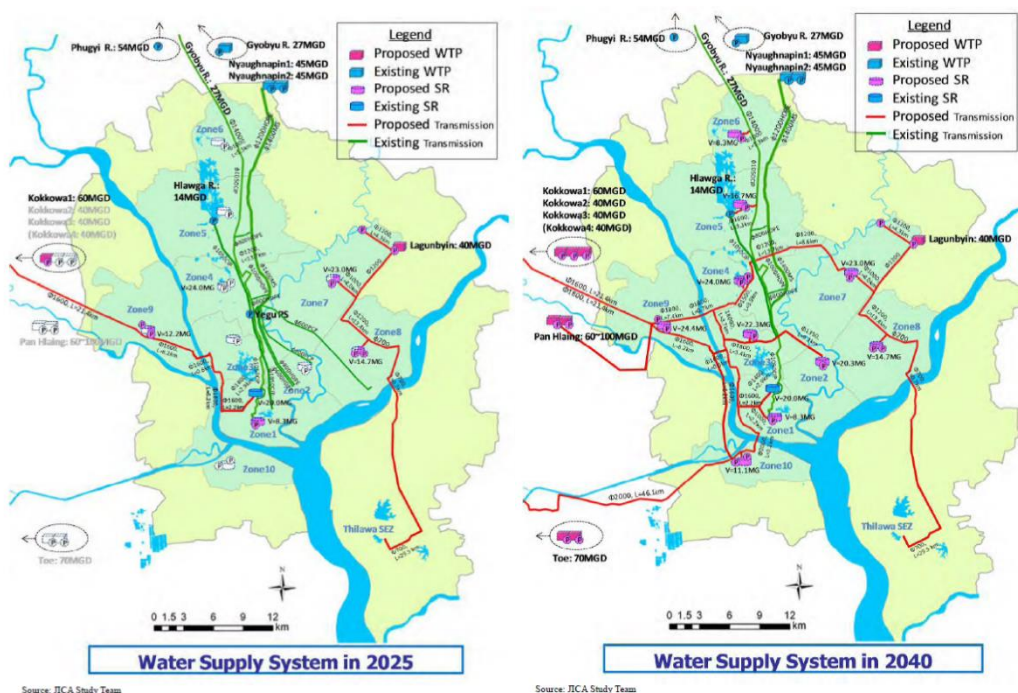


Figure 48: Proposed expansion of the water supply system of Yangon City (Source; revised JICA masterplan, 2017)

The water intakes may influence the discharge distribution among the various river branches. It is expected that the water level decreases near the intake location due to pump operation. The river velocity will rise locally near the pump and it may cause higher sediment transport rates locally (near the pump station). The effects are expected to become significant when the water extraction is relatively large compared to the river discharge at the intake location.

Regarding the salinity, freshwater reduction by pumping may enhance saltwater intrusion. This may affect the salinity levels compared to the baseline. Therefore, this intervention is assessed for the extreme event water scarcity.

6.5.2 Schematization in model

To model the pumping of water in the model, the “SourceSink” feature is used with $Q = 3.2 \text{ m}^3/\text{s}$ (approximately 60 MGD) to simulate the first stage of the Kokowa extraction. To simulate the extraction at the Toe River, the same feature is used with $Q = 3.7 \text{ m}^3/\text{s}$ (approximately 70 MGD). Indicative locations of these intake locations are shown below.

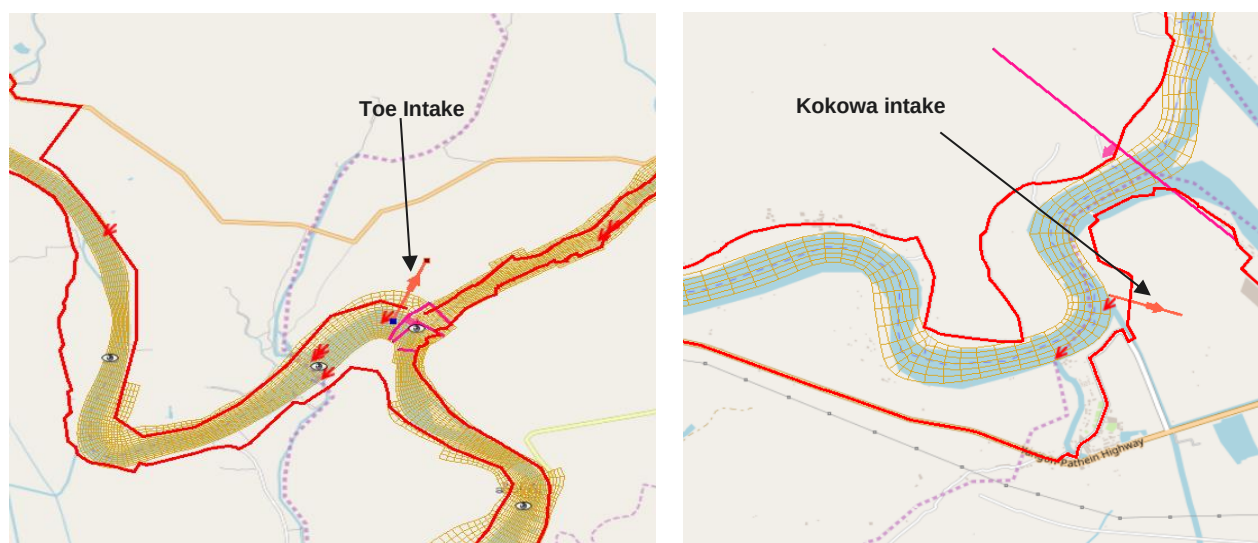


Figure 49: locations of projected water intakes

6.5.3 Results

6.5.3.1 Water scarcity and salt intrusion

The extraction of an additional $3.2 \text{ m}^3/\text{s}$ from the Kokowa River and an additional $3.7 \text{ m}^3/\text{s}$ from the Toe river effectively leads to slightly less available water to force back salt intrusion. Despite only being small extractions, it results in an increase of approximately 10% in frequency of salt intrusion at Kokowa intake (Katwe) and Maubin.

Table 39: Return period for salt intrusion at key-locations, baseline and new fresh-water extractions intervention

Key Locations	RP [1/years] (present)	RP [1/year] (extractions)
Katwe	72	67
Unit03	<1	<1
NYCD	<1	<1
Maubin	12	11
21Mile	<1	<1
Udo	<1	<1
Dedaye	<1	<1
Pyapon	<1	<1

7 PLUVIAL MODELLING USING SOBEK

7.1 Introduction

Currently the RWSS Delft3D FM model provides results regarding pluvial floods in the Greater Yangon Area, at a unit level of detail. A higher level of detail, i.e. specification of areas within the unit that are prone to pluvial flooding, is often not possible as a result of the model resolution. From that perspective, the RWSS model is relatively coarse since it is primarily developed for impact assessments on a regional scale and an increase in spatial resolution would result in a substantial increase of its computational demand. This means that the accurate distribution of pluvial water within the unit is not completely taken into account, which might lead to an incorrect estimation of the amount and time of water present on the land due to extreme rainfall events, identified as pluvial floods. To gain more insight in the distribution and subsequent drainage of water during these pluvial floods, a more detailed analysis is performed for one unit.

7.2 Model set-up and method of assessment

For this study a SOBEK 1D model with the Rainfall Runoff module is developed for Unit08, Yangon South. In this model all water channels present in the unit are taken into account in addition to the sluices and outlet structures of the unit where water flows towards the main rivers enclosing it. The channel's geometry and topographic height are included as well as the channel roughness and a runoff coefficient. Pluvial events with a return period of one in 1, 10, 100 and 1000 years are simulated using the boundary conditions as presented in section 2.4.3. The water height and depth on different locations as well as the discharge through the channel system are modelled. When the channels are at their peak storage capacity, any additional runoff is considered as volume towards inundation and it is possible to calculate the extent of the water on the land in time, which enables the assessment of temporal and spatial behavior of the pluvial flooding.

All channels in Unit08 are connected, meaning that water can flow out of the unit to the rivers enclosing it. In fact, at the eastern and southern side of the unit, there are several locations where water can flow freely towards Yangon River and open sea. This also means that during high tide, there is a possibility that (salt) water intrudes into the area.

In the SOBEK model, the pluvial water within Unit08 can flow towards all available outlets, which can be open creeks or (controlled) structures, in a natural manner. This is different compared to the RWSS model where it is assumed that all water from within certain sub-areas with the unit always flows towards a predesignated outlet. If this outlet is at its capacity, the water is (temporarily) stored on land.

The channels in the SOBEK model are mapped based on satellite images. In SOBEK these are schematized as illustrated in the figure, where the connections of all channels in Unit08 are shown. There are several outlets towards the rivers enclosing the unit. Due to limited data availability and to be able to construct the model within a reasonable amount of time, the channel geometry is assumed to be constant within the unit. A single representative cross section profile is adopted: depth of 5 m and bottom width of 20 m, with a slope of 1:1. Most outlets have a basic irrigation channel shape of 6.5 m high and bottom width of 40 m, with a 1:1 slope as well. Structures at the outlets are adopted from a previously developed SOBEK model (RHDHV, 2019), as well as the channel geometry of the rivers along the Unit08 boundary.

Saturated soil conditions are assumed because pluvial events are likely to occur during wet season when precipitation is almost continuous. The temperature is fixed to an averaged value of 30 °C and the rain is evenly distributed over the area. Evaporation is simulated to be very low as no direct radiation is taken into account in the simulations. For the simulation of pluvial events, this assumption is fair as there will be full cloud coverage.

Water levels are set to an initial level of 3 m, but sufficient spin up time is accounted for to let the water level adjust to their boundary conditions and reach an equilibrium state pre-rainfall event. The friction within the channels is defined with a Manning's coefficient of 0.03 s/m. The water which flows on the land towards the river is fixed with a delay coefficient of 0.0003 min⁻¹ for flat surfaces and 0.003 min⁻¹ for hilly surfaces. The hydrodynamic boundary conditions are generated from the RWSS model on 4 locations on the river (KIP, Maubin, Toe river mouth and Yangon River mouth indicated in magenta in Figure 50) and are representative for wet season conditions.

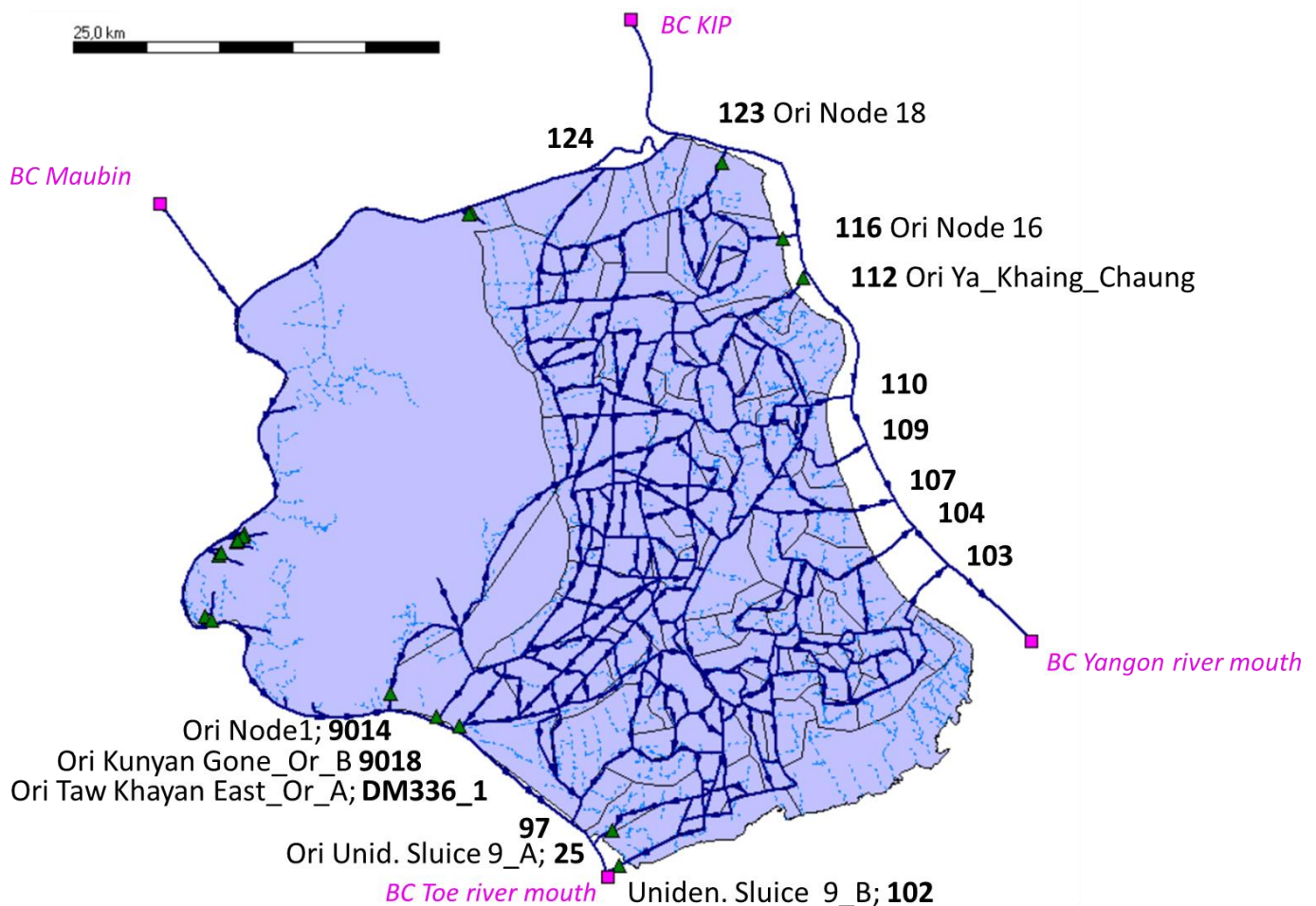


Figure 50: Overview of SOBEK model domain (RWSS Unit08), including relevant connectivity

7.3 Model output

7.3.1 Inundation

To be able to compare the results from the SOBEK model and the RWSS model, the same inundation threshold value is used. Unit08 is considered predominantly rural, so this means that areas where the inundated depth is 0.6 m or more are considered flooded. The total of these flooded areas is used to calculate the percentage of the area of Unit08 which is flooded due to rain events.

The SOBEK results (summarized in Table 40) shows the percentage of the area of Unit08 where the inundation depth is above the threshold value of 0.6 m. The following can be observed:

- For the event with a yearly return period no pluvial floods occur.
- For the event with a return period of 10 years 15 percent of the area of Unit08 is flooded above the threshold value after 24h where this is 0 percent after 48h indicating the water is sufficiently drained.
- The results for the other return events show a decrease in flooded area in time as well. Ultimately the event with a return period of 1000 years results in pluvial flooding in 7 percent of the unit after 48h.

Table 40: Percentage of total inundated area after peak inundation (SOBEK and RWSS model results)

Hours after peak inundation	RP0001	RP0010	RP0100	RP1000
0	0	34	59	73
12	0	30	51	60
24	0	15	36	47
36	0	2	14	29
48	0	0	1	7
RWSS Model after 48h	0	2	4	7

The percentage of inundated area after 48h for the different return events are in agreement with the results of the RWSS model for Unit08, shown in the bottom row of the table. This means that both models provide similar results despite the differences in model schematization. This also indicates that for the results on inundation, solely based on the simulated inundated area after 48 hours, there is no immediate need to revisit the current assessment methodology of the pluvial water security level using the RWSS modelling results.

However, the results of SOBEK do provide the temporal evolution of the inundated land which is currently not possible in an accurate manner using the RWSS model. In the RWSS model the inundated land is calculated as the available drainage would be distributed equally over the area (refer to section 2.4.4). Figure 51 shows the simulated development of the pluvial inundation in space and time for the once per year and once per 10 year events, using the SOBEK model. This allows for the visual identification of areas within the unit that are prone to pluvial flooding. On the maps in the figure, the pluvial floods occurring in Unit08 are visible for two return events for several moments in time, during and after the inundation peak associated with the return period of the pluvial event. Visible from the SOBEK results is that the area in the south-west of the unit is where most floods are sustained. This shows that the water in the area will flow towards these areas which would therefore be the area to consider for the application of potential mitigating measures.

The pluvial inundation maps are constructed based on the results from the SOBEK model of the water depth in the channels. The inundation depth is the result of the subtraction of the surface level of the land from the computed water depth. This is possible since all channels area assumed to have a similar geometry within the unit. To be able to visualize the results spatially the water is allowed to flow over the riverbank to the land which is possible by increasing the width of the geometric cross section of the river above the surface level. This water is assumed to flow over the land, where the water level of the water minus the surface level is the inundated depth.

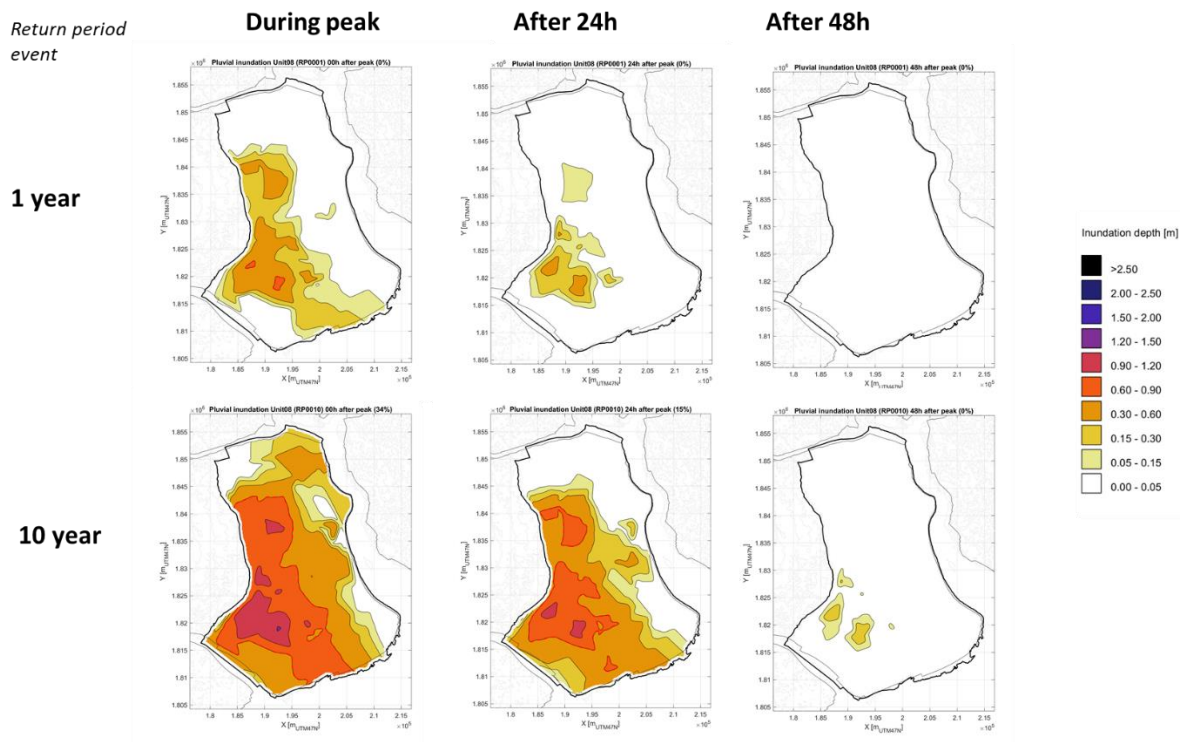


Figure 51: Simulated development of pluvial inundation in space and time, for RP001 (upper frames) and RP010 (lower frames)

7.3.2 Water balance and system discharge during a pluvial event

A water balance for Unit08 is computed based on the results of the SOBEK simulations. It can be observed from the graphs in Figure 52 that the water stored on the land increases quickly and gradually decreases. Eventually there is no stored water on the land left which means all water is draining out of the area.

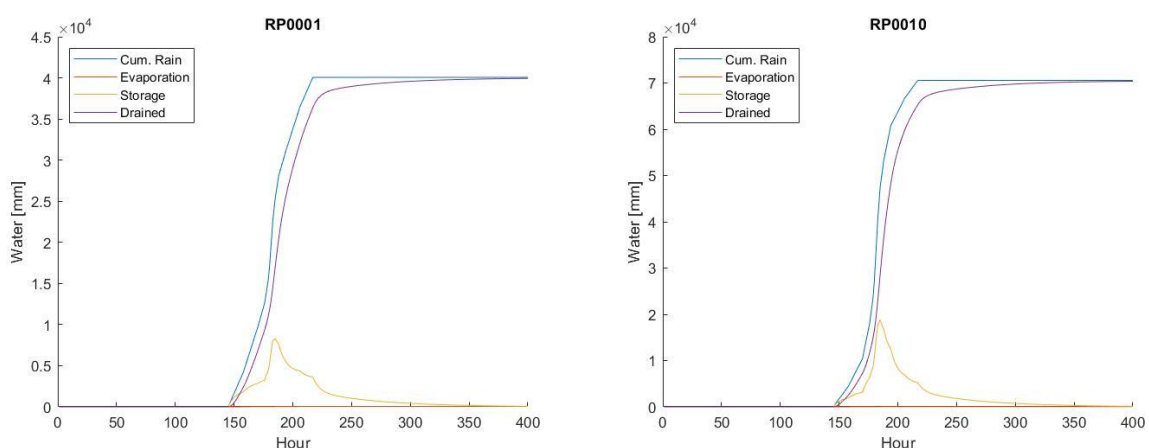


Figure 52: Water balance within Unit08 as computed with the SOBEK model for the RP0001 and RP0010 events

To check whether the SOBEK model results represent realistic values of water drainage after a rain event the discharge at different outlets are listed in table 41 for the return periods of 1, 10 and 100 year (refer to Figure 50 for their respective locations). The table provides the estimated and simulated peak discharges through the outlets. The maximum capacity is estimated using the known cross sectional area and a conservative flow velocity of 1.5 m/s. From the results it can be concluded that the capacity of the structures is more or less

sufficient for the yearly returning event. The 10 year return event shows a discharge exceeding the maximum, however it should be taken into account that the a larger stored volume of water upstream likely results in more head over the structures with a higher flow velocity as a result. The SOBEK model does show this as well.

Finally, visible in Table 41 are the percentages of the discharge per outlet with respect to the total outflow, per pluvial event. The distribution of the water drained per outlet does not differ much per event but does provide insight in the proportion of the total water draining from the unit.

Table 41: Simulated average distribution of drainage with respect to the total drainage.

Q percentage from total [%]				
Outlet Reach	Orifice structure	RP0001	RP0010	RP0100
25	Unidentified Sluice 9_A	2.9	2.0	1.7
9014	Node 1	3.2	4.7	4.8
9018	Kungyan_Gone_Or_B	21.9	20.8	21.1
97		16.8	16.8	17.2
102	Unidentified Sluice 9_B	<0.1	<0.1	<0.1
103		8.1	8.5	8.6
104		11.1	11	11
107		12	12	12.1
109		<0.1	<0.1	<0.1
110		9.1	9.9	10.0
112	Ya_Khaing_Chaung	<0.1	<0.1	<0.1
116	Node 16	1.2	0.9	0.8
123	Node 18	3.7	2.7	2.3
124		8.0	9.4	9.3
DM336_1	Taw_Khayan_East_Or_A	2.0	1.4	1.2

7.4 Sensitivity analysis

To test the impact of the assumed parameters on the output of the SOBEK model, a sensitivity analysis is performed. The results on the impact of the changed parameters for a range of return periods are discussed in this section. Both the sensitivity to model parameters as well as physical parameters is studied.

7.4.1 Sensitivity to channel and creek roughness

The roughness of the channels and creeks within the Unit is schematized using a Manning roughness. The baseline value of $0.03 \text{ s/m}^{1/3}$ is representative for natural creeks, but a certain margin around this value is possible depending on irregularities in the creek bathymetry and/or roughness along the banks. Hence, the value of 0.03 is decreased with 25% leading to a replaced value of 0.0225. The same is done with an increase of 25%, resulting in a value of 0.0375. Both values can be considered as the respective low-end and high-end limits for a representative Manning roughness. The impact of these results on the flow module are visible in the table below.

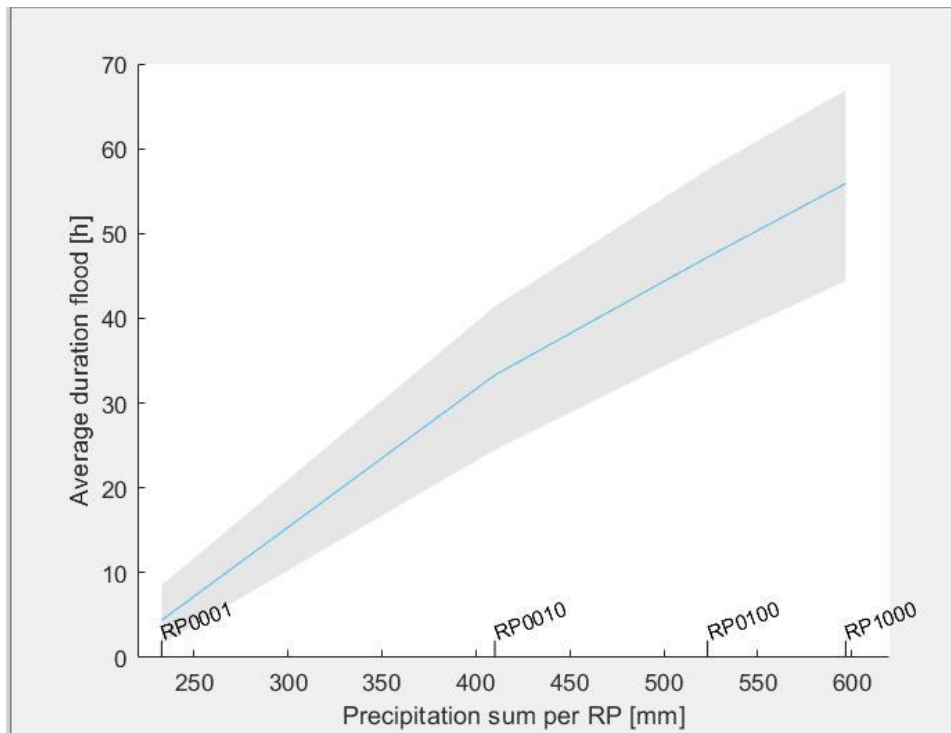


Figure 53: Sensitivity of flooding duration to Manning roughness

The sensitivity to the channel roughness is shown to be 15% in both cases. This means that if the channels and creeks act more smoothly than expected, the flooding duration decreases by up to 15%. Conversely, if the channels provide more resistance than expected, the flooding duration an increase by up to 15%.

7.4.2 Sensitivity to channel and creek width

In the current model, a representative bottom width of 20 m is assumed for all channels and creeks. Based on satellite imagery and field observation this is mostly correct, with an overestimation for a few smaller creeks and an underestimation for a few larger creeks close to open water. In order to quantify the sensitivity to this parameter, a simulation is run where the channel width is doubled to 40 m.

An overview of the flooding extent in percentage of total Unit area flooded as a function of time after peak inundation and return period for both channel geometries is given in the tables below. The impact of the increased channel with varies per return period, but can be considered as very significant. Both a reduction of flooding extent and flooding duration is observed, likely as a result of the combination of a larger storage capacity and a larger conveyance (i.e. drainage) capacity.

Table 42: Overview of flooding extent (% of total Unit area) as a function of time and return period (channel width of 20 m).

Hours after peak inundation	RP0001	RP0010	RP0100	RP1000
0	0	34	59	73
12	0	30	51	60
24	0	15	36	47
36	0	2	14	29
48	0	0	1	7

Table 43: Overview of flooding extent (% of total Unit area) as a function of time and return period (channel width of 40 m).

Hours after peak inundation	RP0001	RP0010	RP0100	RP1000
0	0	7	31	45
12	0	2	19	34
24	0	0	2	7
36	0	0	0	0
48	0	0	0	0

7.4.3 Sensitivity to available head (gravitational flow)

After the precipitation falls on Unit 08, it is collected within the channels and creeks after a certain delay and subsequently conveyed toward the outlets where it is discharge to open water. The water level adjacent to the Unit is dictated by the river discharge upstream and the tidal forcing downstream. Unit 08 is located at a certain vertical height so that, in general, the rainfall can always flow towards the open water using gravitational flow. The gravitational flow is somewhat reduced during (spring) flood ride, but this can be considered negligible. However, there are scenarios when the water level rises further, for example during a storm surge. The available head is then temporarily reduced significantly (on top of the existing tide), possible reducing the drainage capacity and thus increasing inundation within the Unit.

This scenario was studied using the Nargis (2008) event. It was found that Nargis included a storm surge comparable to a 1 in 100 year event, in combination with precipitation comparable to a 1 in 10 year event (for this the reader is referred to the main report). The surge as computed by the larger RWSS model is translated to both downstream boundaries of the SOBEK model (Toe and Yangon River mouth) and a 1 in 10 year pluvial event is forced.

The table below gives an overview of the flooding extent in percentage of total Unit area flooded as a function of time after peak inundation and return period. The right-most column shows the results for the surge scenario.

Table 44: Overview of flooding extent (% of total Unit area) as a function of time and return period. Surge scenario included in the column on the right.

Hours after peak inundation	RP0001	RP0010	RP0100	RP1000	RP0010 incl. RP0100 surge
0	0	34	59	73	36
12	0	30	51	60	31
24	0	15	36	47	17
36	0	2	14	29	2
48	0	0	1	7	0

It can be concluded that:

- Including storm surge leads to a slight increase in (pluvial) inundation in Unit08 relative to the same pluvial event without surge;
- The sensitivity of the drainage capacity to the water level on the boundaries (within realistic limits) is relatively small with an increase of roughly 10% in peak inundation extent. The duration of the inundation remain identical, as the duration of the surge is short in comparison.

7.5 Discussion and conclusion

Due to a lack of data and no possibility to collect this in the field at this moment, detailed model validation is not possible. However, the areas where pluvial floods appear to occur regularly seem to have more vegetation comparing to surrounding areas which is visible from open available satellite images. In addition, local experts confirm that these areas are prone to (frequent) pluvial flooding. The fact that the model is in agreement with these observation builds confidence in the model.

That model also predicts that most pluvial water is drained within 48 hours. Only for the more extreme events, the full drainage takes longer. The associated discharge through the different outlets are generally close to the estimated peak discharges. Again, this is confirmed by local experts. They observe that, while drainage is still adequate for the more frequent events, limitation can likely be found at the capacity of the current outlet structures. During more extreme events, a bottleneck might be expected there.

All the above does indicate that, despite all the necessary assumptions, the simulated pluvial flooding behavior using the SOBEK model do represent reality to a large extent.

From the detailed drainage study using the SOBEK model it can be concluded that when adopting the assessment criteria for pluvial flooding, the RWSS and SOBEK model provide comparable results. The SOBEK model provides more realistic insights regarding the distribution of the pluvial flooding within the unit, as well as the distribution of the pluvial water over the available outlets. Following the above, the RWSS model is capable of modelling an indicative level of water security regarding pluvial flooding. However, for the design of mitigating measures, the use of a more detailed (SOBEK) model is recommended. Alternatively, another model capable to study pluvial floods as (direct) result of water ponding on the land from precipitation can be adopted. However, any future online coupling with the larger RWSS model is then much more difficult.

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APPENDIX C FACTSHEETS

1. Factsheet C.1.1.U1 Reinforcement of an existing dike by heightening the dike (Unit 1)
2. Factsheet C.1.1.U2 Reinforcement of an existing dike by heightening the dike (Unit 2)
3. Factsheet C.1.1.U3 Reinforcement of an existing dike by heightening the dike (Unit 3)
4. Factsheet C.1.1.U4 Reinforcement of an existing dike by heightening the dike (Unit 4)
5. Factsheet C.1.1.U5 Reinforcement of an existing dike by heightening the dike (Unit 5)
6. Factsheet C.1.1.U6 Reinforcement of an existing dike by heightening the dike (Unit 6)
7. Factsheet C.1.1.U7 Reinforcement of an existing dike by heightening the dike (Unit 7)
8. Factsheet C.1.1.U8 Reinforcement of an existing dike by heightening the dike (Unit 8)
9. Factsheet C.1.1.U10 Reinforcement of an existing dike by heightening the dike (Unit 10)
10. Factsheet C.1.1.U13 Reinforcement of an existing dike by heightening the dike (Unit 13)
11. Factsheet C.1.1.U14 Reinforcement of an existing dike by heightening the dike (Unit 14)
12. Factsheet C.1.1.U15 Reinforcement of an existing dike by heightening the dike (Unit 15)
13. Factsheet C.1.1.U18 Reinforcement of an existing dike by heightening the dike (Unit 18)

14. Factsheet 2.1: Rural Household Water Supply
15. Factsheet 2.2: Kawhmu and Kungyangon Towns Water Supply
16. Factsheet 2.3: Rural Villages Water Supply

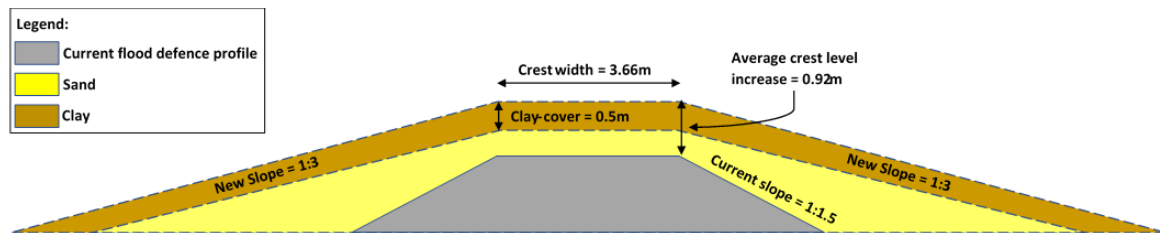
17. Factsheet 3.1.U4: Sluice structures (Unit 4)
18. Factsheet 3.2.U5: Sluice structures (Unit 5)
19. Factsheet 3.3.U6: Sluice structures (Unit 6)
20. Factsheet 3.4.U7: Sluice structures (Unit 7)
21. Factsheet 3.5.U8: Sluice structures (Unit 8)

Factsheet C.1.1.U1 Reinforcement of an existing dike by heightening the dike (Unit 1)

1. Description of Measure

In light of program 1 of the RWSS flood risk analysis, the fluvial and coastal flood risks have been quantified to set a conforming flood protection standard for each of the unit areas around the city of Yangon. For unit area 1, it is proposed to raise the flood protection level provided by the current flood protection system of the unit to a 1:100 protection level for fluvial and coastal flooding. In line with this goal, the following specific measures should be taken:

- Dike improvement along 42.9km of existing flood defenses. A first impression of a cross-view of the proposed dike improvement strategy is visualized below. This visualization shows the average crest level increase for all locations where interventions are required. The site-specific profile will therefore vary from the presented cross-section depending on the local crest level deficit. Furthermore, the currently presented dike profile is based on best-practice values and should be further detailed before implementation.



2. Purpose & targets (incl. Mainland use and unit)

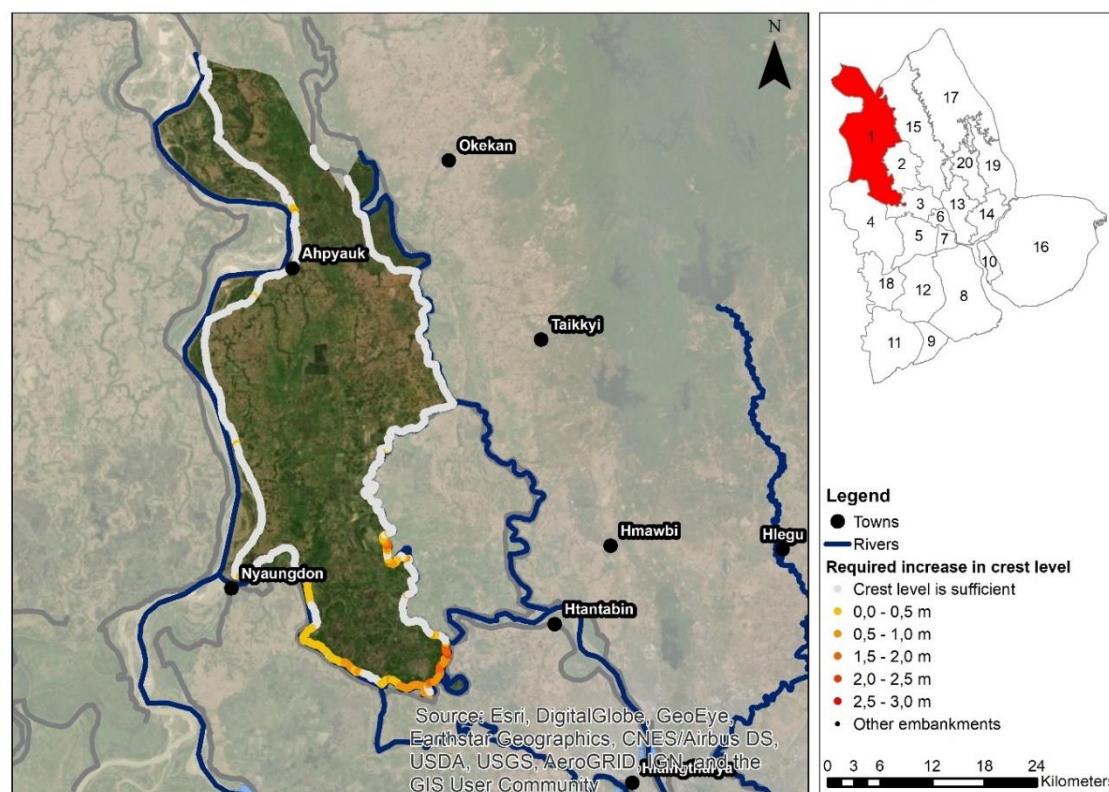
The purpose of the dike improvements is to decrease the flood risks within unit area 1, by reduction of the annual flood probabilities. This measure especially targets the flood defense stretches which can currently be considered as the weakest links. Those stretches are improved, to decrease the overall flood risks.

3. Location (s)

The location of the proposed flood defense improvements is concentrated along the southern side of Unit area 1, along the Hlaing river. The figure presented below provides an overview of all locations along this unit which are recognized by a crest level deficit for the proposed flood protection level.

The exact configuration of the flood defense improvement strategy should be made more explicit in a future stadium of the project and depends e.g. on the current land use along the flood defense system and the location-specific improvement task.

Unit 1: embankment reinforcements and additional sluices



4. Preliminary indication of ownership

Within Myanmar the Irrigation and Water Utilization Management Department (IWUMD) is responsible for operation and maintenance of flood protection embankments and polders system all over the country. Therefore, the ownership of this intervention is expected to lie with IWUMD.

5. Preliminary indication of collaboration

IWUMD is expected to be the owner and legally responsible organization for the implementation of the proposed measures. However, before implementation, additional analyses, further modelling, planning and a water governance structure should be in place.

6. Level of urgency

The level of urgency is determined for every unit area based on a combination of three characteristics: The benefit-cost ratios for the current and future land use and the affected people risk reduction of the proposed measures. Unit area 1 can be categorized as high priority, because the proposed measures are cost-efficient regardless of the future development of the area, and the reduction of annual expected affected people is among the highest. The measures in Unit area 1 should therefore be prioritized.

Unit	BC-ratio current land use	BC-ratio future land use	Affected people risk reduction (annually)	Priority category
1	4.54	4.54	19882	High priority
18	4.33	4.33	12338	
3	1.08	96.1	3025	
6	1.83	9.65	1058	
4	11.34	11.34	38811	
5	0.88	0.88	4055	
7	0.18	20.97	844	
2	1.08	8.77	1940	Medium priority
13	1.36	1.67	1041	
15	0.33	26.87	94	
10	0.27	5.27	43	Low priority
8	0.19	1.25	252	
14	0.29	0.44	104	

7. Effectiveness (Incl. indicators and thresholds)

Flood defense improvement is an immediate and effective way to counter flood risks in the area. The strength of the system (total flood defense system of unit area 1) is dependent on the strength of the separate components within the system. Much of the currently present flood defense system along this unit suffices already. However, due to the weak links within the system, the system as a whole does not suffice. Investing in these weak links in the system is therefore a very effective manner to decrease the overall flood risks. After adaptation of the weakest links, the full potential of the existing flood defenses can be exploited again and the system as a whole will be able to cope with the future flood threats.

8. Social and Environmental Safeguards

The acquisition of land for realization of the flood defense improvements might include resettlement of local residents at locations where people reside directly next to the current flood defense. Furthermore, depending on the local configuration of the improvement strategy, agricultural lands will become occupied by the strengthened flood defenses. Local land-owners should be compensated for these losses of land. Positive social impacts of the proposed measures include a reduction of flood nuisance for residents, as well as a more stable environment for growing crops and setting up businesses, providing a more stable economic output of the area.

9. Cost estimates (CAPEX & OPEX)

A short quantification overview of the CAPEX and OPEX of the proposed flood defense improvement strategy is presented below. The OPEX expenditure quantification is based on 0.1% annual operating and maintenance costs and 3% periodical maintenance once every 5 years. The design horizon is 2040 for the proposed measures and a discount rate of 6% was assumed.

PV Dike improvement CAPEX	USD 17.56 million
PV Dike improvement OPEX	USD 1.27 million
PV total investment costs	USD 18.83 million

10. Cost recovery indication

The proposed measures will significantly reduce the total flood risk of the area, as indicated below. The investment benefits account for 4.54 times the investment costs. It was assumed that the residual value of the initial investment at the end of the life cycle accounts for 50% of the initial investment.

	Current Land use	Future Land use
PV Flood risk reduction	USD 82.68 million	USD 82.68 million
PV Residual value investments	USD 2.74 million	USD 2.74 million
PV total investment benefits	USD 85.42 million	USD 85.42 million
Benefit/cost ratio	4.54	4.54

11. Robustness & Adaptiveness

To assure that the proposed flood defense improvements are executed in an adaptive manner, it is recommended to assure that the inner and outer slopes of the new dike are sufficiently smooth. This makes it easier in case of future flood defense improvements to further increase the crest levels within the existing profile of the flood defense.

The used construction materials are recoverable after the life cycle of the flood defense has ended and can be reused in future projects.

12. Combinations and/or cumulative impacts

There is a relation with several other interventions and cumulative impacts within the RWSS flood risk analysis:

- The construction of new/improved dikes might negatively impact local runoff of the areas behind the flood defense, affecting the pluvial flood risks. There is a link with Program 3 within the RWSS flood risk project
- The flood defense system and flood risk in the entire study area is interconnected. Flood defense improvements in one place reduce flood risks in one area, but might increase flood probabilities and flood risks in another area. This system-effect should be further quantified based on the proposed measures.

13. Construction capacity requirements

Dikes within the area around Yangon and the rest of Myanmar are managed by IWUMD. IWUMD and local contractors are familiar with these structures. The flood defense improvements can be carried out by local contractors in collaboration with the IWUMD.

14. Suggested next steps

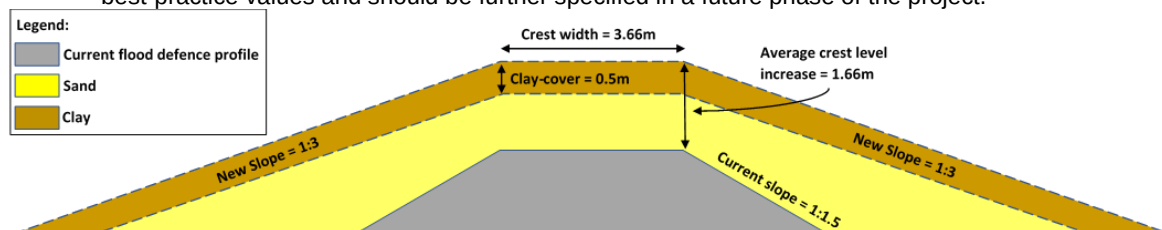
- Additional data collection (surveying, amongst others for the current flood defense profiles, open channel crossings, existing hydraulic structures and surface elevation levels)
- Updated and more in-depth analysis of the effects of the proposed measures
- Setting-up of a detailed implementation planning and design

Factsheet C.1.1.U2 Reinforcement of an existing dike by heightening the dike (Unit 2)

1. Description of Measure

In light of program 1 of the RWSS flood risk analysis, the fluvial and coastal flood risks have been quantified to set a conforming flood protection standard for each of the unit areas around the city of Yangon. For unit area 2, it is proposed to raise the flood protection level provided by the current flood protection system of the unit to a 1:200 protection level for fluvial and coastal flooding. In line with this goal, the following specific measures should be taken:

- Dike improvement along 19.5km of existing flood defenses. A first impression of a cross-view of the proposed dike improvement strategy is visualized below. This visualization shows the average crest level increase for all locations where interventions are required. The site-specific profile will therefore vary from the presented cross-section. Furthermore, the currently presented new profile is based on best-practice values and should be further specified in a future phase of the project.



2. Purpose & targets (incl. Mainland use and unit)

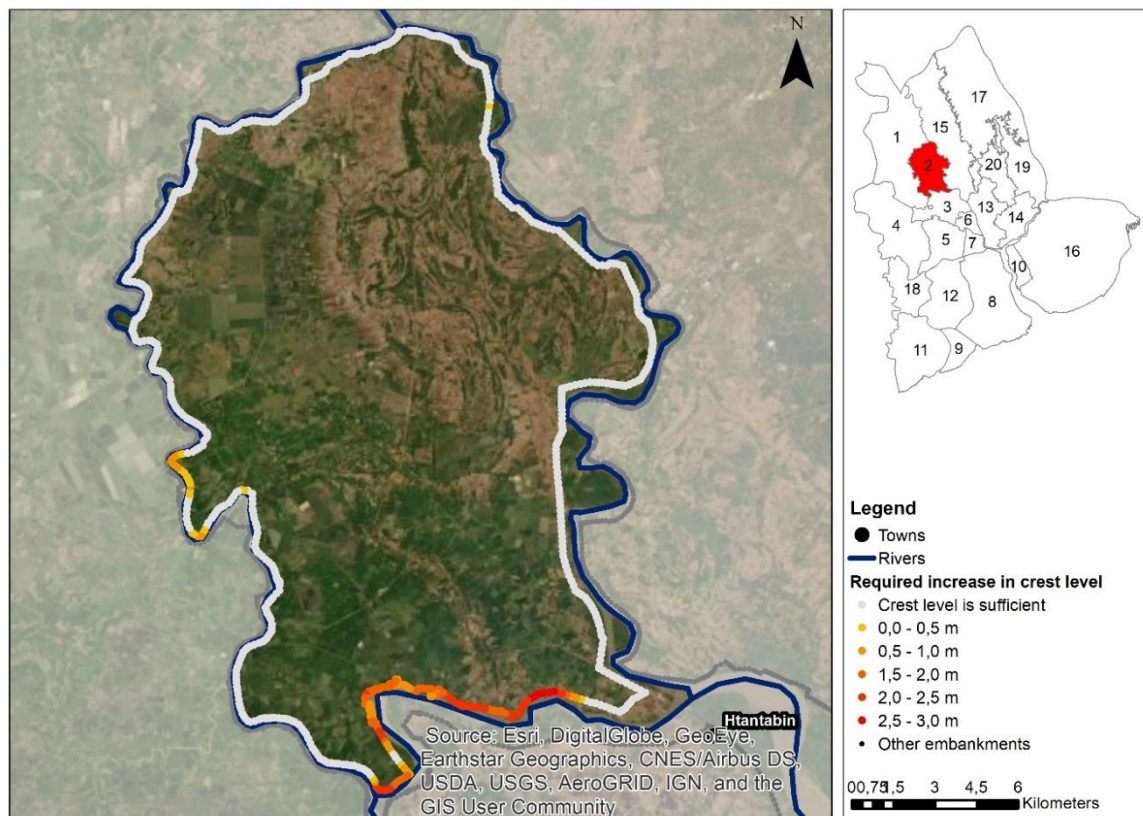
The purpose of the dike improvements is to decrease the flood risks within unit area 2, by reduction of the annual flood probabilities. This measure especially targets the flood defense stretches which can currently be considered as the weakest links of the flood defense system of this unit. Those stretches are improved, to decrease the overall flood risk.

3. Location (s)

The location of the proposed flood defense improvements is concentrated along the southern side of unit area 2, along the Hlaing river. Furthermore, several short stretches along the western side of this unit area require small improvements as well. The figure presented below provides an overview of all locations along this unit area which are recognized by a crest level deficit for the proposed flood protection level.

The exact configuration of the flood defense improvement strategy should be made more explicit in a future stadium of the project. This is amongst other dependent on the current land use along the flood defense system and the location-specific improvement task.

Unit 2: embankment reinforcements and additional sluices



4. Preliminary indication of ownership

Within Myanmar the Irrigation and Water Utilization Management Department (IWUMD) is responsible for operation and maintenance of flood protection embankments and polders system all over the country. Therefore, the ownership of this intervention is expected to lie with IWUMD.

5. Preliminary indication of collaboration

IWUMD is expected to be the owner and legally responsible organization for the implementation of the proposed measures. However, before implementation, additional analyses, further modelling, planning and a water governance structure should be in place.

6. Level of urgency

The level of urgency is determined for every unit area based on a combination of three characteristics: The benefit-cost ratios for the current and future land use and the affected people risk reduction of the proposed measures. Unit area 2 can be categorized as medium priority. The proposed measures are cost-efficient in both the current and (especially) the future land use situation. The affected people risk reduction is slightly lower than in other unit areas. The measures in Unit 2 should therefore be categorized among the interventions with a medium priority

Unit	BC-ratio current land use	BC-ratio future land use	Affected people risk reduction (annually)	Priority category
1	4.54	4.54	19882	High priority
18	4.33	4.33	12338	
3	1.08	96.1	3025	
6	1.83	9.65	1058	
4	11.34	11.34	38811	
5	0.88	0.88	4055	
7	0.18	20.97	844	
2	1.08	8.77	1940	Medium priority
13	1.36	1.67	1041	
15	0.33	26.87	94	
10	0.27	5.27	43	Low priority
8	0.19	1.25	252	
14	0.29	0.44	104	

7. Effectiveness (Incl. indicators and thresholds)

Flood defense improvement is an immediate and effective way to counter flood risks in the area. The strength of the system (total flood defense system of unit area 2) is dependent on the strength of the separate components within the system. Much of the currently present flood defense system along this unit suffices already. However, due to the weak links within the system, the system does not suffice. Investing in these weak links in the system is therefore a very effective manner to decrease the overall flood risks. After adaptation of the weakest links, the full potential of the existing flood defenses can be exploited again, and the system as a whole will be able to cope with the future flood threats.

8. Social and Environmental Safeguards

The acquisition of land for realization of the flood defense improvements might include resettlement of residents at locations where people reside directly next to the current flood defense. Furthermore, depending on the local configuration of the improvement strategy, agricultural lands will become occupied by the strengthened flood defenses. Local landowners should be compensated for these losses of land. Positive social impacts of the proposed measures include a reduction of flood nuisance for residents, as well as a more stable environment for growing crops and setting up businesses, providing a more stable economic output of the area.

9. Cost estimates (CAPEX & OPEX)

A short quantification overview of the CAPEX and OPEX of the proposed flood defense improvement strategy is presented below. The OPEX expenditure quantification is based on 0.1% annual operating and maintenance costs and 3% periodical maintenance once every 5 years. The design horizon is 2040 for the proposed measures and a discount rate of 6% was assumed.

PV Dike improvement CAPEX	USD 9.88 million
PV Dike improvement OPEX	USD 0.73 million
PV total investment costs	USD 10.61 million

10. Cost recovery indication

The proposed measures will significantly reduce the total flood risk of the area, as indicated below. The effectiveness is dependent on the future land use developments. Under current land use, the benefit/cost ratio is 0.95, but based on the current land use projections in 2040, the benefit/cost ratio would be 8.77. It can therefore be said that the proposed measures will likely be cost-effective regardless of the exact configuration if the future land use developments. It was assumed that the residual value of the initial investment at the end of the life cycle accounts for 50% of the initial investment.

	Current Land use scenario:	Future Land use scenario:
PV Flood risk reduction	USD 8.57 million	USD 91.40 million
PV Residual value investments	USD 1.54 million	USD 1.54 million
PV total investment benefits	USD 10.11 million	USD 92.95 million
Benefit/cost ratio	0.95	8.77

11. Robustness & Adaptiveness

To assure that the proposed flood defense improvements are executed in an adaptive manner, it is recommended to assure that the inner and outer slopes of the new dike are sufficiently smooth. This makes it easier in case of future flood defense improvements to further increase the crest levels within the existing profile of the flood defense.

The used construction materials are recoverable after the life cycle of the flood defense has ended and can be reused in future projects.

12. Combinations and/or cumulative impacts

There is a relation with several other interventions and cumulative impacts within the RWSS flood risk analysis:

- The construction of new/improved dikes might negatively impact local runoff of the areas behind the flood defense, affecting the pluvial flood risks. There is a link with Program 3 within the RWSS flood risk project
- The flood defense system and flood risk in the entire study area is interconnected. Flood defense improvements in one place reduce flood risks in one area but might increase flood probabilities and flood risks in another area. This system-effect should be further quantified based on the proposed measures.

13. Construction capacity requirements

Dikes within the area around Yangon and the rest of Myanmar are managed by IWUMD. IWUMD and local contractors are familiar with these structures. The flood defense improvements can be carried out by local contractors in collaboration with the IWUMD.

14. Suggested next steps

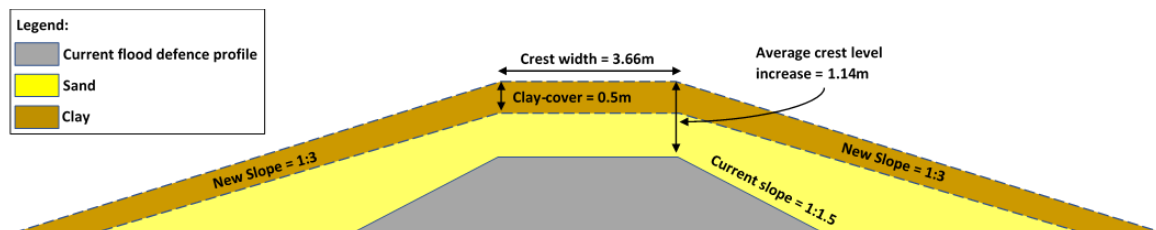
- Additional data collection (surveying, amongst others for the current flood defense profiles, open channel crossings, existing hydraulic structures and surface elevation levels)
- Updated and more in-depth analysis of the effects of the proposed measures
- Setting-up of a detailed implementation planning and design

Factsheet C.1.1.U3 Reinforcement of an existing dike by heightening the dike (Unit 3)

1. Description of Measure

In light of program 1 of the RWSS flood risk analysis, the fluvial and coastal flood risks have been quantified to set a conforming flood protection standard for each of the unit areas around the city of Yangon. For unit area 3, it is proposed to raise the flood protection level offered by the current flood protection system of the unit to a 1:200 protection level for fluvial and coastal flooding. In line with this goal, the following specific measures should be taken:

Dike improvement along 31.2km of existing flood defenses. A first impression of a cross-view of the proposed dike improvement strategy is visualized below. This visualization shows the average crest level increase for all locations where interventions are required. The site-specific profile will therefore vary from the presented cross-section. Furthermore, the currently presented dimensioning of the new profile are based on best-practice values and should be further specified in a future phase of the project.



Important: Unit Area 3 is hydraulically connected to Unit Area 6. Therefore, a flood protection level of 1:200 can only be achieved in Unit Area 3 if Unit Area 6 is similarly reinforced to the same flood protection level.

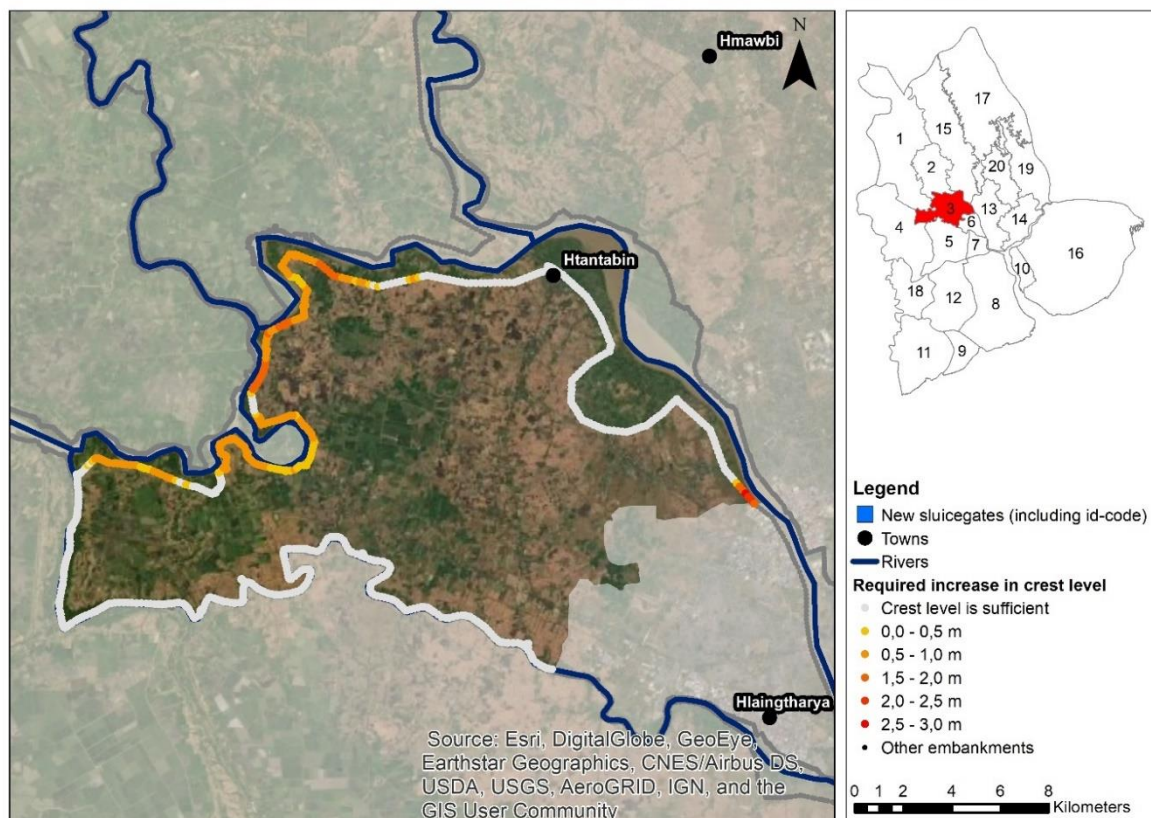
2. Purpose & targets (incl. Mainland use and unit)

The purpose of the dike improvements is to decrease the flood risks within unit area 3, by reduction of the annual flood probabilities. This measure especially targets the flood defense stretches which can currently be considered as the weakest links of the flood defense system of this unit. Those stretches are improved, to decrease the overall flood risks.

3. Location (s)

The location of the proposed flood defense improvements is concentrated along the full Western and Southern border of this unit area, along the Hlaing river and the Pun Hlaing river. Almost all dikes along these sides require improvements. The figure presented below provides an overview of all locations along this unit area which are recognized by a crest level deficit for the proposed flood protection level. The exact configuration of the flood defense improvement strategy should be made more explicit in a future stadium of the project.

Unit 3: embankment reinforcements and additional sluices



4. Preliminary indication of ownership

Within Myanmar the Irrigation and Water Utilization Management Department (IWUMD) is responsible for operation and maintenance of flood protection embankments and polders system all over the country. Therefore, the ownership of this intervention is expected to lie with IWUMD.

5. Preliminary indication of collaboration

IWUMD is expected to be the owner and legally responsible organization for the implementation of the proposed measures. However, before implementation, additional analyses, further modelling, planning and a water governance structure should be in place.

6. Level of urgency

The level of urgency is determined for every unit area based on a combination of three characteristics: The benefit-cost ratios for the current and future land use and the affected people risk reduction of the proposed measures. Unit area 3 is interconnected with unit area 6, which is why both units should be tackled simultaneously. Units 3 and 6 should be categorized as high priority. Both in the current and future situation the foreseen investments are cost-efficient, which implies that it is already worthwhile to initiate the interventions on short term. The interventions should especially be installed before the future developments are implemented, to maximize the flood risk reduction purpose. Furthermore, the affected people reduction is relatively high, especially considering that future urban development is not even considered in these numbers.

Unit	BC-ratio current land use	BC-ratio future land use	Affected people risk reduction (annually)	Priority category
1	4.54	4.54	19882	High priority
18	4.33	4.33	12338	
3	1.08	96.1	3025	
6	1.83	9.65	1058	
4	11.34	11.34	38811	
5	0.88	0.88	4055	
7	0.18	20.97	844	
2	1.08	8.77	1940	Medium priority
13	1.36	1.67	1041	
15	0.33	26.87	94	
10	0.27	5.27	43	Low priority
8	0.19	1.25	252	
14	0.29	0.44	104	

7. Effectiveness (Incl. indicators and thresholds)

Flood defense improvement is an immediate and effective way to counter flood risks in the area. The strength of the system (total flood defense system of unit area 3) is dependent on the strength of the separate components within the system. Much of the currently present flood defense system along this unit suffices already. However, due to the weak links within the system, the system as a whole does not suffice. Investing in these weak links in the system is therefore a very effective manner to decrease the overall flood risks. After adaptation of the weakest links, the full potential of the existing flood defenses can be exploited again and the system as a whole will be able to cope with the future flood threats.

Specifically, for unit area 3, the flood protection function of the Mezali sluice and the Cofferd dam in the Pan Hlaing sluices are an important prerequisite for the effectiveness of the proposed investments. Mezali sluice prevents high river levels downstream along unit area 3, preventing fluvial flooding along this side of the unit area. The Cofferdam downstream prevents high storm surge levels upstream during storms. If one of these two structures cannot fulfill their flood retention function, flooding can occur within the unit areas along the Pan Hlaing river.

8. Social and Environmental Safeguards

The acquisition of land for realization of the flood defense improvements and additional hydraulic structures might include resettlement of local residents at locations where people reside directly next to the current flood defense. Furthermore, depending on the local configuration of the improvement strategy, agricultural lands will become occupied by the strengthened flood defenses. Local landowners should be compensated for these losses of land.

Positive social impacts of the proposed measures include a reduction of flood nuisance for residents, as well as a more stable environment for growing crops and setting up businesses, providing a more stable economic output of the area.

9. Cost estimates (CAPEX & OPEX)

A short quantification overview of the CAPEX and OPEX of the proposed flood defense improvement strategy is presented below. The OPEX expenditure quantification is based on 0.1% annual operating and maintenance costs and 3% periodical maintenance once every 5 years. The design horizon is 2040 for the proposed measures and a discount rate of 6% was assumed.

PV Dike improvement CAPEX	USD 8.63 million
PV Dike improvement OPEX	USD 0.63 million
PV total investment costs	USD 9.26 million

10. Cost recovery indication

The proposed measures will significantly reduce the total flood risk of the area, as indicated below. The effectiveness is strongly dependent on the future land use developments. Under current land use, the benefit/cost ratio is already above 1 (1.08), but based on the current land use projections in 2040, the

benefit/cost ratio would increase drastically towards 96.1. It was assumed that the residual value of the initial investment at the end of the life cycle accounts for 50% of the initial investment.

	Current Land use scenario:	Future Land use scenario:
PV Flood risk reduction	USD 8.68 million	USD 888.59 million
PV Residual value investments	USD 1.35 million	USD 1.35 million
<i>PV total investment benefits</i>	<i>USD 10.03 million</i>	<i>USD 889.94 million</i>
<i>Benefit/cost ratio</i>	<i>1.08</i>	<i>96.1</i>

11. Robustness & Adaptiveness

To assure that the proposed flood defense improvements are executed in an adaptive manner, it is recommended to assure that the inner and outer slopes of the new dikes are sufficiently smooth. This makes it easier in case of future flood defense improvements to further increase the crest levels within the existing profile of the flood defense.

The used construction materials are recoverable after the life cycle of the flood defense has ended and can be reused in future projects.

12. Combinations and/or cumulative impacts

There is a relation with several other interventions and cumulative impacts within the RWSS flood risk analysis:

- The construction of new/improved dikes might negatively impact local runoff of the areas behind the flood defense, affecting the pluvial flood risks. There is a link with Program 3 within the RWSS flood risk project
- The flood defense system and flood risk in the entire study area is interconnected. Flood defense improvements in one place reduce flood risks in one area, but might increase flood probabilities and flood risks in another area. This system-effect should be further quantified based on the proposed measures.

13. Construction capacity requirements

Dikes and sluices within the area around Yangon and the rest of Myanmar are managed by IWUMD. IWUMD and local contractors are familiar with these structures. The flood defense improvements can be carried out by local contractors in collaboration with the IWUMD.

14. Suggested next steps

- Additional data collection (surveying, amongst others for the current flood defense profiles, open channel crossings, existing hydraulic structures and surface elevation levels)
- Updated and more in-depth analysis of the effects of the proposed measures
- Setting-up of a detailed implementation planning and design

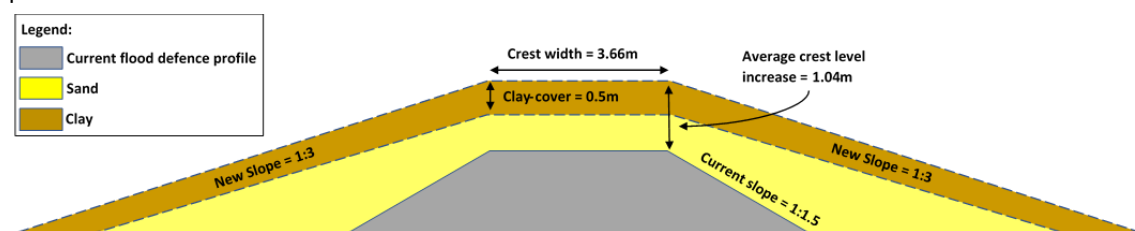
Factsheet C.1.1.U4 Reinforcement of an existing dike by heightening the dike (Unit 4)

1. Description of Measure

In light of program 1 of the RWSS flood risk analysis, the fluvial and coastal flood risks have been quantified to set a conforming flood protection standard for each of the unit areas around the city of Yangon. For unit area 4, it is proposed to raise the flood protection level offered by the current flood protection system of the unit to a 1:200 protection level for fluvial and coastal flooding. In line with this goal, the following specific measures should be taken:

- Dike improvement along 68.0km of existing flood defenses. A first impression of a cross-view of the proposed dike improvement strategy is visualized below. This visualization shows the average crest level increase for all locations where interventions are required. The site-specific profile will therefore vary from the presented cross-section. Furthermore, the currently presented dimensioning of the new profile are based on best-practice values and should be further specified in a future phase of the project.
- Construction of 3 additional sluices/hydraulic structures at the crossing of the flood defense with three small local streams. Two of these streams are approximately 5m wide, so relatively small structures are required. The last structure should be placed in an almost 50m wide river, which requires a medium sized structure.

Important: Unit Area 4 is hydraulically connected to Unit Areas 5 and 7. Therefore, a flood protection level of 1:200 can only be achieved in Unit Area 4 if Unit Areas 5 and 7 are similarly reinforced to the same flood protection level.



2. Purpose & targets (incl. Mainland use and unit)

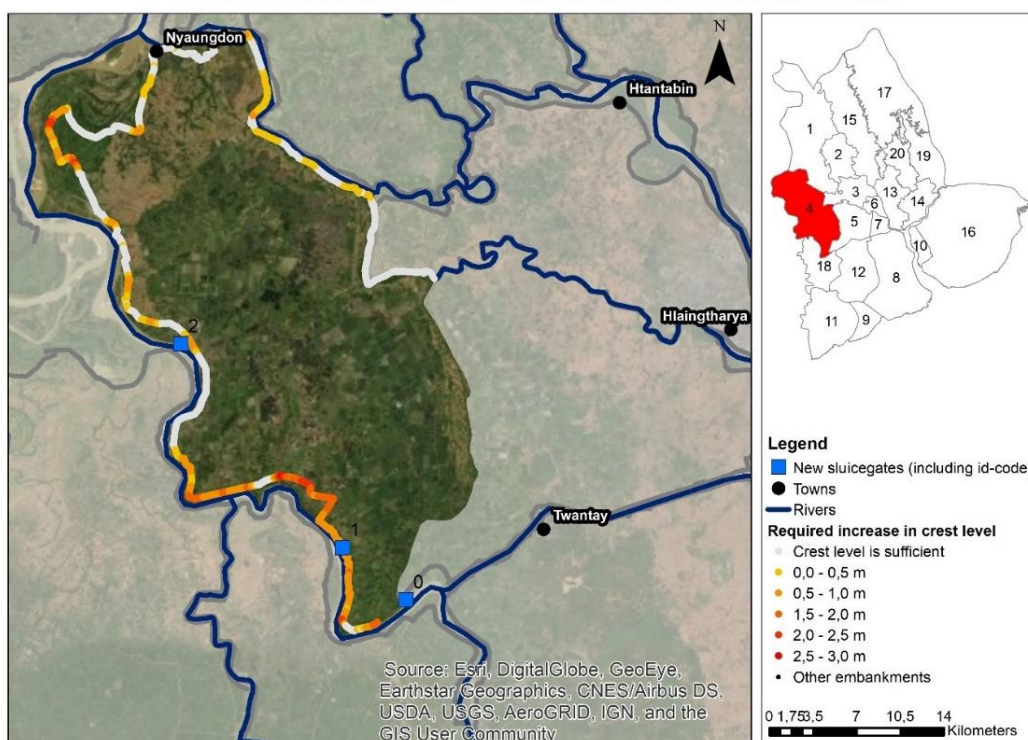
The purpose of the dike improvements is to decrease the flood risks within unit area 4, by reduction of the annual flood probabilities. This measure especially targets the flood defense stretches which can currently be considered as the weakest links of the flood defense system of this unit. Those stretches are improved, to decrease the overall flood risks.

The purpose of the additional hydraulic structures within the system is to prevent that flooding of the interior of unit area 4 occurs via inflow through the open channel crossings. By controlling the outflow of these streams, flooding can be prevented.

3. Location (s)

Dike improvement is required along large parts of the current flood defense system of unit area 4, along all sides of the area. The figure presented below provides an overview of all locations along this unit area which

Unit 4: embankment reinforcements and additional sluices



are recognized by a crest level deficit for the proposed flood protection level. The exact configuration of the flood defense improvement strategy should be made more explicit in a future stadium of the project. The location of the proposed additional hydraulic structures is shown in the figure as well. These are situated along the Thande river. Hydraulic structure with ID-0 is located at the 50m wide river crossing.

4. Preliminary indication of ownership

Within Myanmar the Irrigation and Water Utilization Management Department (IWUMD is responsible for operation and maintenance of flood protection embankments and polders system all over the country. Therefore, the ownership of this intervention is expected to lie with IWUMD.

5. Preliminary indication of collaboration

IWUMD is expected to be the owner and legally responsible organization for the implementation of the proposed measures. However, before implementation, additional analyses, further modelling, planning and a water governance structure should be in place.

6. Level of urgency

The level of urgency is determined for every unit area based on a combination of three characteristics: The benefit-cost ratios for the current and future land use and the affected people risk reduction of the proposed measures. Unit areas 4, 5 and 7 are interconnected, with overlapping flood patterns. As a result, these three unit areas should be considered simultaneously, as flood protection of one unit area will not be guaranteed without interventions in the other two unit areas.

Unit areas 4, 5 and 7 can be categorized as high priority unit areas. The proposed measures are especially for unit area 4 very cost-effective for the current land use scenario, indicating that it is valuable to initiate these interventions on the short term. Furthermore, the affected people risk reduction value is highest for unit area 4, adding to the urgency to start interventions soon.

Unit	BC-ratio current land use	BC-ratio future land use	Affected people risk reduction (annually)	Priority category
1	4.54	4.54	19882	High priority
18	4.33	4.33	12338	
3	1.08	96.1	3025	
6	1.83	9.65	1058	
4	11.34	11.34	38811	
5	0.88	0.88	4055	
7	0.18	20.97	844	
2	1.08	8.77	1940	Medium priority
13	1.36	1.67	1041	
15	0.33	26.87	94	
10	0.27	5.27	43	Low priority
8	0.19	1.25	252	
14	0.29	0.44	104	

7. Effectiveness (Incl. indicators and thresholds)

Flood defense improvement is an immediate and effective way to counter flood risks in the area. The strength of the system (total flood defense system of unit area 4) is dependent on the strength of the separate components within the system. Much of the currently present flood defense system along this unit suffices already. However, due to the weak links within the system, the system as a whole does not suffice. Investing in these weak links in the system is therefore a very effective manner to decrease the overall flood risks. After adaptation of the weakest links, the full potential of the existing flood defenses can be exploited again and the system as a whole will be able to cope with the future flood threats. The three open channel crossings of the flood defense system are an essential link in the system as well. Without construction of these structures, the whole system will not comprise with the proposed flood protection standards.

8. Social and Environmental Safeguards

The acquisition of land for realization of the flood defense improvements and additional hydraulic structures might include resettlement of local residents at locations where people reside directly next to the current flood defense. Furthermore, depending on the local configuration of the improvement strategy, agricultural lands will become occupied by the strengthened flood defenses. Local land-owners should be compensated for these losses of land.

Furthermore, the construction of additional sluices in the local surface water system might affect the local water supply system and aquatic life. Specifically relevant for this unit area is the presence of many aquaculture plots. The currently open channels crossing the flood defense play an important role in the water supply of these aquaculture plots. Further analysis of the impacts of the construction of additional sluices on the water supply system to these areas is required. Furthermore, the impact of these structures on local aquatic life should be investigated as well.

Positive social impacts of the proposed measures include a reduction of flood nuisance for residents, as well as a more stable environment for growing crops and setting up businesses, providing a more stable economic output of the area.

9. Cost estimates (CAPEX & OPEX)

A short quantification overview of the CAPEX and OPEX of the proposed flood defense improvement strategy is presented below. The OPEX expenditure quantification is based on 0.1% annual operating and maintenance costs and 3% periodical maintenance once every 5 years. The design horizon is 2040 for the proposed measures and a discount rate of 6% was assumed.

PV Dike improvement CAPEX	USD 18.59 million
PV Dike improvement OPEX	USD 1.35 million
PV total investment costs	USD 19.94 million

10. Cost recovery indication

The proposed measures will significantly reduce the total flood risk of the area, as indicated below. The investment benefits account for 11.34 times the investment costs, making the proposed measures very cost effective, regardless of future land use developments. It was assumed that the residual value of the initial investment at the end of the life cycle accounts for 50% of the initial investment.

	Current Land use scenario:	Future Land use scenario:
PV Flood risk reduction	USD 223.13 million	USD 223.13 million
PV Residual value investments	USD 2.90 million	USD 2.90 million
PV total investment benefits	USD 226.03 million	USD 226.03 million
Benefit/cost ratio	11.34	11.34

11. Robustness & Adaptiveness

To assure that the proposed flood defense improvements are executed in an adaptive manner, it is recommended to assure that the inner and outer slopes of the new dikes are sufficiently smooth. This makes it easier in case of future flood defense improvements to further increase the crest levels within the existing profile of the flood defense.

The used construction materials are recoverable after the life cycle of the flood defense has ended and can be reused in future projects.

The new hydraulic structures/sluices should be constructed in a robust way, as they will become an essential link in the flood protection system of this unit area. This can for instance be assured by installing both a mechanical and manual operation system to assure effectivity in case of required closure and setting up a solid operation- and maintenance program for these structures.

12. Combinations and/or cumulative impacts

There is a relation with several other interventions and cumulative impacts within the RWSS flood risk analysis:

- The construction of new/improved dikes and the construction of additional sluices in open channel crossings might negatively impact local runoff of the areas behind the flood defense, affecting the pluvial flood risks. There is a link with Program 3 within the RWSS flood risk project
- The flood defense system and flood risk in the entire study area is interconnected. Flood defense improvements in one place reduce flood risks in one area, but might increase flood probabilities and flood risks in another area. This system-effect should be further quantified based on the proposed measures.

13. Construction capacity requirements

Dikes and sluices within the area around Yangon and the rest of Myanmar are managed by IWUMD. IWUMD and local contractors are familiar with these structures. The flood defense improvements can be carried out by local contractors in collaboration with the IWUMD.

14. Suggested next steps

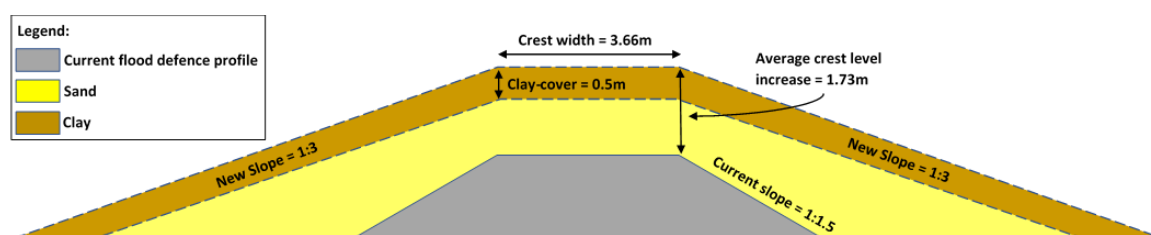
- Additional data collection (surveying, amongst others for the current flood defense profiles, open channel crossings, existing hydraulic structures and surface elevation levels)
- Updated and more in-depth analysis of the effects of the proposed measures
- Setting-up of a detailed implementation planning and design

Factsheet C.1.1.U5 Reinforcement of an existing dike by heightening the dike (Unit 5)

1. Description of Measure

In light of program 1 of the RWSS flood risk analysis, the fluvial and coastal flood risks have been quantified to set a conforming flood protection standard for each of the unit areas around the city of Yangon. For unit area 5, it is proposed to raise the flood protection level offered by the current flood protection system of the unit to a 1:200 protection level for fluvial and coastal flooding. In line with this goal, the following specific measures should be taken:

- Dike improvement along 44.5km of existing flood defenses. A first impression of a cross-view of the proposed dike improvement strategy is visualized below. This visualization shows the average crest level increase for all locations where interventions are required. The site-specific profile will therefore vary from the presented cross-section. Furthermore, the currently presented dimensioning of the new profile are based on best-practice values and should be further specified in a future phase of the project.
- Construction of 10 additional sluices/hydraulic structures at the crossing of the flood defense with three small local streams. 7 of these streams are less than 25m wide, so relatively small structures are required. 3 mid sized structures are required (for streams of 25 to 50m width).



Important: Unit Area 5 is hydraulically connected to Unit Areas 4 and 7. Therefore, a flood protection level of 1:200 can only be achieved in Unit Area 5 if Unit Areas 4 and 7 are similarly reinforced to the same flood protection level.

2. Purpose & targets (incl. Mainland use and unit)

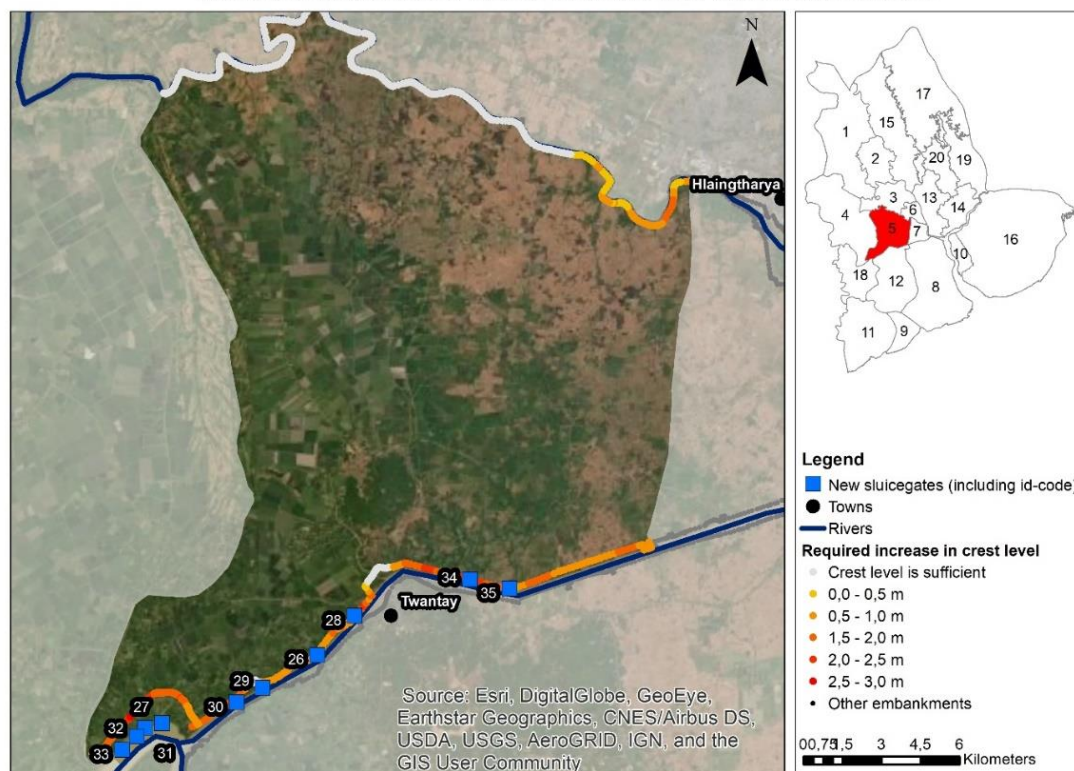
The purpose of the dike improvements is to decrease the flood risks within unit area 5, by reduction of the annual flood probabilities. This measure especially targets the flood defense stretches which can currently be considered as the weakest links of the flood defense system of this unit. Those stretches are improved, to decrease the overall flood risks.

The purpose of the additional hydraulic structures within the system is to prevent that flooding of the interior of unit area 5 occurs via inflow through the open channel crossings. By controlling the outflow of these streams, flooding can be prevented.

3. Location (s)

Dike improvement is required along large parts of the current flood defense system of unit area 5. The entire Southern border requires dike strengthening, while a small part of the Northern border requires dike strengthening. Only the dikes downstream of the Cofferdam require strengthening, as the Cofferdam was assumed to be stable under these circumstances. The figure presented below provides an overview of all locations along this unit area which are recognized by a crest level deficit for the proposed flood protection level. The exact configuration of the flood defense improvement strategy should be made more explicit in a future stadium of the project. The location of the proposed additional hydraulic structures is shown in the figure as well. These are all situated along the Southern side of the area, along the Twante canal or the Thande river.

Unit 5: embankment reinforcements and additional sluices



4. Preliminary indication of ownership

Within Myanmar the Irrigation and Water Utilization Management Department (IWUMD) is responsible for operation and maintenance of flood protection embankments and polders system all over the country. Therefore, the ownership of this intervention is expected to lie with IWUMD.

5. Preliminary indication of collaboration

IWUMD is expected to be the owner and legally responsible organization for the implementation of the proposed measures. However, before implementation, additional analyses, further modelling, planning and a water governance structure should be in place.

6. Level of urgency

The level of urgency is determined for every unit area based on a combination of three characteristics: The benefit-cost ratios for the current and future land use and the affected people risk reduction of the proposed measures. As part of the interconnected island consisting of unit areas 4,5 and 7, unit area 5 can be categorized as high priority, as the measures in this unit area act as prerequisite for the flood protection of the entire island. Furthermore, the affected people risk reduction value is relatively high in unit area 5 for this unit, adding to the urgency to start interventions soon.

Unit	BC-ratio current land use	BC-ratio future land use	Affected people risk reduction (annually)	Priority category
1	4.54	4.54	19882	High priority
18	4.33	4.33	12338	
3	1.08	96.1	3025	
6	1.83	9.65	1058	
4	11.34	11.34	38811	
5	0.88	0.88	4055	
7	0.18	20.97	844	Medium priority
2	1.08	8.77	1940	
13	1.36	1.67	1041	
15	0.33	26.87	94	Low priority
10	0.27	5.27	43	
8	0.19	1.25	252	
14	0.29	0.44	104	

7. Effectiveness (Incl. indicators and thresholds)

Flood defense improvement is an immediate and effective way to counter flood risks in the area. The strength of the system (total flood defense system of unit area 5) is dependent on the strength of the separate components within the system. Much of the currently present flood defense system along this unit suffices already. However, due to the weak links within the system, the system as a whole does not suffice. Investing in these weak links in the system is therefore a very effective manner to decrease the overall flood risks. After adaptation of the weakest links, the full potential of the existing flood defenses can be exploited again and the system as a whole will be able to cope with the future flood threats. The three open channel crossings of the

flood defense system are an essential link in the system as well. Without construction of these structures, the whole system will not comprise with the proposed flood protection standards.

Specifically for unit area 5, the flood protection function of the Mezali sluice and the Cofferdam in the Pan Hlaing sluices are an important prerequisite for the effectiveness of the proposed investments. Mezali sluice prevents high river levels downstream along unit area 5, preventing fluvial flooding along this side of the unit area. The Cofferdam downstream prevents high storm surge levels upstream during storms. If one of these two structures cannot fulfill their flood retention function, flooding can occur within the units along the Pan Hlaing river.

8. Social and Environmental Safeguards

The acquisition of land for realization of the flood defense improvements and additional hydraulic structures might include resettlement of local residents at locations where people reside directly next to the current flood defense. Furthermore, depending on the local configuration of the improvement strategy, agricultural lands will become occupied by the strengthened flood defenses. Local landowners should be compensated for these losses of land.

Furthermore, the construction of additional sluices in the local surface water system might affect the local water supply system and aquatic life. Specifically, relevant for this unit area is the presence of many aquaculture plots. The currently open channels crossing the flood defense play an important role in the water supply of these aquaculture plots. Further analysis of the impacts of the construction of additional sluices on the water supply system to these areas is required. Furthermore, the impact of these structures on local aquatic life should be investigated as well.

Positive social impacts of the proposed measures include a reduction of flood nuisance for residents, as well as a more stable environment for growing crops and setting up businesses, providing a more stable economic output of the area.

9. Cost estimates (CAPEX & OPEX)

A short quantification overview of the CAPEX and OPEX of the proposed flood defense improvement strategy is presented below. The OPEX expenditure quantification is based on 0.1% annual operating and maintenance costs and 3% periodical maintenance once every 5 years. The design horizon is 2040 for the proposed measures and a discount rate of 6% was assumed.

PV Dike improvement CAPEX	USD 31.23 million
PV Dike improvement OPEX	USD 2.26 million
PV total investment costs	USD 33.50 million

10. Cost recovery indication

Solely based on the data for unit area 5, enhanced flood protection does not pay off, as indicated by the cost-benefit ratios below 1. However, as explained in the main report, unit areas 4, 5 and 7 are interconnected, which is why flood protection for unit area 5 impacts the other two unit areas as well. Therefore, given the fact that the cost-benefit ratio for unit area 5 is only slightly below 1 and for unit areas 4 and 7 are far above 1, it easily pays off to enhance flood protection along unit area 5. It was assumed that the residual value of the initial investment at the end of the life cycle accounts for 50% of the initial investment.

	Current Land use scenario:	Future Land use scenario:
PV Flood risk reduction	USD 24.67 million	USD 24.67 million
PV Residual value investments	USD 4.87 million	USD 4.87 million
PV total investment benefits	USD 29.54 million	USD 29.54 million
Benefit/cost ratio	0.88	0.88

11. Robustness & Adaptiveness

To assure that the proposed flood defense improvements are executed in an adaptive manner, it is recommended to assure that the inner and outer slopes of the new dikes are sufficiently smooth. This makes it easier in case of future flood defense improvements to further increase the crest levels within the existing profile of the flood defense.

The used construction materials are recoverable after the life cycle of the flood defense has ended and can be reused in future projects.

The new hydraulic structures/sluices should be constructed in a robust way, as they will become an essential link in the flood protection system of this unit area. This can for instance be assured by installing both a mechanical and manual operation system to assure effectivity in case of required closure and setting up a solid operation- and maintenance program for these structures.

12. Combinations and/or cumulative impacts

There is a relation with several other interventions and cumulative impacts within the RWSS flood risk analysis:

- The construction of new/improved dikes and the construction of additional sluices in open channel crossings might negatively impact local runoff of the areas behind the flood defense, affecting the pluvial flood risks. There is a link with Program 3 within the RWSS flood risk project
- The flood defense system and flood risk in the entire study area is interconnected. Flood defense improvements in one place reduce flood risks in one area, but might increase flood probabilities and flood risks in another area. This system-effect should be further quantified based on the proposed measures.

13. Construction capacity requirements

Dikes and sluices within the area around Yangon and the rest of Myanmar are managed by IWUMD. IWUMD and local contractors are familiar with these structures. The flood defense improvements can be carried out by local contractors in collaboration with the IWUMD.

14. Suggested next steps

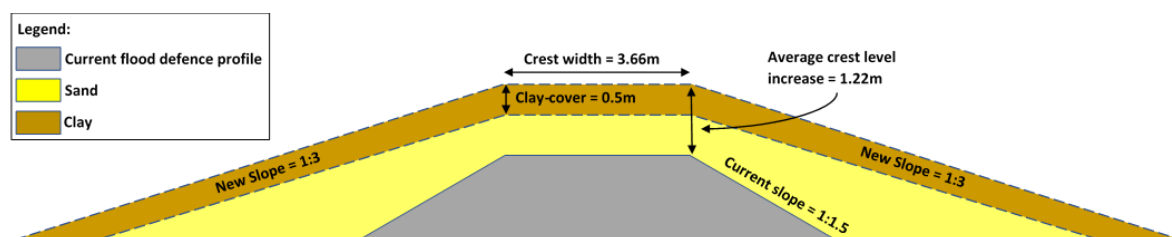
- Additional data collection (surveying, amongst others for the current flood defense profiles, open channel crossings, existing hydraulic structures and surface elevation levels)
- Updated and more in-depth analysis of the effects of the proposed measures
- Setting-up of a detailed implementation planning and design

Factsheet C.1.1.U6 Reinforcement of an existing dike by heightening the dike (Unit 6)

1. Description of Measure

In light of program 1 of the RWSS flood risk analysis, the fluvial and coastal flood risks have been quantified to set a conforming flood protection standard for each of the unit areas around the city of Yangon. For unit area 6, it is proposed to raise the flood protection level offered by the current flood protection system of the unit to a 1:200 protection level for fluvial and coastal flooding. In line with this goal, the following specific measures should be taken:

- Dike improvement along 25.2km of existing flood defenses. A first impression of a cross-view of the proposed dike improvement strategy is visualized below. This visualization shows the average crest level increase for all locations where interventions are required. The site-specific profile will therefore vary from the presented cross-section. Furthermore, the currently presented dimensioning of the new profile are based on best-practice values and should be further specified in a future phase of the project.
- Construction of 3 additional sluices/hydraulic structures at the crossing of the flood defense with three small local streams. Two of these streams require a small sluice structure (<25m), and one requires a medium sized structure.



Important: Unit Area 6 is hydraulically connected to Unit Area 3. Therefore, a flood protection level of 1:200 can only be achieved in Unit Area 6 if Unit Area 3 is similarly reinforced to the same flood protection level.

2. Purpose & targets (incl. Mainland use and unit)

The purpose of the dike improvements is to decrease the flood risks within unit area 6, by reduction of the annual flood probabilities. This measure especially targets the flood defense stretches which can currently be considered as the weakest links of the flood defense system of this unit. Those stretches are improved, to decrease the overall flood risks.

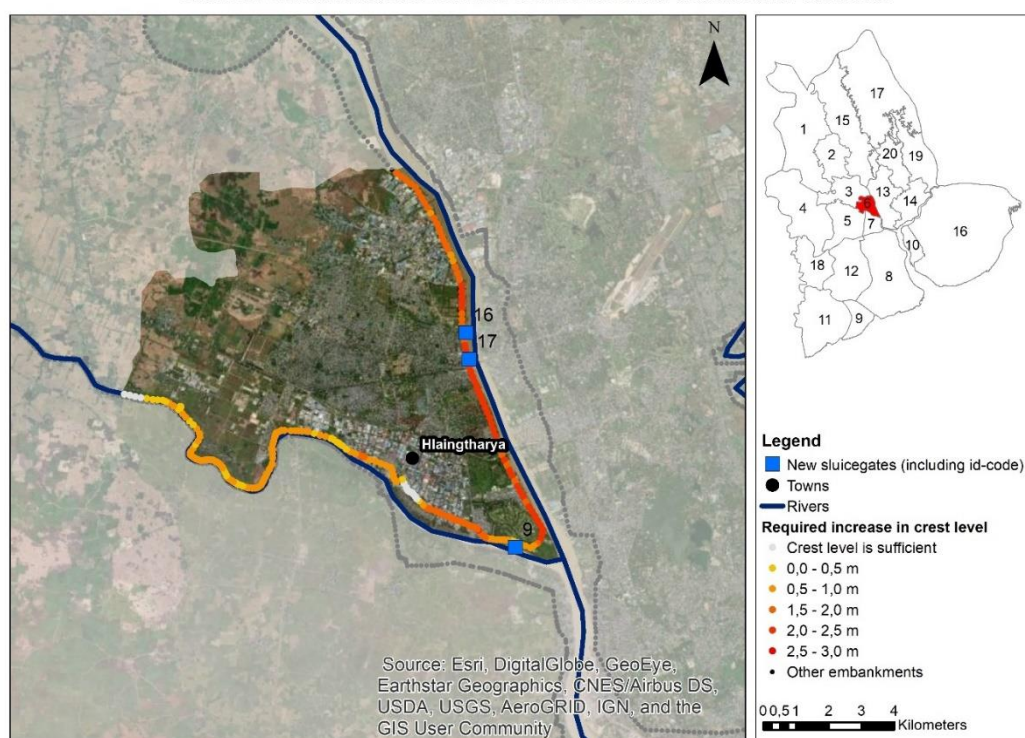
The purpose of the additional hydraulic structures within the system is to prevent that flooding of the interior of unit area 6 occurs via inflow through the open channel crossings. By controlling the outflow of these streams, flooding can be prevented.

3. Location (s)

Dike improvement is required along the full perimeter of unit area 6, as none of the currently present flood defense structures meet a 1:200 flood protection level. The figure presented below provides an overview of all locations along this unit area which are recognized by a crest level deficit for the proposed flood protection level. It becomes clear that especially the Eastern dikes face a major crest level deficit. The exact configuration of the flood defense improvement strategy should be made more explicit in a future stadium of the project.

The location of the proposed additional hydraulic structures is shown in the figure as well. These are situated both along the Hlaing and Pan Hlaing rivers, directly next to urbanized areas.

Unit 6: embankment reinforcements and additional sluices



4. Preliminary indication of ownership

Within Myanmar the Irrigation and Water Utilization Management Department (IWUMD) is responsible for operation and maintenance of flood protection embankments and polders system all over the country. Therefore, the ownership of this intervention is expected to lie with IWUMD.

5. Preliminary indication of collaboration

IWUMD is expected to be the owner and legally responsible organization for the implementation of the proposed measures. However, before implementation, additional analyses, further modelling, planning and a water governance structure should be in place.

6. Level of urgency

The level of urgency is determined for every unit area based on a combination of three characteristics: The benefit-cost ratios for the current and future land use and the affected people risk reduction of the proposed measures. Unit area 6 is part of the interconnected island made up of unit areas 3 and 6. Unit area 6 can be categorized as high priority. The proposed measures are cost-efficient in both the current and (especially) the future land use situation, while they also act as prerequisite to decrease flood risks in unit area 3. The affected people risk reduction is relatively low in this unit area, but considering that future urban development is not incorporated in these numbers yet, this unit area should be prioritized.

Unit	BC-ratio current land use	BC-ratio future land use	Affected people risk reduction (annually)	Priority category
1	4.54	4.54	19882	High priority
18	4.33	4.33	12338	
3	1.08	96.1	3025	
6	1.83	9.65	1058	
4	11.34	11.34	38811	
5	0.88	0.88	4055	
7	0.18	20.97	844	Medium priority
2	1.08	8.77	1940	
13	1.36	1.67	1041	
15	0.33	26.87	94	Low priority
10	0.27	5.27	43	
8	0.19	1.25	252	
14	0.29	0.44	104	

7. Effectiveness (Incl. indicators and thresholds)

Flood defense improvement is an immediate and effective way to counter flood risks in the area. The strength of the system (total flood defense system of unit area 6) is dependent on the strength of the separate components within the system. Much of the currently present flood defense system along this unit suffices already. However, due to the weak links within the system, the system as a whole does not suffice. Investing in these weak links in the system is therefore a very effective manner to decrease the overall flood risks. After adaptation of the weakest links, the full potential of the existing flood defenses can be exploited again and the system as a whole will be able to cope with the future flood threats. The three open channel crossings of the flood defense system are an essential link in the system as well. Without construction of these structures, the whole system will not comprise with the proposed flood protection standards.

8. Social and Environmental Safeguards

The acquisition of land for realization of the flood defense improvements and additional hydraulic structures might include resettlement of local residents at locations where people reside directly next to the current flood defense. Furthermore, depending on the local configuration of the improvement strategy, agricultural lands will become occupied by the strengthened flood defenses. Local landowners should be compensated for these losses of land.

Also, the construction of additional sluices in the local surface water system might affect the local water supply system and aquatic life. Specifically relevant for this unit area is the fact that some of these streams are currently used for local shipping as well. The impacts of additional hydraulic structures on these shipping activities should be further analyzed. Furthermore, the impact of these structures on local aquatic life should be investigated as well.

Positive social impacts of the proposed measures include a reduction of flood nuisance for residents, as well as a more stable environment for growing crops and setting up businesses, providing a more stable economic output of the area.

9. Cost estimates (CAPEX & OPEX)

A short quantification overview of the CAPEX and OPEX of the proposed flood defense improvement strategy is presented below. The OPEX expenditure quantification is based on 0.1% annual operating and maintenance costs and 3% periodical maintenance once every 5 years. The design horizon is 2040 for the proposed measures and a discount rate of 6% was assumed.

PV Dike improvement CAPEX	USD 8.35 million
PV Dike improvement OPEX	USD 0.61 million
PV total investment costs	USD 8.96 million

10. Cost recovery indication

The proposed measures will significantly reduce the total flood risk of the area, as indicated below. The effectiveness is strongly dependent on the future land use developments. Under current land use, the benefit/cost ratio is 1.83, but based on the current land use projections in 2040, the benefit/cost ratio would be 9.65. This does however indicate that the proposed measures are effective regardless of the future land use development. It was assumed that the residual value of the initial investment at the end of the life cycle accounts for 50% of the initial investment.

	Current Land use scenario:	Future Land use scenario:
PV Flood risk reduction	USD 15.10 million	USD 85.10 million
PV Residual value investments	USD 1.30 million	USD 2.02 million
PV total investment benefits	USD 16.40 million	USD 87.12 million
Benefit/cost ratio	1.83	9.65

11. Robustness & Adaptiveness

To assure that the proposed flood defense improvements are executed in an adaptive manner, it is recommended to assure that the inner and outer slopes of the new dikes are sufficiently smooth. This makes it easier in case of future flood defense improvements to further increase the crest levels within the existing profile of the flood defense.

The used construction materials are recoverable after the life cycle of the flood defense has ended and can be reused in future projects.

The new hydraulic structures/sluices should be constructed in a robust way, as they will become an essential link in the flood protection system of this unit area. This can for instance be assured by installing both a mechanical and manual operation system to assure effectivity in case of required closure and setting up a solid operation- and maintenance program for these structures.

12. Combinations and/or cumulative impacts

There is a relation with several other interventions and cumulative impacts within the RWSS flood risk analysis:

- The construction of new/improved dikes and the construction of additional sluices in open channel crossings might negatively impact local runoff of the areas behind the flood defense, affecting the pluvial flood risks. There is a link with Program 3 within the RWSS flood risk project
- The flood defense system and flood risk in the entire study area is interconnected. Flood defense improvements in one place reduce flood risks in one area, but might increase flood probabilities and flood risks in another area. This system-effect should be further quantified based on the proposed measures.

13. Construction capacity requirements

Dikes and sluices within the area around Yangon and the rest of Myanmar are managed by IWUMD. IWUMD and local contractors are familiar with these structures. The flood defense improvements can be carried out by local contractors in collaboration with the IWUMD.

14. Suggested next steps

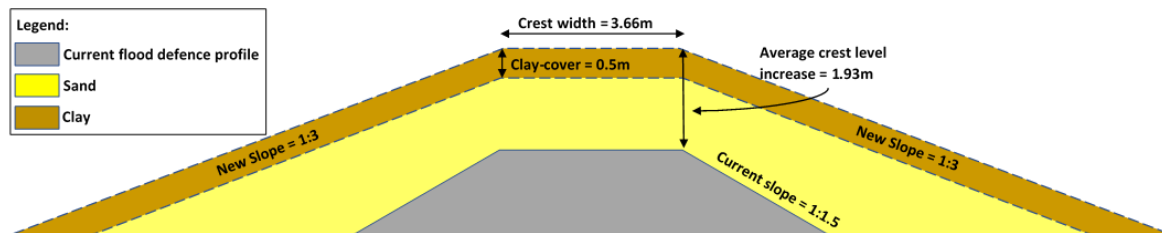
- Additional data collection (surveying, amongst others for the current flood defense profiles, open channel crossings, existing hydraulic structures, and surface elevation levels)
- Updated and more in-depth analysis of the effects of the proposed measures
- Setting-up of a detailed implementation planning and design

Factsheet C.1.1.U7 Reinforcement of an existing dike by heightening the dike (Unit 7)

1. Description of Measure

In light of program 1 of the RWSS flood risk analysis, the fluvial and coastal flood risks have been quantified to set a conforming flood protection standard for each of the unit areas around the city of Yangon. For unit area 7, it is proposed to raise the flood protection level offered by the current flood protection system of the unit to a 1:200 protection level for fluvial and coastal flooding. In line with this goal, the following specific measures should be taken:

- Dike improvement along 27.9km of existing flood defenses. A first impression of a cross-view of the proposed dike improvement strategy is visualized below. This visualization shows the average crest level increase for all locations where interventions are required. The site-specific profile will therefore vary from the presented cross-section. Furthermore, the currently presented dimensioning of the new profile are based on best-practice values and should be further specified in a future phase of the project.
- Construction of 11 additional sluices/hydraulic structures at the crossing of the flood defense with 11 small local streams. 10 of these streams are <25m wide, which requires small sized sluices, while one is between 25 and 50m wide, requiring a medium sized structure.



Important: Unit Area 7 is hydraulically connected to Unit Areas 4 and 5. Therefore, a flood protection level of 1:200 can only be achieved in Unit Area 7 if Unit Areas 4 and 5 are similarly reinforced to the same flood protection level.

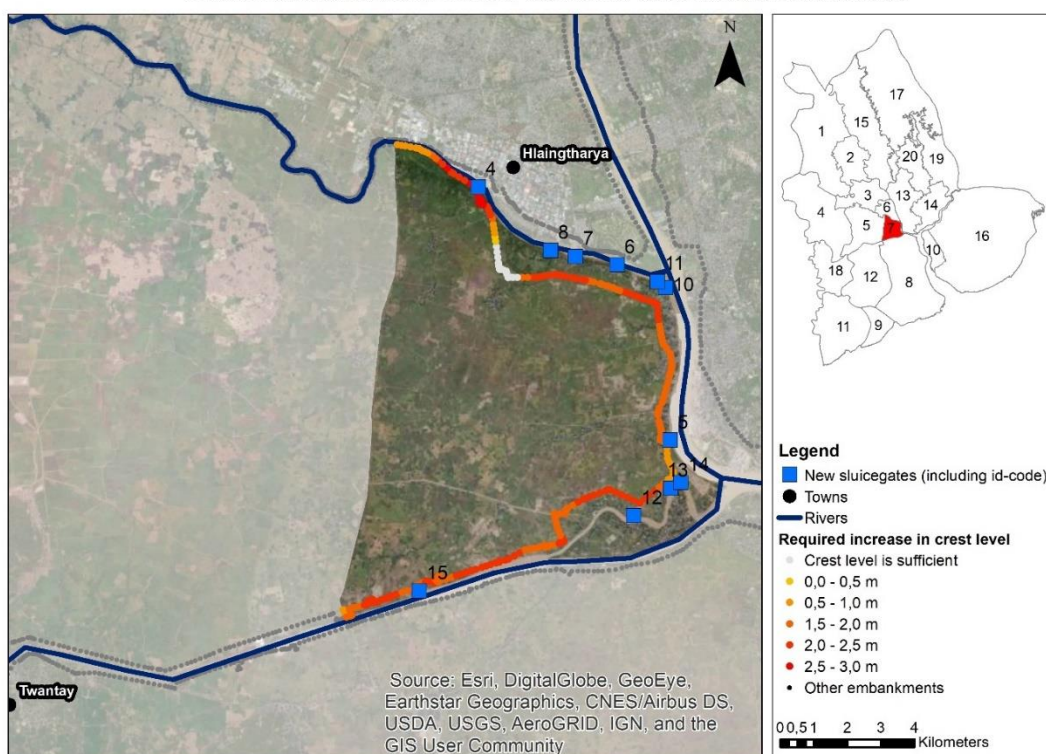
2. Purpose & targets (incl. Mainland use and unit)

The purpose of the dike improvements is to decrease the flood risks within unit area 7, by reduction of the annual flood probabilities. This measure especially targets the flood defense stretches which can currently be considered as the weakest links of the flood defense system of this unit. Those stretches are improved, to decrease the overall flood risks. The purpose of the additional hydraulic structures within the system is to prevent that flooding of the interior of unit area 7 occurs via inflow through the open channel crossings. By controlling the outflow of these streams, flooding can be prevented.

3. Location (s)

Dike improvement is required along the full perimeter of unit area 7, as hardly any of the currently present flood defense structures meet a 1:200 flood protection level. The figure presented below provides an overview of all locations along this unit area which are recognized by a crest level deficit for the proposed flood protection level. The exact configuration of the flood defense improvement strategy should be made more explicit in a future stadium of the project. The location of the proposed additional hydraulic structures is shown in the figure as well. These are situated both along the Hlaing river, Pun Hlaing river and the Twante canal.

Unit 7: embankment reinforcements and additional sluices



4. Preliminary indication of ownership

Within Myanmar the Irrigation and Water Utilization Management Department (IWUMD) is responsible for operation and maintenance of flood protection embankments and polders system all over the country. Therefore, the ownership of this intervention is expected to lie with IWUMD.

5. Preliminary indication of collaboration

IWUMD is expected to be the owner and legally responsible organization for the implementation of the proposed measures. However, before implementation, additional analyses, further modelling, planning and a water governance structure should be in place.

6. Level of urgency

The level of urgency is determined for every unit area based on a combination of three characteristics: The benefit-cost ratios for the current and future land use and the affected people risk reduction of the proposed measures. Unit area 7 is connected to unit areas 4 and 5 and flood protection measures to either of these unit areas act as prerequisite to assure flood protection in the other units. The measures in unit 7 can be categorized as high priority. The cost-effectiveness is highly dependent on the future development of the area, but the cost-effectiveness of measures into the area is high for the projected future land use. It is therefore recommended to assure first that the foreseen developments within this unit will become a reality, before implementing the proposed measures. If so, these measures are however very cost-efficient, which is why it is important to install these interventions before the area is urbanized. This will also prevent that construction within urbanized areas results in additional costs and efforts. As the number of affected people in unit areas 4, 5 and 7 is high, flood protection should be prioritized here.

Unit	BC-ratio current land use	BC-ratio future land use	Affected people risk reduction (annually)	Priority category
1	4.54	4.54	19882	High priority
18	4.33	4.33	12338	
3	1.08	96.1	3025	
6	1.83	9.65	1058	
4	11.34	11.34	38811	
5	0.88	0.88	4055	
7	0.18	20.97	844	
2	1.08	8.77	1940	Medium priority
13	1.36	1.67	1041	
15	0.33	26.87	94	
10	0.27	5.27	43	Low priority
8	0.19	1.25	252	
14	0.29	0.44	104	

7. Effectiveness (Incl. indicators and thresholds)

Flood defense improvement is an immediate and effective way to counter flood risks in the area. The strength of the system (total flood defense system of unit area 7) is dependent on the strength of the separate components within the system. Much of the currently present flood defense system along this unit suffices already. However, due to the weak links within the system, the system as a whole does not suffice. Investing in these weak links in the system is therefore a very effective manner to decrease the overall flood risks. After adaptation of the weakest links, the full potential of the existing flood defenses can be exploited again and the system as a whole will be able to cope with the future flood threats. The open channel crossings of the flood defense system are an essential link in the system as well. Without construction of these structures, the whole system will not comprise with the proposed flood protection standards.

8. Social and Environmental Safeguards

The acquisition of land for realization of the flood defense improvements and additional hydraulic structures might include resettlement of local residents at locations where people reside directly next to the current flood defense. Furthermore, depending on the local configuration of the improvement strategy, agricultural lands will become occupied by the strengthened flood defenses. Local landowners should be compensated for these losses of land. Furthermore, the construction of additional sluices in the local surface water system might affect the local water supply system and aquatic life. Specifically relevant for this unit area is the presence of many agriculture plots. The currently open channels crossing the flood defense might be used as water supply source by the agriculture plots. Further analysis of the impacts of the construction of additional sluices on the water supply system to these areas is required. Furthermore, the impact of these structures on local aquatic life should be investigated as well. Positive social impacts of the proposed measures include a reduction of flood nuisance for residents, as well as a more stable environment for growing crops and setting up businesses, providing a more stable economic output of the area.

9. Cost estimates (CAPEX & OPEX)

A short quantification overview of the CAPEX and OPEX of the proposed flood defense improvement strategy is presented below. The OPEX expenditure quantification is based on 0.1% annual operating and maintenance costs and 3% periodical maintenance once every 5 years. The design horizon is 2040 for the proposed measures and a discount rate of 6% was assumed.

PV Dike improvement CAPEX	USD 23.20 million
PV Dike improvement OPEX	USD 1.42 million
PV total investment costs	USD 24.88 million

10. Cost recovery indication

The proposed measures will significantly reduce the total flood risk of the area, as indicated below. The effectiveness is strongly dependent on the future land use developments. Under current land use, the benefit/cost ratio is 0.18, but based on the current land use projections in 2040, the benefit/cost ratio would be 20.97. It was assumed that the residual value of the initial investment at the end of the life cycle accounts for 50% of the initial investment.

	Current Land use scenario:	Future Land use scenario:
PV Flood risk reduction	USD 0.98 million	USD 518.02 million
PV Residual value investments	USD 3.62 million	USD 3.62 million
PV total investment benefits	USD 4.60 million	USD 521.64 million
Benefit/cost ratio	0.18	20.97

11. Robustness & Adaptiveness

To assure that the proposed flood defense improvements are executed in an adaptive manner, it is recommended to assure that the inner and outer slopes of the new dikes are sufficiently smooth. This makes it easier in case of future flood defense improvements to further increase the crest levels within the existing profile of the flood defense. The used construction materials are recoverable after the life cycle of the flood defense has ended and can be reused in future projects.

The new hydraulic structures/sluices should be constructed in a robust way, as they will become an essential link in the flood protection system of this unit area. This can for instance be assured by installing both a mechanical and manual operation system to assure effectivity in case of required closure and setting up a solid operation- and maintenance program for these structures.

12. Combinations and/or cumulative impacts

There is a relation with several other interventions and cumulative impacts within the RWSS flood risk analysis:

- The construction of new/improved dikes and the construction of additional sluices in open channel crossings might negatively impact local runoff of the areas behind the flood defense, affecting the pluvial flood risks. There is a link with Program 3 within the RWSS flood risk project
- The flood defense system and flood risk in the entire study area is interconnected. Flood defense improvements in one place reduce flood risks in one area, but might increase flood probabilities and flood risks in another area. This system-effect should be further quantified based on the proposed measures.

13. Construction capacity requirements

Dikes and sluices within the area around Yangon and the rest of Myanmar are managed by IWUMD. IWUMD and local contractors are familiar with these structures. The flood defense improvements can be carried out by local contractors in collaboration with the IWUMD.

14. Suggested next steps

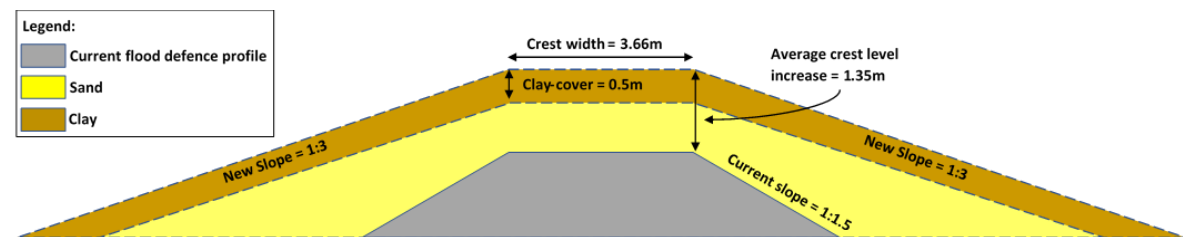
- Additional data collection (surveying, amongst others for the current flood defense profiles, open channel crossings, existing hydraulic structures and surface elevation levels)
- Updated and more in-depth analysis of the effects of the proposed measures
- Setting-up of a detailed implementation planning and design

Factsheet C.1.1.U8 Reinforcement of an existing dike by heightening the dike (Unit 8)

1. Description of Measure

In light of program 1 of the RWSS flood risk analysis, the fluvial and coastal flood risks have been quantified to set a conforming flood protection standard for each of the unit areas around the city of Yangon. For unit area 8, it is proposed to raise the flood protection level offered by the current flood protection system of the unit to a 1:200 protection level for fluvial and coastal flooding. In line with this goal, the following specific measures should be taken:

- Dike improvement along 64.7km of existing flood defenses. A first impression of a cross-view of the proposed dike improvement strategy is visualized below. This visualization shows the average crest level increase for all locations where interventions are required. The site-specific profile will therefore vary from the presented cross-section. Furthermore, the currently presented dimensioning of the new profile are based on best-practice values and should be further specified in a future phase of the project.
- Construction of 9 additional sluices/hydraulic structures at the crossing of the flood defense with 9 smaller local streams. 7 of these are <25m wide, requiring a small sized structure. One requires a medium sized structure, and there is also one large river requiring a large hydraulic structure.



2. Purpose & targets (incl. Mainland use and unit)

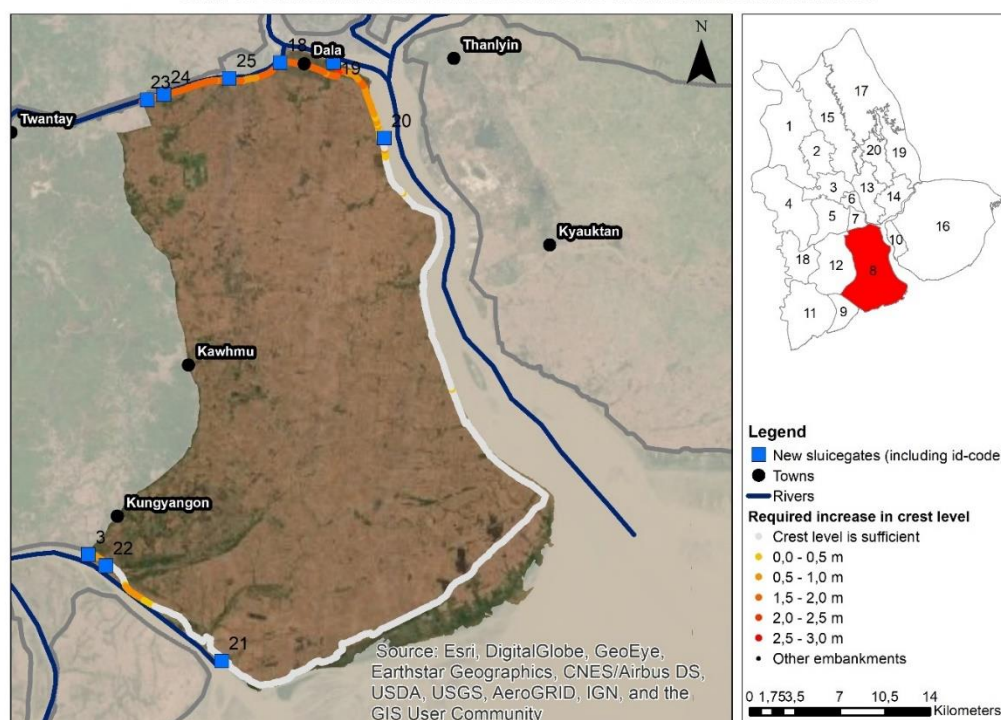
The purpose of the dike improvements is to decrease the flood risks within unit area 8, by reduction of the annual flood probabilities. This measure especially targets the flood defense stretches which can currently be considered as the weakest links of the flood defense system of this unit. Those stretches are improved, to decrease the overall flood risks.

The purpose of the additional hydraulic structures within the system is to prevent that flooding of the interior of unit area 8 occurs via inflow through the open channel crossings. By controlling the outflow of these streams, flooding can be prevented.

3. Location (s)

Dike improvement is required mostly along the Northern side of unit area 8. Additionally, along the southwestern border of this unit area, several solitary stretches of flood defense currently do not meet the 1:200 flood protection level requirement. The figure presented below provides an overview of all locations along this unit area which are recognized by a crest level deficit for the proposed flood protection level. The exact configuration of the flood defense improvement strategy should be made more explicit in a future stadium of the project.

Unit 8: embankment reinforcements and additional sluices



The location of the proposed additional hydraulic structures is shown in the figure as well. These are situated both along the Northern and Southwestern sides of the unit area. Hydraulic structure ID-3 is situated at the ca. 100m wide confluence of a relatively large local river with the Thande river.

4. Preliminary indication of ownership

Within Myanmar the Irrigation and Water Utilization Management Department (IWUMD) is responsible for operation and maintenance of flood protection embankments and polders system all over the country. Therefore, the ownership of this intervention is expected to lie with IWUMD.

5. Preliminary indication of collaboration

IWUMD is expected to be the owner and legally responsible organization for the implementation of the proposed measures. However, before implementation, additional analyses, further modelling, planning and a water governance structure should be in place.

6. Level of urgency

The level of urgency is for every unit area determined based on a combination of three characteristics: The benefit-cost ratios for the current and future land use and the affected people risk reduction of the proposed measures. The measures in unit 8 can be categorized as low priority. The cost-efficiency of the proposed measures is dependent on future land use development, and even under the foreseen future land use of the area, there are many other unit areas where the cost-efficiency of the proposed measures is higher. Furthermore, the affected people reduction value appointed to the measures in unit 8 is limited compared to other unit areas around Yangon city.

Unit	BC-ratio current land use	BC-ratio future land use	Affected people risk reduction (annually)	Priority category
1	4.54	4.54	19882	High priority
18	4.33	4.33	12338	
3	1.08	96.1	3025	
6	1.83	9.65	1058	
4	11.34	11.34	38811	
5	0.88	0.88	4055	
7	0.18	20.97	844	
2	1.08	8.77	1940	Medium priority
13	1.36	1.67	1041	
15	0.33	26.87	94	
10	0.27	5.27	43	Low priority
8	0.19	1.25	252	
14	0.29	0.44	104	

7. Effectiveness (Incl. indicators and thresholds)

Flood defense improvement is an immediate and effective way to counter flood risks in the area. The strength of the system (total flood defense system of unit area 8) is dependent on the strength of the separate components within the system. Much of the currently present flood defense system along this unit suffices already. However, due to the weak links within the system, the system does not suffice. Investing in these weak links in the system is therefore a very effective manner to decrease the overall flood risks. After adaptation of the weakest links, the full potential of the existing flood defenses can be exploited again, and the system as a whole will be able to cope with the future flood threats. The open channel crossings of the flood defense system are an essential link in the system as well. Without construction of these structures, the whole system will not comprise with the proposed flood protection standards.

8. Social and Environmental Safeguards

The acquisition of land for realization of the flood defense improvements and additional hydraulic structures might include resettlement of residents at locations where people reside directly next to the current flood defense. Furthermore, depending on the local configuration of the improvement strategy, agricultural lands will become occupied by the strengthened flood defenses. Local landowners should be compensated for these losses of land.

Furthermore, the construction of additional sluices in the local surface water system might affect the local water supply system and aquatic life. Specifically, relevant for this unit area is the presence of many agriculture plots. The currently open channels crossing the flood defense might be used as water supply source by the agriculture plots. Further analysis of the impacts of the construction of additional sluices on the water supply system to these areas is required. Furthermore, the impact of these structures on local aquatic life should be investigated as well. Also, the large open channel which should be controlled with hydraulic structure ID-3, connects to several villages upstream. This river is used as local transport mode. This aspect should also be further investigated to minimize negative impacts on local shipping conditions.

Positive social impacts of the proposed measures include a reduction of flood nuisance for residents, as well as a more stable environment for growing crops and setting up businesses, providing a more stable economic output of the area.

9. Cost estimates (CAPEX & OPEX)

A short quantification overview of the CAPEX and OPEX of the proposed flood defense improvement strategy is presented below. The OPEX expenditure quantification is based on 0.1% annual operating and maintenance costs and 3% periodical maintenance once every 5 years. The design horizon is 2040 for the proposed measures and a discount rate of 6% was assumed.

PV Dike improvement CAPEX	USD 32.75 million
PV Dike improvement OPEX	USD 2.38 million
PV total investment costs	USD 35.13 million

10. Cost recovery indication

The proposed measures will significantly reduce the total flood risk of the area, as indicated below. The effectiveness is strongly dependent on the future land use developments. Under current land use, the benefit/cost ratio is 0.18, but based on the current land use projections in 2040, the benefit/cost ratio would be 20.97. It was assumed that the residual value of the initial investment at the end of the life cycle accounts for 50% of the initial investment.

	Current Land use scenario:	Future Land use scenario:
PV Flood risk reduction	USD 1.65 million	USD 38.84 million
PV Residual value investments	USD 5.11 million	USD 5.11 million
PV total investment benefits	USD 6.76 million	USD 43.95 million
Benefit/cost ratio	0.19	1.25

11. Robustness & Adaptiveness

To assure that the proposed flood defense improvements are executed in an adaptive manner, it is recommended to assure that the inner and outer slopes of the new dikes are sufficiently smooth. This makes it easier in case of future flood defense improvements to further increase the crest levels within the existing profile of the flood defense.

The used construction materials are recoverable after the life cycle of the flood defense has ended and can be reused in future projects.

The new hydraulic structures/sluices should be constructed in a robust way, as they will become an essential link in the flood protection system of this unit area. This can for instance be assured by installing both a mechanical and manual operation system to assure effectivity in case of required closure and setting up a solid operation- and maintenance program for these structures.

12. Combinations and/or cumulative impacts

There is a relation with several other interventions and cumulative impacts within the RWSS flood risk analysis:

- The construction of new/improved dikes and the construction of additional sluices in open channel crossings might negatively impact local runoff of the areas behind the flood defense, affecting the pluvial flood risks. There is a link with Program 3 within the RWSS flood risk project
- The flood defense system and flood risk in the entire study area is interconnected. Flood defense improvements in one place reduce flood risks in one area, but might increase flood probabilities and flood risks in another area. This system-effect should be further quantified based on the proposed measures.

13. Construction capacity requirements

Dikes and sluices within the area around Yangon and the rest of Myanmar are managed by IWUMD. IWUMD and local contractors are familiar with these structures. The flood defense improvements can be carried out by local contractors in collaboration with the IWUMD.

14. Suggested next steps

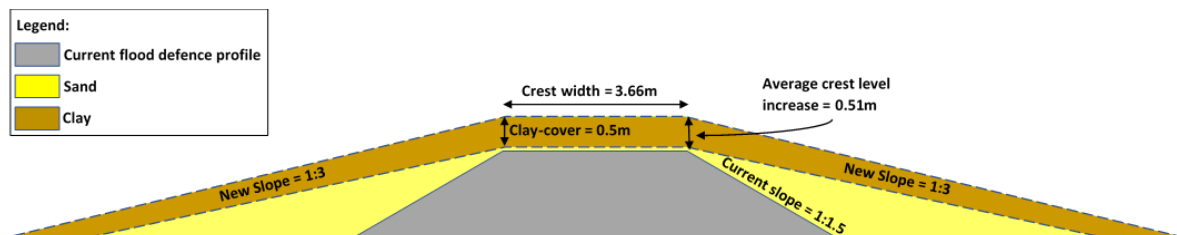
- Additional data collection (surveying, amongst others for the current flood defense profiles, open channel crossings, existing hydraulic structures and surface elevation levels)
- Updated and more in-depth analysis of the effects of the proposed measures
- Setting-up of a detailed implementation planning and design

Factsheet C.1.1.U10 Reinforcement of an existing dike by heightening the dike (Unit 10)

1. Description of Measure

In light of program 1 of the RWSS flood risk analysis, the fluvial and coastal flood risks have been quantified to set a conforming flood protection standard for each of the unit areas around the city of Yangon. For unit area 10, it is proposed to raise the flood protection level offered by the current flood protection system of the unit to a 1:200 protection level for fluvial and coastal flooding. In line with this goal, the following specific measures should be taken:

Dike improvement along 12.9km of existing flood defenses. A first impression of a cross-view of the proposed dike improvement strategy is visualized below. This visualization shows the average crest level increase for all locations where interventions are required. The site-specific profile will therefore vary from the presented cross-section. Furthermore, the currently presented dimensioning of the new profile is based on best-practice values and should be further specified in a future phase of the project.



2. Purpose & targets (incl. Mainland use and unit)

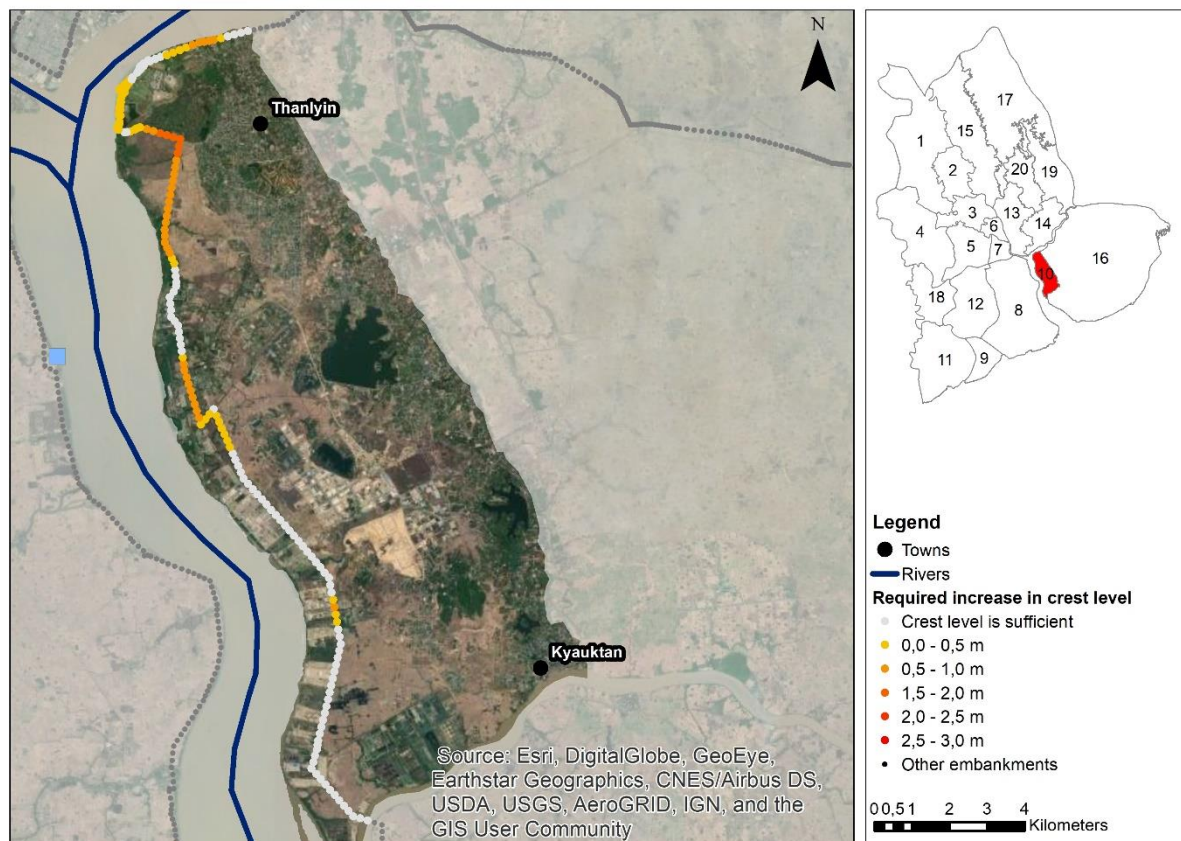
The purpose of the dike improvements is to decrease the flood risks within unit area 10, by reduction of the annual flood probabilities. This measure especially targets the flood defense stretches which can currently be considered as the weakest links of the flood defense system of this unit. Those stretches are improved, to decrease the overall flood risks.

3. Location (s)

The location of the proposed flood defense improvements is concentrated along the Northwestern side of unit area 10, where the current crest level deficit averages 0.51m. The figure presented below provides an overview of all locations along this unit area which are recognized by a crest level deficit for the proposed flood protection level.

The exact configuration of the flood defense improvement strategy should be made more explicit in a future stadium of the project. This is amongst other dependent on the current land use along the flood defense system and the location-specific improvement task.

Unit 10: embankment reinforcements and additional sluices



4. Preliminary indication of ownership

Within Myanmar the Irrigation and Water Utilization Management Department (IWUMD) is responsible for operation and maintenance of flood protection embankments and polders system all over the country. Therefore, the ownership of this intervention is expected to lie with IWUMD.

5. Preliminary indication of collaboration

IWUMD is expected to be the owner and legally responsible organization for the implementation of the proposed measures. However, before implementation, additional analyses, further modelling, planning and a water governance structure should be in place.

6. Level of urgency

The level of urgency is determined for every unit area based on a combination of three characteristics: The benefit-cost ratios for the current and future land use and the affected people risk reduction of the proposed measures. The measures in unit 10 can be categorized as low priority. The cost-efficiency of the proposed measures is dependent on future land use development, and even under the foreseen future land use of the area, there are other unit areas where the cost-efficiency of the proposed measures is higher. Furthermore, the affected people reduction value appointed to the measures in unit 10 is limited compared to other unit areas around Yangon city.

Unit	BC-ratio current land use	BC-ratio future land use	Affected people risk reduction (annually)	Priority category
1	4.54	4.54	19882	High priority
18	4.33	4.33	12338	
3	1.08	96.1	3025	
6	1.83	9.65	1058	
4	11.34	11.34	38811	
5	0.88	0.88	4055	
7	0.18	20.97	844	
2	1.08	8.77	1940	Medium priority
13	1.36	1.67	1041	
15	0.33	26.87	94	
10	0.27	5.27	43	Low priority
8	0.19	1.25	252	
14	0.29	0.44	104	

7. Effectiveness (Incl. indicators and thresholds)

Flood defense improvement is an immediate and effective way to counter flood risks in the area. The strength of the system (total flood defense system of unit area 10) is dependent on the strength of the separate components within the system. Much of the currently present flood defense system along this unit suffices already. However, due to the weak links within the system, the system as a whole does not suffice. Investing in these weak links in the system is therefore a very effective manner to decrease the overall flood risks. After adaptation of the weakest links, the full potential of the existing flood defenses can be exploited again and the system as a whole will be able to cope with the future flood threats.

8. Social and Environmental Safeguards

The acquisition of land for realization of the flood defense improvements might include resettlement of local residents at locations where people reside directly next to the current flood defense. Furthermore, depending on the local configuration of the improvement strategy, agricultural lands will become occupied by the strengthened flood defenses. Local landowners should be compensated for these losses of land. Positive social impacts of the proposed measures include a reduction of flood nuisance for residents, as well as a more stable environment for growing crops and setting up businesses, providing a more stable economic output of the area.

9. Cost estimates (CAPEX & OPEX)

A short quantification overview of the CAPEX and OPEX of the proposed flood defense improvement strategy is presented below. The OPEX expenditure quantification is based on 0.1% annual operating and maintenance costs and 3% periodical maintenance once every 5 years. The design horizon is 2040 for the proposed measures and a discount rate of 6% was assumed.

PV Dike improvement CAPEX	USD 1.74 million
PV Dike improvement OPEX	USD 0.13 million
PV total investment costs	USD 1.87 million

10. Cost recovery indication

The proposed measures will significantly reduce the total flood risk of the area, as indicated below. The effectiveness is however dependent on the future land use developments. Under the current land use scenario, the benefit/cost ratio is below 1, but based on the land use projections for 2040, the benefit/cost ratio would become 5.27, justifying investments in the flood defense system of this unit. The effectivity and cost recovery of the proposed measures will therefore depend on the land use development in the area. It was assumed that the residual value of the initial investment at the end of the life cycle accounts for 50% of the initial investment.

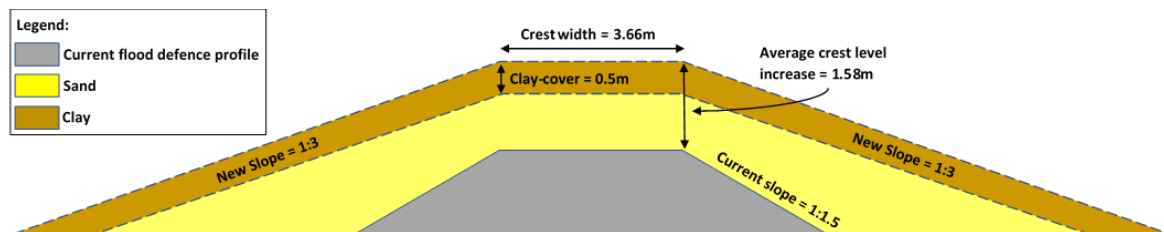
	Current Land use scenario:	Future Land use scenario:
PV Flood risk reduction	USD 0.23 million	USD 9.54 million
PV Residual value investments	USD 0.27 million	USD 0.27 million
PV total investment benefits	USD 0.50 million	USD 9.81 million
Benefit/cost ratio	0.27	5.27
11. Robustness & Adaptiveness To assure that the proposed flood defense improvements are executed in an adaptive manner, it is recommended to assure that the inner and outer slopes of the new dike are sufficiently smooth. This makes it easier in case of future additional flood defense improvements to further increase the crest levels within the existing profile of the flood defense. The used construction materials are recoverable after the life cycle of the flood defense has ended and can be reused in future projects.		
12. Combinations and/or cumulative impacts There is a relation with several other interventions and cumulative impacts within the RWSS flood risk analysis: • The construction of new/improved dikes might negatively impact local runoff of the areas behind the flood defense, affecting the pluvial flood risks. There is a link with Program 3 within the RWSS flood risk project • The flood defense system and flood risk in the entire study area is interconnected. Flood defense improvements in one place reduce flood risks in one area, but might increase flood probabilities and flood risks in another area. This system-effect should be further quantified based on the proposed measures.		
13. Construction capacity requirements Dikes within the area around Yangon and the rest of Myanmar are managed by IWUMD. IWUMD and local contractors are familiar with these structures. The flood defense improvements can be carried out by local contractors in collaboration with the IWUMD.		
14. Suggested next steps • Additional data collection (surveying, amongst others for the current flood defense profiles, open channel crossings, existing hydraulic structures and surface elevation levels) • Updated and more in-depth analysis of the effects of the proposed measures • Setting-up of a detailed implementation planning and design		

Factsheet C.1.1.U13 Reinforcement of an existing dike by heightening the dike (Unit 13)

1. Description of Measure

In light of program 1 of the RWSS flood risk analysis, the fluvial and coastal flood risks have been quantified to set a conforming flood protection standard for each of the unit areas around the city of Yangon. For unit area 13, it is proposed to raise the flood protection level offered by the current flood protection system of the unit to a 1:200 protection level for fluvial and coastal flooding. In line with this goal, the following specific measures should be taken:

Dike improvement along 35.8km of existing flood defenses. A first impression of a cross-view of the proposed dike improvement strategy is visualized below. This visualization shows the average crest level increase for all locations where interventions are required. The site-specific profile will therefore vary from the presented cross-section. Furthermore, the currently presented dimensioning of the new profile is based on best-practice values and should be further specified in a future phase of the project.



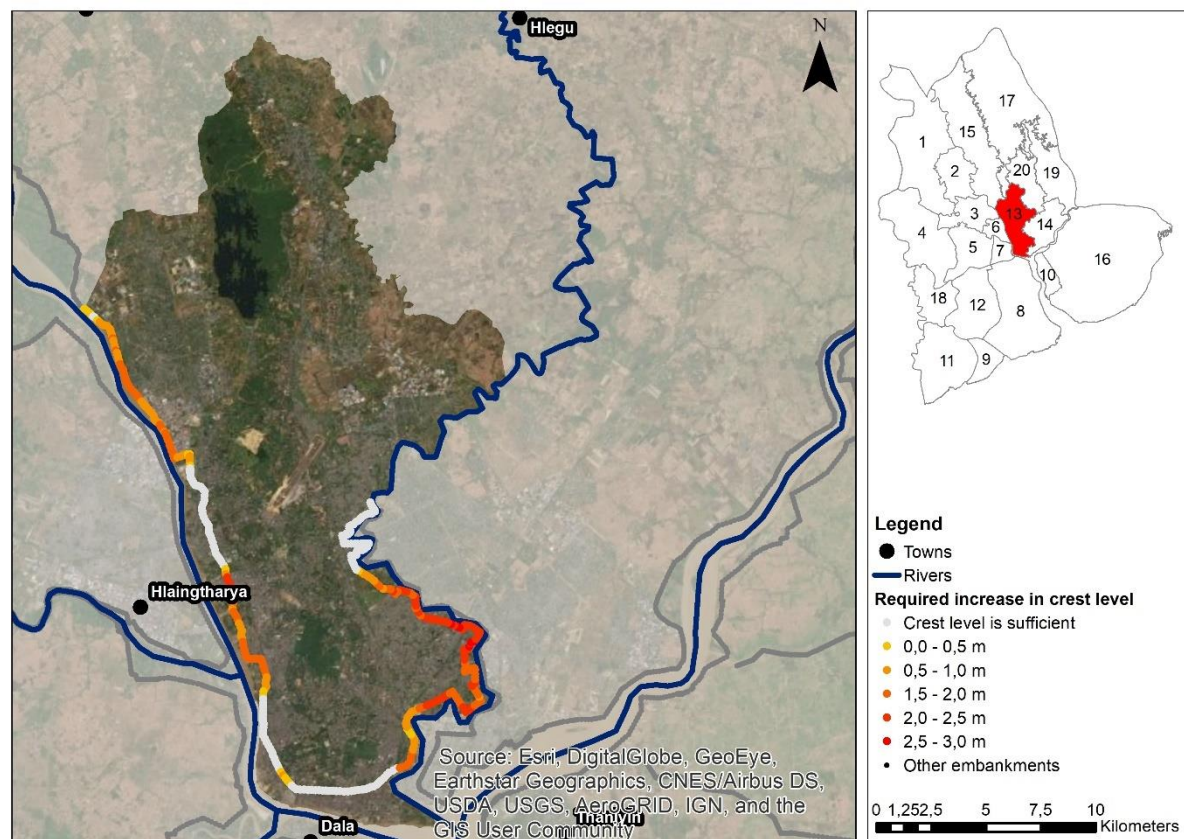
2. Purpose & targets (incl. Mainland use and unit)

The purpose of the dike improvements is to decrease the flood risks within unit area 13, by reduction of the annual flood probabilities. This measure especially targets the flood defense stretches which can currently be considered as the weakest links of the flood defense system of this unit. Those stretches are improved, to decrease the overall flood risks.

3. Location (s)

The location of the proposed flood defense improvements is concentrated along the Western and Eastern sides of unit area 13, along the Hlaing river and the Pazundaung creek which flows through the middle of Yangon. The average crest level deficit of these flood defense stretches equals 1.58m. Especially along the Pazundaung creek, the crest level deficit is large. The figure presented below provides an overview of all locations along this unit area which are recognized by a crest level deficit for the proposed flood protection level. The exact configuration of the flood defense improvement strategy should be made more explicit in a future stadium of the project. This is amongst other dependent on the current land use along the flood defense system and the location-specific improvement task.

Unit 13: embankment reinforcements and additional sluices



4. Preliminary indication of ownership

Within Myanmar the Irrigation and Water Utilization Management Department (IWUMD) is responsible for operation and maintenance of flood protection embankments and polders system all over the country. Therefore, the ownership of this intervention is expected to lie with IWUMD.

5. Preliminary indication of collaboration

IWUMD is expected to be the owner and legally responsible organization for the implementation of the proposed measures. However, before implementation, additional analyses, further modelling, planning and a water governance structure should be in place.

6. Level of urgency

The level of urgency is for every unit area determined based on a combination of three characteristics: The benefit-cost ratios for the current and future land use and the affected people risk reduction of the proposed measures. The measures in unit 13 can be categorized as medium priority. Although the measures are already cost-efficient in the current land use scenario, there are other units with a higher cost-efficiency. Furthermore, the affected people risk reduction value is lower compared to other unit areas, making the measures in unit area 13 medium priority measures.

Unit	BC-ratio current land use	BC-ratio future land use	Affected people risk reduction (annually)	Priority category
1	4.54	4.54	19882	High priority
18	4.33	4.33	12338	
3	1.08	96.1	3025	
6	1.83	9.65	1058	
4	11.34	11.34	38811	
5	0.88	0.88	4055	
7	0.18	20.97	844	
2	1.08	8.77	1940	Medium priority
13	1.36	1.67	1041	
15	0.33	26.87	94	
10	0.27	5.27	43	Low priority
8	0.19	1.25	252	
14	0.29	0.44	104	

7. Effectiveness (Incl. indicators and thresholds)

Flood defense improvement is an immediate and effective way to counter flood risks in the area. The strength of the system (total flood defense system of unit area 13) is dependent on the strength of the separate components within the system. Much of the currently present flood defense system along this unit suffices already. However, due to the weak links within the system, the system as a whole does not suffice. Investing in these weak links in the system is therefore a very effective manner to decrease the overall flood risks. After adaptation of the weakest links, the full potential of the existing flood defenses can be exploited again, and the system as a whole will be able to cope with the future flood threats.

8. Social and Environmental Safeguards

The acquisition of land for realization of the flood defense improvements might include resettlement of local residents at locations where people reside directly next to the current flood defense. Furthermore, depending on the local configuration of the improvement strategy, agricultural lands will become occupied by the strengthened flood defenses. Local landowners should be compensated for these losses of land. Positive social impacts of the proposed measures include a reduction of flood nuisance for residents, as well as a more stable environment for growing crops and setting up businesses, providing a more stable economic output of the area.

9. Cost estimates (CAPEX & OPEX)

A short quantification overview of the CAPEX and OPEX of the proposed flood defense improvement strategy is presented below. The OPEX expenditure quantification is based on 0.1% annual operating and maintenance costs and 3% periodical maintenance once every 5 years. The design horizon is 2040 for the proposed measures and a discount rate of 6% was assumed.

PV Dike improvement CAPEX	USD 9.78 million
PV Dike improvement OPEX	USD 0.71 million
PV total investment costs	USD 10.49 million

10. Cost recovery indication

The proposed measures will significantly reduce the total flood risk of the area, as indicated below. The effectiveness is however dependent on the future land use developments. Under the current land use scenario, the benefit/cost ratio is 1.36, and considering the future land use scenario, the ratio could climb up to 1.67, which justifies investments in the flood defense system of this unit. The effectivity and cost recovery of the proposed measures is independent on the land use development in the area. It was assumed that the residual value of the initial investment at the end of the life cycle accounts for 50% of the initial investment.

	Current Land use scenario:	Future Land use scenario:
PV Flood risk reduction	USD 12.74 million	USD 15.98 million
PV Residual value investments	USD 1.53 million	USD 1.53 million
PV total investment benefits	USD 14.27 million	USD 17.51 million
Benefit/cost ratio	1.36	1.67

11. Robustness & Adaptiveness

To assure that the proposed flood defense improvements are executed in an adaptive manner, it is recommended to assure that the inner and outer slopes of the new dike are sufficiently smooth. This makes it easier in case of future additional flood defense improvements to further increase the crest levels within the existing profile of the flood defense.

The used construction materials are recoverable after the life cycle of the flood defense has ended and can be reused in future projects.

12. Combinations and/or cumulative impacts

There is a relation with several other interventions and cumulative impacts within the RWSS flood risk analysis:

- The construction of new/improved dikes might negatively impact local runoff of the areas behind the flood defense, affecting the pluvial flood risks. There is a link with Program 3 within the RWSS flood risk project
- The flood defense system and flood risk in the entire study area is interconnected. Flood defense improvements in one place reduce flood risks in one area, but might increase flood probabilities and flood risks in another area. This system-effect should be further quantified based on the proposed measures.

13. Construction capacity requirements

Dikes within the area around Yangon and the rest of Myanmar are managed by IWUMD. IWUMD and local contractors are familiar with these structures. The flood defense improvements can be carried out by local contractors in collaboration with the IWUMD.

14. Suggested next steps

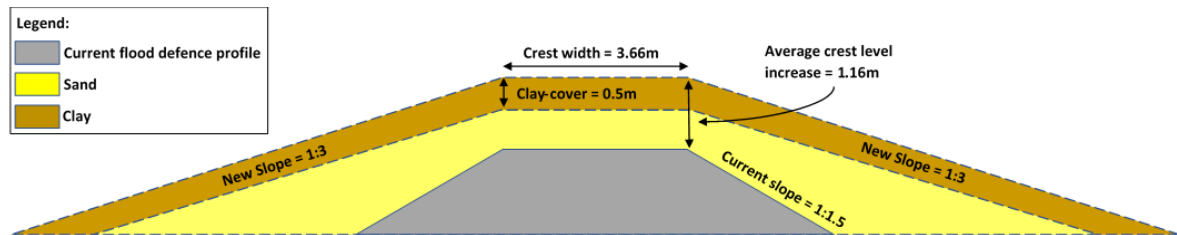
- Additional data collection (surveying, amongst others for the current flood defense profiles, open channel crossings, existing hydraulic structures and surface elevation levels)
- Updated and more in-depth analysis of the effects of the proposed measures
- Setting-up of a detailed implementation planning and design

Factsheet C.1.1.U14 Reinforcement of an existing dike by heightening the dike (Unit 14)

1. Description of Measure

In light of program 1 of the RWSS flood risk analysis, the fluvial and coastal flood risks have been quantified to set a conforming flood protection standard for each of the unit areas around the city of Yangon. For unit area 14, it is proposed to raise the flood protection level offered by the current flood protection system of the unit to a 1:200 protection level for fluvial and coastal flooding. In line with this goal, the following specific measures should be taken:

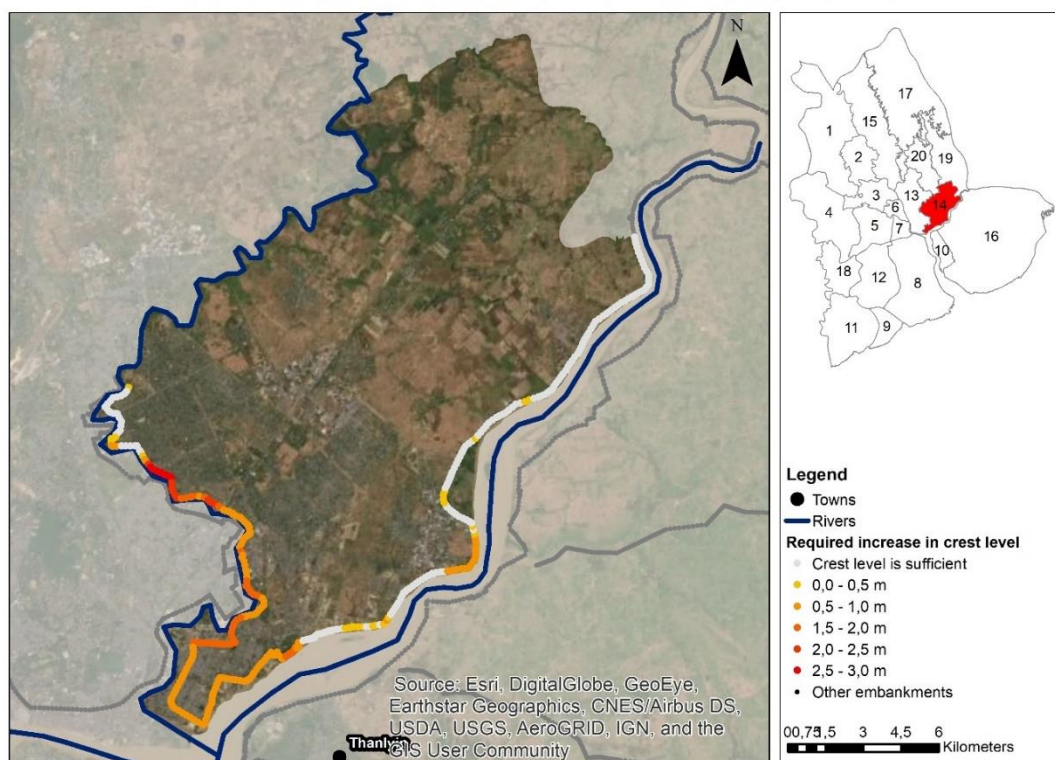
- Dike improvement along 30.5km of existing flood defenses. A first impression of a cross-view of the proposed dike improvement strategy is visualized below. This visualization shows the average crest level increase for all locations where interventions are required. The site-specific profile will therefore vary from the presented cross-section. Furthermore, the currently presented dimensioning of the new profile are based on best-practice values and should be further specified in a future phase of the project.



2. Purpose & targets (incl. Mainland use and unit)

The purpose of the dike improvements is to decrease the flood risks within unit area 14, by reduction of the annual flood probabilities. This measure especially targets the flood defense stretches which can currently be considered as the weakest links of the flood defense system of this unit. Those stretches are improved, to decrease the overall flood risks.

Unit 14: embankment reinforcements and additional sluices



3. Location (s)

The location of the proposed flood defense improvements is concentrated along the Southwestern side of unit area 14, along the Pazundaung creek and the confluence with the Bago river. The average crest level deficit of these flood defense stretches equals 1.16m. Especially along the Pazundaung creek, the crest level deficit is large. The figure presented below provides an overview of all locations along this unit area which are recognized by a crest level deficit for the proposed flood protection level.

The exact configuration of the flood defense improvement strategy should be made more explicit in a future stadium of the project. This is amongst other dependent on the current land use along the flood defense system and the location-specific improvement task.

4. Preliminary indication of ownership

Within Myanmar the Irrigation and Water Utilization Management Department (IWUMD) is responsible for operation and maintenance of flood protection embankments and polders system all over the country. Therefore, the ownership of this intervention is expected to lie with IWUMD.

5. Preliminary indication of collaboration

IWUMD is expected to be the owner and legally responsible organization for the implementation of the proposed measures. However, before implementation, additional analyses, further modelling, planning and a water governance structure should be in place.

6. Level of urgency

The level of urgency is determined for every unit area based on a combination of three characteristics: The benefit-cost ratios for the current and future land use and the affected people risk reduction of the proposed measures. The measures in unit 14 can be categorized as low priority. Both for current and future land use, the proposed measures are not directly cost-efficient. Furthermore, the affected people risk reduction is relatively small in this unit area. As a result, the implementation of measures in unit area 14 should be considered low priority.

Unit	BC-ratio current land use	BC-ratio future land use	Affected people risk reduction (annually)	Priority category
1	4.54	4.54	19882	High priority
18	4.33	4.33	12338	
3	1.08	96.1	3025	
6	1.83	9.65	1058	
4	11.34	11.34	38811	
5	0.88	0.88	4055	
7	0.18	20.97	844	
2	1.08	8.77	1940	Medium priority
13	1.36	1.67	1041	
15	0.33	26.87	94	
10	0.27	5.27	43	Low priority
8	0.19	1.25	252	
14	0.29	0.44	104	

7. Effectiveness (Incl. indicators and thresholds)

Flood defense improvement is an immediate and effective way to counter flood risks in the area. The strength of the system (total flood defense system of unit area 14) is dependent on the strength of the separate components within the system. Much of the currently present flood defense system along this unit suffices already. However, due to the weak links within the system, the system as a whole does not suffice. Investing in these weak links in the system is therefore a very effective manner to decrease the overall flood risks. After adaptation of the weakest links, the full potential of the existing flood defenses can be exploited again and the system as a whole will be able to cope with the future flood threats.

8. Social and Environmental Safeguards

The acquisition of land for realization of the flood defense improvements might include resettlement of residents at locations where people reside directly next to the current flood defense. Furthermore, depending on the local configuration of the improvement strategy, agricultural lands will become occupied by the strengthened flood defenses. Local landowners should be compensated for these losses of land. Positive social impacts of the proposed measures include a reduction of flood nuisance for residents, as well as a more stable environment for growing crops and setting up businesses, providing a more stable economic output of the area.

9. Cost estimates (CAPEX & OPEX)

A short quantification overview of the CAPEX and OPEX of the proposed flood defense improvement strategy is presented below. The OPEX expenditure quantification is based on 0.1% annual operating and maintenance costs and 3% periodical maintenance once every 5 years. The design horizon is 2040 for the proposed measures and a discount rate of 6% was assumed.

PV Dike improvement CAPEX	USD 7.24 million
PV Dike improvement OPEX	USD 0.53 million
PV total investment costs	USD 7.76 million

10. Cost recovery indication

As shown in the table below, the proposed measures in unit area 14 are not cost-effective, neither for the current land use scenario, nor for the future land use scenario. Nevertheless, as this is an important urban unit area, part of central Yangon, it is advisable to set the same flood protection level for this area as for the other urban unit areas around.

	Current Land use scenario:	Future Land use scenario:
PV Flood risk reduction	USD 1.12 million	USD 2.30 million
PV Residual value investments	USD 1.13 million	USD 1.13 million
PV total investment benefits	USD 2.25 million	USD 3.43 million
Benefit/cost ratio	0.29	0.44

11. Robustness & Adaptiveness

To assure that the proposed flood defense improvements are executed in an adaptive manner, it is recommended to assure that the inner and outer slopes of the new dike are sufficiently smooth. This makes it easier in case of future additional flood defense improvements to further increase the crest levels within the existing profile of the flood defense.

The used construction materials are recoverable after the life cycle of the flood defense has ended and can be reused in future projects.

12. Combinations and/or cumulative impacts

There is a relation with several other interventions and cumulative impacts within the RWSS flood risk analysis:

- The construction of new/improved dikes might negatively impact local runoff of the areas behind the flood defense, affecting the pluvial flood risks. There is a link with Program 3 within the RWSS flood risk project
- The flood defense system and flood risk in the entire study area is interconnected. Flood defense improvements in one place reduce flood risks in one area, but might increase flood probabilities and flood risks in another area. This system-effect should be further quantified based on the proposed measures.

13. Construction capacity requirements

Dikes within the area around Yangon and the rest of Myanmar are managed by IWUMD. IWUMD and local contractors are familiar with these structures. The flood defense improvements can be carried out by local contractors in collaboration with the IWUMD.

14. Suggested next steps

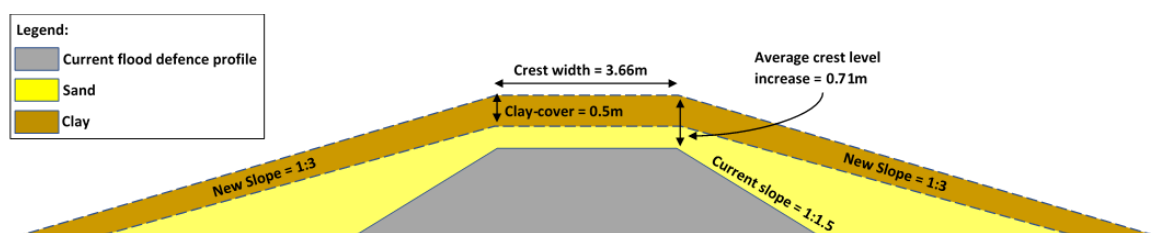
- Additional data collection (surveying, amongst others for the current flood defense profiles, open channel crossings, existing hydraulic structures and surface elevation levels)
- Updated and more in-depth analysis of the effects of the proposed measures
- Setting-up of a detailed implementation planning and design

Factsheet C.1.1.U15 Reinforcement of an existing dike by heightening the dike (Unit 15)

1. Description of Measure

In light of program 1 of the RWSS flood risk analysis, the fluvial and coastal flood risks have been quantified to set a conforming flood protection standard for each of the unit areas around the city of Yangon. For unit area 15, it is proposed to raise the flood protection level offered by the current flood protection system of the unit to a 1:200 protection level for fluvial and coastal flooding. In line with this goal, the following specific measures should be taken:

Dike improvement along 9.6km of existing flood defenses. A first impression of a cross-view of the proposed dike improvement strategy is visualized below. This visualization shows the average crest level increase for all locations where interventions are required. The site-specific profile will therefore vary from the presented cross-section. Furthermore, the currently presented dimensioning of the new profile are based on best-practice values and should be further specified in a future phase of the project.



2. Purpose & targets (incl. Mainland use and unit)

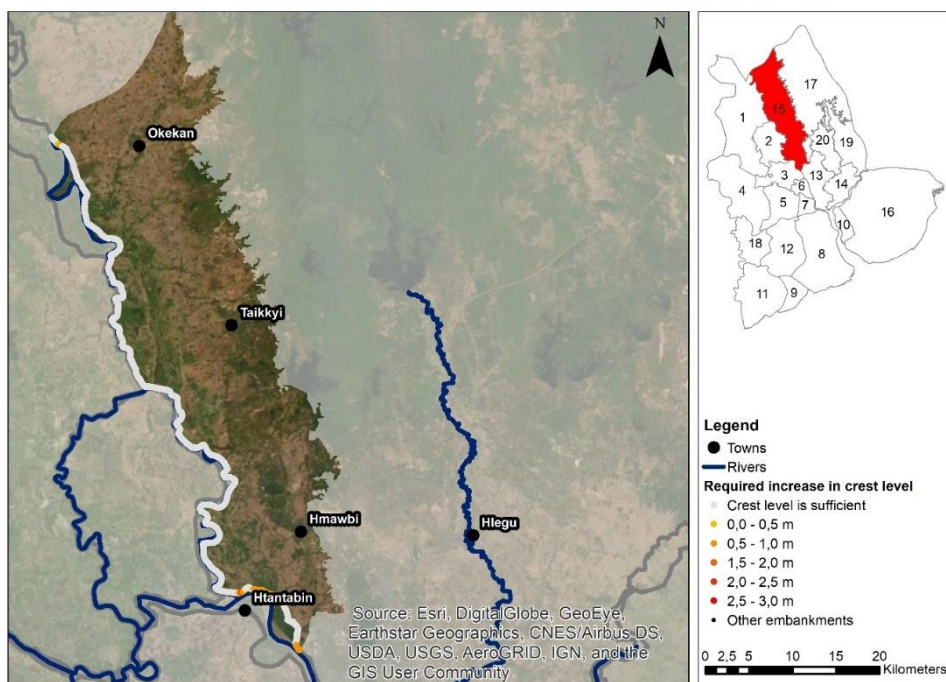
The purpose of the dike improvements is to decrease the flood risks within unit area 15, by reduction of the annual flood probabilities. This measure especially targets the flood defense stretches which can currently be considered as the weakest links of the flood defense system of this unit. Those stretches are improved, to decrease the overall flood risks.

3. Location (s)

The location of the proposed flood defense improvements is concentrated along the Southernmost border of unit area 15, along the Hlaing river. The rest of the flood defense system currently present along the Western border suffices already. The average crest level deficit of the insufficient southern flood defense stretches equals 0.71m. The figure presented below provides an overview of all locations along this unit area which are recognized by a crest level deficit for the proposed flood protection level.

The exact configuration of the flood defense improvement strategy should be made more explicit in a future stadium of the project. This is amongst other dependent on the current land use along the flood defense system and the location-specific improvement task.

Unit 15: embankment reinforcements and additional sluices



4. Preliminary indication of ownership

Within Myanmar the Irrigation and Water Utilization Management Department (IWUMD) is responsible for operation and maintenance of flood protection embankments and polders system all over the country. Therefore, the ownership of this intervention is expected to lie with IWUMD.

5. Preliminary indication of collaboration

IWUMD is expected to be the owner and legally responsible organization for the implementation of the proposed measures. However, before implementation, additional analyses, further modelling, planning and a water governance structure should be in place.

6. Level of urgency The level of urgency is determined for every unit area based on a combination of three characteristics: The benefit-cost ratios for the current and future land use and the affected people risk reduction of the proposed measures. The measures in unit 15 can be categorized as medium priority. The cost-effectiveness is highly dependent on the future development of the area. Under the current land use scenario, the measures are not cost-efficient. It is therefore recommended to assure first that the foreseen developments within this unit will become a reality, before implementing the proposed measures. If so, these measures are however very cost-efficient, which is why it is important to install these interventions before the area is urbanized. This will also prevent that construction within urbanized areas results in additional costs and efforts. The affected people risk reduction value in this unit area is relatively low.	Unit	BC-ratio current land use	BC-ratio future land use	Affected people risk reduction (annually)	Priority category
	1	4.54	4.54	19882	High priority
	18	4.33	4.33	12338	
	3	1.08	96.1	3025	
	6	1.83	9.65	1058	
	4	11.34	11.34	38811	
	5	0.88	0.88	4055	
	7	0.18	20.97	844	
	2	1.08	8.77	1940	Medium priority
	13	1.36	1.67	1041	
	15	0.33	26.87	94	
	10	0.27	5.27	43	Low priority
	8	0.19	1.25	252	
	14	0.29	0.44	104	

7. Effectiveness (Incl. indicators and thresholds)

Flood defense improvement is an immediate and effective way to counter flood risks in the area. The strength of the system (total flood defense system of unit area 15) is dependent on the strength of the separate components within the system. Much of the currently present flood defense system along this unit suffices already. However, due to the weak links within the system, the system as a whole does not suffice. Investing in these weak links in the system is therefore a very effective manner to decrease the overall flood risks. After adaptation of the weakest links, the full potential of the existing flood defenses can be exploited again and the system as a whole will be able to cope with the future flood threats.

8. Social and Environmental Safeguards

The acquisition of land for realization of the flood defense improvements might include resettlement of local residents at locations where people reside directly next to the current flood defense. Furthermore, depending on the local configuration of the improvement strategy, agricultural lands will become occupied by the strengthened flood defenses. Local landowners should be compensated for these losses of land. Positive social impacts of the proposed measures include a reduction of flood nuisance for residents, as well as a more stable environment for growing crops and setting up businesses, providing a more stable economic output of the area.

9. Cost estimates (CAPEX & OPEX)

A short quantification overview of the CAPEX and OPEX of the proposed flood defense improvement strategy is presented below. The OPEX expenditure quantification is based on 0.1% annual operating and maintenance costs and 3% periodical maintenance once every 5 years. The design horizon is 2040 for the proposed measures and a discount rate of 6% was assumed.

PV Dike improvement CAPEX	USD 1.38 million
PV Dike improvement OPEX	USD 0.10 million
PV total investment costs	USD 1.48 million

10. Cost recovery indication

The proposed measures will significantly reduce the total flood risk of the area, as indicated below. The effectiveness is however dependent on the future land use developments. Under the current land use scenario, the benefit/cost ratio is below 1, but based on the land use projections for 2040, the benefit/cost ratio would rise strongly to 26.9, justifying investments in the flood defense system of this unit. The effectivity and cost recovery of the proposed measures will therefore depend on the land use development in the area. It was assumed that the residual value of the initial investment at the end of the life cycle accounts for 50% of the initial investment.

	Current Land use scenario:	Future Land use scenario:
PV Flood risk reduction	USD 0.28 million	USD 39.52 million
PV Residual value investments	USD 0.22 million	USD 0.22 million
PV total investment benefits	USD 0.44 million	USD 39.68 million
Benefit/cost ratio	0.33	26.9

11. Robustness & Adaptiveness

To assure that the proposed flood defense improvements are executed in an adaptive manner, it is recommended to assure that the inner and outer slopes of the new dike are sufficiently smooth. This makes it easier in case of future additional flood defense improvements to further increase the crest levels within the existing profile of the flood defense.

The used construction materials are recoverable after the life cycle of the flood defense has ended and can be reused in future projects.

12. Combinations and/or cumulative impacts

There is a relation with several other interventions and cumulative impacts within the RWSS flood risk analysis:

- The construction of new/improved dikes might negatively impact local runoff of the areas behind the flood defense, affecting the pluvial flood risks. There is a link with Program 3 within the RWSS flood risk project
- The flood defense system and flood risk in the entire study area is interconnected. Flood defense improvements in one place reduce flood risks in one area, but might increase flood probabilities and flood risks in another area. This system-effect should be further quantified based on the proposed measures.

13. Construction capacity requirements

Dikes within the area around Yangon and the rest of Myanmar are managed by IWUMD. IWUMD and local contractors are familiar with these structures. The flood defense improvements can be carried out by local contractors in collaboration with the IWUMD.

14. Suggested next steps

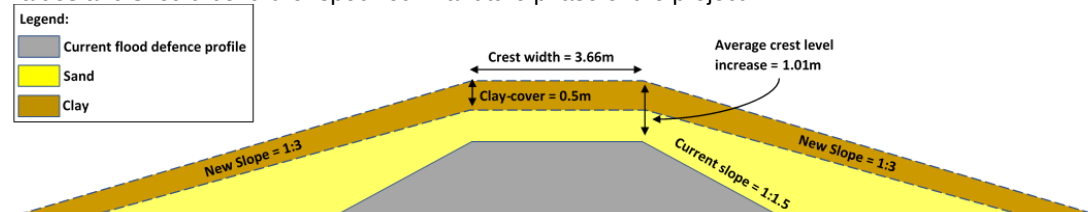
- Additional data collection (surveying, amongst others for the current flood defense profiles, open channel crossings, existing hydraulic structures and surface elevation levels)
- Updated and more in-depth analysis of the effects of the proposed measures
- Setting-up of a detailed implementation planning and design

Factsheet C.1.1.U18 Reinforcement of an existing dike by heightening the dike (Unit 18)

1. Description of Measure

In light of program 1 of the RWSS flood risk analysis, the fluvial and coastal flood risks have been quantified to set a conforming flood protection standard for each of the unit areas around the city of Yangon. For unit area 18, it is proposed to raise the flood protection level offered by the current flood protection system of the unit to a 1:50 protection level for fluvial and coastal flooding. In line with this goal, the following specific measures should be taken:

Dike improvement along 23.0km of existing flood defenses. A first impression of a cross-view of the proposed dike improvement strategy is visualized below. This visualization shows the average crest level increase for all locations where interventions are required. The site-specific profile will therefore vary from the presented cross-section. Furthermore, the currently presented dimensioning of the new profile is based on best-practice values and should be further specified in a future phase of the project



2. Purpose & targets (incl. Mainland use and unit)

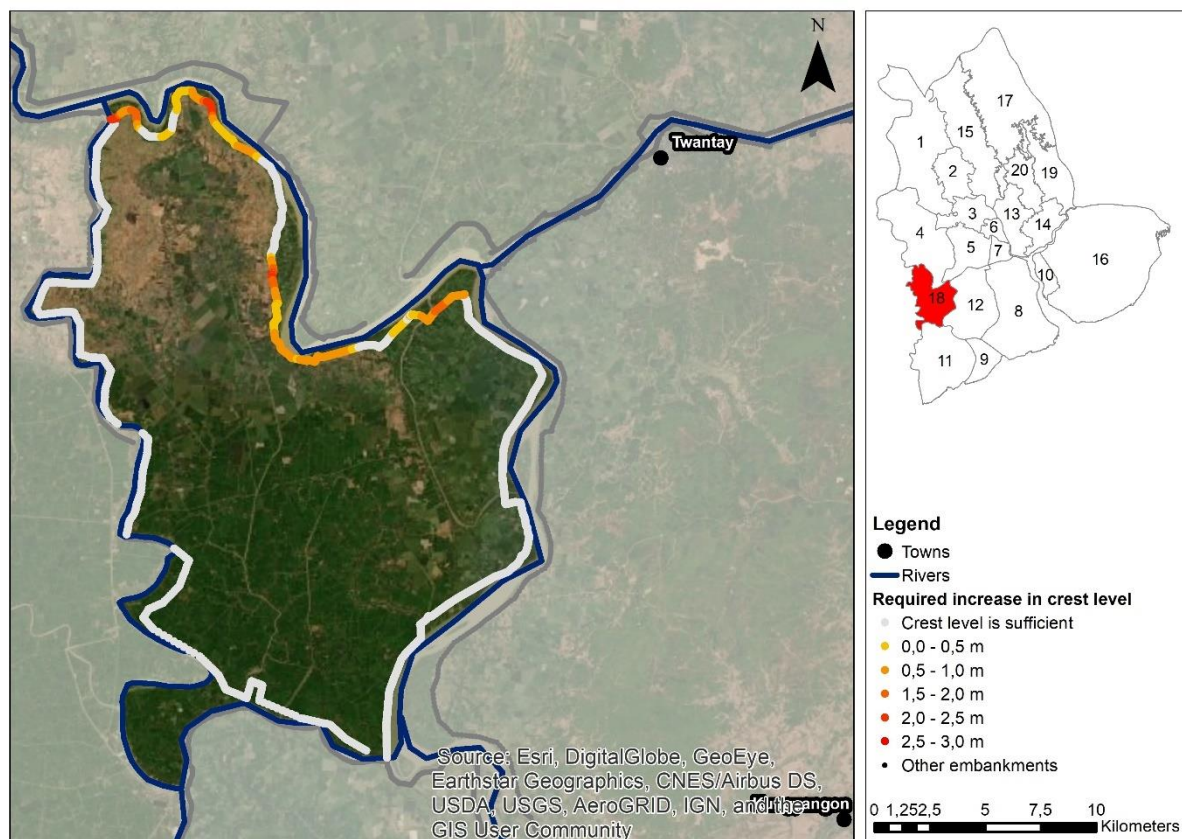
The purpose of the dike improvements is to decrease the flood risks within unit area 18, by reduction of the annual flood probabilities. This measure especially targets the flood defense stretches which can currently be considered as the weakest links of the flood defense system of this unit. Those stretches are improved, to decrease the overall flood risks.

3. Location (s)

The locations of the proposed flood defense improvements are strongly concentrated along the Northern border of unit area 18, along the Thande river. The rest of the flood defense system suffices for a large majority. The average crest level deficit of the insufficient flood defense stretches equals 0.94m. The figure presented below provides an overview of all locations along this unit area which are recognized by a crest level deficit for the proposed flood protection level.

The exact configuration of the flood defense improvement strategy should be made more explicit in a future stadium of the project. This is amongst other dependent on the current land use along the flood defense system and the location-specific improvement task.

Unit 18: embankment reinforcements and additional sluices



4. Preliminary indication of ownership

Within Myanmar the Irrigation and Water Utilization Management Department (IWUMD) is responsible for operation and maintenance of flood protection embankments and polders system all over the country. Therefore, the ownership of this intervention is expected to lie with IWUMD.

5. Preliminary indication of collaboration

IWUMD is expected to be the owner and legally responsible organization for the implementation of the proposed measures. However, before implementation, additional analyses, further modelling, planning and a water governance structure should be in place.

6. Level of urgency

The level of urgency is determined for every unit area based on a combination of three characteristics: The benefit-cost ratios for the current and future land use and the affected people risk reduction of the proposed measures. Measures in unit area 18 can be categorized as high priority, because the proposed measures are cost-efficient regardless of the future development of the area, and the affected people risk reduction is among the highest.

Unit	BC-ratio current land use	BC-ratio future land use	Affected people risk reduction (annually)	Priority category
1	4.54	4.54	19882	High priority
18	4.33	4.33	12338	
3	1.08	96.1	3025	
6	1.83	9.65	1058	
4	11.34	11.34	38811	
5	0.88	0.88	4055	
7	0.18	20.97	844	
2	1.08	8.77	1940	Medium priority
13	1.36	1.67	1041	
15	0.33	26.87	94	
10	0.27	5.27	43	Low priority
8	0.19	1.25	252	
14	0.29	0.44	104	

7. Effectiveness (Incl. indicators and thresholds)

Flood defense improvement is an immediate and effective way to counter flood risks in the area. The strength of the system (total flood defense system of unit area 18) is dependent on the strength of the separate components within the system. Much of the currently present flood defense system along this unit suffices already. However, due to the weak links within the system, the system as a whole does not suffice. Investing in these weak links in the system is therefore a very effective manner to decrease the overall flood risks. After adaptation of the weakest links, the full potential of the existing flood defenses can be exploited again and the system as a whole will be able to cope with the future flood threats.

8. Social and Environmental Safeguards

The acquisition of land for realization of the flood defense improvements might include resettlement of local residents at locations where people reside directly next to the current flood defense. Furthermore, depending on the local configuration of the improvement strategy, agricultural lands will become occupied by the strengthened flood defenses. Local landowners should be compensated for these losses of land. Positive social impacts of the proposed measures include a reduction of flood nuisance for residents, as well as a more stable environment for growing crops and setting up businesses, providing a more stable economic output of the area.

9. Cost estimates (CAPEX & OPEX)

A short quantification overview of the CAPEX and OPEX of the proposed flood defense improvement strategy is presented below. The OPEX expenditure quantification is based on 0.1% annual operating and maintenance costs and 3% periodical maintenance once every 5 years. The design horizon is 2040 for the proposed measures and a discount rate of 6% was assumed.

PV Dike improvement CAPEX	USD 7.07 million
PV Dike improvement OPEX	USD 0.51 million
PV total investment costs	USD 7.58 million

10. Cost recovery indication

The proposed measures will significantly reduce the total flood risk of the area, as indicated below. The investment benefits account for 2.74 times the investment costs. It was assumed that the residual value of the initial investment at the end of the life cycle accounts for 50% of the initial investment.

	Current Land use scenario:	Future Land use scenario:
PV Flood risk reduction	USD 31.75 million	USD 31.75 million
PV Residual value investments	USD 1.10 million	USD 1.10 million
PV total investment benefits	USD 32.85 million	USD 32.85 million
Benefit/cost ratio	2.59	2.59

11. Robustness & Adaptiveness

To assure that the proposed flood defense improvements are executed in an adaptive manner, it is recommended to assure that the inner and outer slopes of the new dike are sufficiently smooth. This makes it easier in case of future additional flood defense improvements to further increase the crest levels within the existing profile of the flood defense.

The used construction materials are recoverable after the life cycle of the flood defense has ended and can be reused in future projects.

12. Combinations and/or cumulative impacts

There is a relation with several other interventions and cumulative impacts within the RWSS flood risk analysis:

- The construction of new/improved dikes might negatively impact local runoff of the areas behind the flood defense, affecting the pluvial flood risks. There is a link with Program 3 within the RWSS flood risk project
- The flood defense system and flood risk in the entire study area is interconnected. Flood defense improvements in one place reduce flood risks in one area but might increase flood probabilities and flood risks in another area. This system-effect should be further quantified based on the proposed measures.

13. Construction capacity requirements

Dikes within the area around Yangon and the rest of Myanmar are managed by IWUMD. IWUMD and local contractors are familiar with these structures. The flood defense improvements can be carried out by local contractors in collaboration with the IWUMD.

14. Suggested next steps

- Additional data collection (surveying, amongst others for the current flood defense profiles, open channel crossings, existing hydraulic structures, and surface elevation levels)
- Updated and more in-depth analysis of the effects of the proposed measures
- Setting-up of a detailed implementation planning and design

Factsheet 2.1: Rural Household Water Supply

1. Description of Measure

To provide a water tank (or similar) to stand alone household which is located in the sparsely populated rural areas outside of villages. The aim of the measure is to collect and store water during the wet season months for domestic use during the dry season months.



The water tank would have a stored water capacity in the order of 15 m³ and would collect water through rainwater harvesting from the house roof. This is assuming a domestic water demand of 100 liters / day / household.

2. Purpose & targets (incl. Mainland use and unit)

Current census results suggest the rural population located within Unit Areas 5, 7 & 8 do not have their current and/or future water supply needs met. The rural population within Unit Area 8, for example, have in the order of 40% of their required water demand met through existing services. This leaves approximately 150,000 people without access to domestic water supply.

The purpose and target of this measure is to provide a reliable and economical water supply solution for standalone houses located in rural areas throughout the dry season months.

3. Location (s)

The estimated total households located in the sparsely populated rural areas outside of villages in Unit Areas 5, 7 and 8 are detailed below:

- Unit Area 5: 5,900 Households
- Unit Area 7: 2,900 Households
- Unit Area 8: 13,000 Households

4. Preliminary indication of ownership

Tanks are expected to be privately owned.

5. Preliminary indication of collaboration

Collaboration will be required between the municipalities of townships within which the standalone houses are located and the private house owners.

6. Level of urgency

On average, only 30% - 40% of the rural communities within Unit Areas 5, 7 and 8 have their domestic water demands met. This measure given a high priority to ensure citizens have the access to the basic right of an accessibility and reliable water supply.

7. Effectiveness (Incl. indicators and thresholds)

This measure aims to meet the future domestic water demand of standalone houses located in the sparsely populated rural areas outside of villages in Unit Areas 5, 7 and 8. This measure is made up of a 'building block' engineering solution, which can be replicated from one house to another.

8. Social and Environmental Safeguards

N/A

9. Cost estimates (CAPEX & OPEX)

Assuming a locally aligned and durable rainwater capturing solution can be developed for a cost in the order of \$500 per person (or \$2000 per household), the total estimated CAPEX cost for standalone houses is approximated as follows:

Unit Area	Total households with unmet water demand	Total CAPEX	Estimated cost per person
5	5,900	\$12,000,000	\$500
7	2,900	\$6,000,000	
8	13,000	\$26,000,000	

- Assumes 4 people per household
- Assumes 300 households per village

Note: CAPEX estimates can be considered to have an accuracy within the range of +/- 40%

OPEX costs are expected to be less than 5% of the estimated CAPEX cost.

10. Cost recovery indication

Cost recovery is achieved indirectly through socio-economic benefits. These benefits may include:

- A reduction of health incidences related to diseases;
- Increased economic input due to a reduction in time loss associated with fetching water, or financial loss associated with paying for water. Often profiteering can occur in situations of water scarcity, whereby water suppliers charge above reasonable market prices;
- Overall wellbeing and quality of life of those positively affected.

The costs recovered from these socio-economic benefits are difficult to quantify and further quantification may be desired in the subsequent feasibility stage.

11. Robustness & Adaptiveness

It is envisaged that a cost effective and locally aligned storage tank solution can be designed to be durable and with a long design life.

12. Combinations and/or cumulative impacts

None

13. Construction capacity requirements

The skills required to install the storage tanks and connect it to the house roof are considered to be readily available within the Yangon Region. These measures require basic civil engineering design and construction skills.

14. Suggested next steps

- Undertake baseline study to confirm which households are in need of a rainwater water harvesting and tank storage solution.
- Undertake conceptual design solution
- Tendering to market.

Factsheet 2.2: Kawmhu and Kungyangon Towns Water Supply

1. Description of Measure

Rehabilitation of the existing ponds and lakes located within or near to the highly populated centers of the towns of Kawmhu and Kungyangon, with the aim of collecting and storing water during the wet season months for domestic use during the dry season months. It is anticipated the existing ponds would need to be lined, protected using perimeter dikes from contaminated surface water ingress and fenced off to avoid animal entry. New ponds at town or neighborhood level may be required if the existing ponds are determined to be inappropriate for rehabilitation or are unable to provide the required water supply capacity.

Furthermore, a water distribution network from the ponds throughout the towns is recommended to ensure accessibility to the supplied water at household level. Ensuring accessibility is considered important in order to change the existing practice of extracting lower quality groundwater through conveniently located and low cost groundwater wells. A water tower and pump at each pond will likely be required to provide pressure into the distribution network. Filtering of the supplied water through ceramic filters is recommended.

2. Purpose & targets (incl. Mainland use and unit)

Current census results suggest less than 10% of the domestic water demand in the populated centers of Kawmhu and Kungyangon Towns are met. Kawmhu town is understood to source its domestic water supply from municipal groundwater wells which are known to experience groundwater quality problems associated with salinity. Kungyangon town is understood to partially source its domestic water supply (circa 30%) from surface reservoirs and ponds located near to or within the town centers.

The purpose and target of this measure is to rehabilitate existing ponds and lakes to provide the necessary domestic water supply requirements for the towns Kawmhu and Kungyangon during the dry season. The household water demand has been assumed at 100 liters / day.

3. Location (s)

A number of ponds and lakes already exist with close proximity to the populated towns centers and these are shown in the Figures below. It is noted that other ponds also exist outside the extents of these photos which could also be considered.

Kawmhu



Figure 1: Existing ponds and lakes located within the town of Kawmhu

Kungyangon



Figure 2: Existing ponds and lakes located within the town of Kungyangon

4. Preliminary indication of ownership

The current ownership of the land within which the ponds and lakes are located is unknown and need to be investigated. Land purchases may be required if not government owned or if new ponds are considered necessary. Easements for the distribution network will also need to be established which may exist on government or private land. Involvement of the Department of Rural Development (DRD) of MOALI is recommended.

5. Preliminary indication of collaboration

Collaboration will be required between the municipalities of both townships and private land owners in the event the existing ponds, any new ponds, or the distribution network are located on private land. Confirmation of the required water volume and spatial demand within the local communities is also required to ensure the appropriate sizing of the ponds.

6. Level of urgency

Rehabilitation of the existing ponds for the towns of Kawhmu and Kungyangon have been given a highest priority of all measures under Program 2. The reason for this being that less than 10% of the domestic water demand in the populated centers of these towns are met. Unacceptable levels of salinity in the extracted groundwater in Kawhmu demonstrate the unsustainable nature of the current water supply. Furthermore, there is insufficient surface water currently supplied from the ponds / lakes within Kungyangon.

Rehabilitation of existing ponds was also considered by the Consultative Group as the preferred engineering solution to increase domestic water supply.

7. Effectiveness (Incl. indicators and thresholds)

This measure aims to meet the future domestic water demand of these two rural towns. This based on a future 2040 forecast population and a water supply of 100 liters per day per household.

8. Social and Environmental Safeguards

The acquisition of land for realization of this measure would only be required in the case new ponds are required. This may include resettlement of local residents. However, it would be preferable to relocate new ponds on greenfield sites to avoid any resettlement.

Environmental impacts are unlikely to be a factor given this measures is focused towards rehabilitating existing assets only.

9. Cost estimates (CAPEX & OPEX)

Town	Rehabilitate Existing Ponds	Distribution Network	Total CAPEX	Total Households	Cost per person
Kawhmu	\$470,000	\$3,200,000	\$3,700,000	2,200	\$420 ¹
Kungyangon	\$735,000	\$6,000,000	\$6,700,000	4,000	
Total			\$10,400,000		

CAPEX estimates can be considered to have an accuracy within the range of +/- 40%
OPEX costs are expected to be less than 5% of the estimated CAPEX cost.

Note 1: It may be determined through further feasibility studies that establishing rainwater harvesting and storage on a neighborhood level may be more cost effective than rehabilitating existing large ponds / lakes and installing a comprehensive distribution network. This is likely the case if the locally aligned 500 m³ covered pond solution (See Section 6.2) is selected. The ability to acquire land within the more populated neighborhoods within the town may however be a constraint for this solution. In this case, a buried storage tank solution may be preferable however with a higher cost.

10. Cost recovery indication

Cost recovery is achieved indirectly through socio-economic benefits. These benefits may include:

- A reduction of health incidences related to diseases;
- Increased economic input due to a reduction in time loss associated with fetching water, or financial loss associated with paying for water. Often profiteering can occur in situations of water scarcity, whereby water suppliers charge above reasonable market prices;
- Overall wellbeing and quality of life of those positively affected.

The costs recovered from these socio-economic benefits are difficult to quantify and further quantification may be desired in the subsequent feasibility stage.

11. Robustness & Adaptiveness

The rehabilitation of ponds (or construction of new ponds if required) can be designed to be durable and with a long design life. This measure is unlikely to be replaced through future developments. In fact further ponds may be required beyond 2040 should the population with the town grow.

12. Combinations and/or cumulative impacts

The group of ponds with the towns could be designed in such a way that they are integrated and water supply can be balanced across the group of ponds in the case a particular pond is depleted before the end of the dry season months. By doing so, the risk of depleting the water supply during the summer season is shared across the group of ponds and whole town. This avoids one part of the town having no water supply, while other parts of the town do have water supply.

The ponds could also be utilized as environmental or landscaping features, providing an attractive asset to the town center. This in turn can have positive cumulative socio-economic impacts to the residents of the town, including social gatherings, increase trade through shops located nearby, recreational activities, etc.

13. Construction capacity requirements

The skills required to rehabilitate or construct new ponds are considered to be readily available within the Yangon Region. These measures require basic civil engineering design and construction skills.

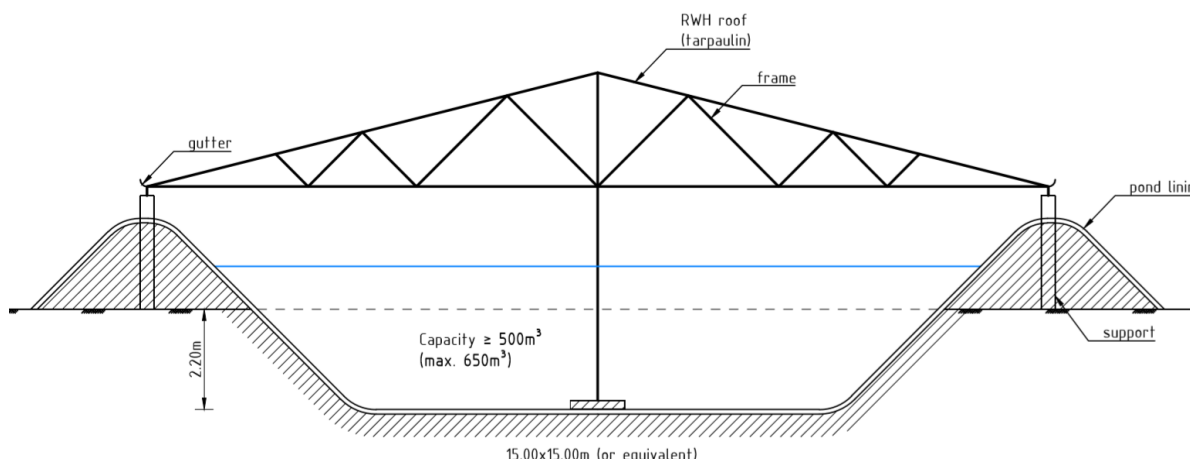
14. Suggested next steps

- Undertake baseline study to confirm existing suitable water supply infrastructure capacity, including its condition
- Confirm unmet domestic water demand up to year 2040.
- Catalogue feasible ponds / lakes, investigate land ownership and possibility for domestic water supply use;
- Detailed inspection of existing ponds / lakes to assess physical conditions and rehabilitation requirements
- Evaluation of the rainwater catchment areas of the existing ponds / lakes and water supply capacity
- Undertake conceptual design of water supply ponds (including requirements for any new ponds) and distribution network.
- Preliminary ESIA.
- Detailed design development
- Tendering to market.

Factsheet 2.3: Rural Villages Water Supply

1. Description of Measure

To provide water supply ponds at neighborhood level within rural villages, with the aim of collecting and storing water during the wet season months for domestic use during the dry season months. The ponds would have a stored water capacity in the order of 500 m³ and would collect water through rainwater harvesting. One pond would be able to supply sufficient water for approximately 35 households over the five dry season months, assuming a water demand of 100 liters / day / household. A sketch of the concept pond solution is provided below.



The roof which utilizes tarpaulin for rainwater harvesting, is supported on a frame and has an area of 400 m² (20 m x 20 m). This would allow the pond to fill to 500 m³ with only 1.1 m of rainfall during the wet season. The roof would be sealed to avoid evaporation and the ingress of airborne debris into the pond. The pond would be lined to avoid seepage loss / ingress and would be surrounded by embankments to prevent contamination from surface water flows.

Furthermore, a water distribution network is proposed to distribute water from the ponds to households. Ensuring accessibility to the stored water is considered important in order to change the existing practice of extracting lower quality groundwater through conveniently located and low cost groundwater wells. A water tower and pump at each pond will likely be required to provide pressure into the distribution network. Filtering of the supplied water through ceramic filters is recommended.

2. Purpose & targets (incl. Mainland use and unit)

Current census results suggest the rural population located within Unit Areas 5, 7 & 8 do not have their current and/or future water supply needs met. The rural population within Unit Area 8, for example, have in the order of 40% of their required water demand met through existing services. This leaves approximately 150,000 people without access to domestic water supply.

The purpose and target of this measure is to provide a reliable and economical water supply solution for rural villages throughout the five dry season months. A total of 10 covered ponds would be required to service a village comprising 350 households with a water supply demand of 100 liters / day / household.

3. Location (s)

The estimated total number of rural villages in Unit Areas 5, 7 and 8 are detailed below:

- Unit Area 5: 49 Villages
- Unit Area 7: 10 Villages
- Unit Area 8: 144 Villages

The approximate villages locations and spatial distribution are illustrated in Figure 1 below.

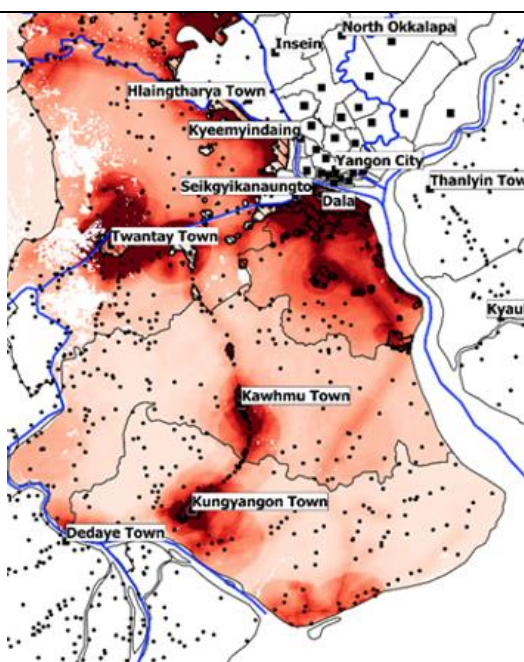


Figure 1: Approximate locations of villages is Unit Areas 5, 7 and 8

4. Preliminary indication of ownership

The current ownership of the land within which the new ponds are located are unknown and will need to be investigated. Land purchases may be required if not government owned. Easements for the distribution network will also need to be established which may exist on government or private land. Involvement of the Department of Rural Development (DRD) of MOALI is recommended.

5. Preliminary indication of collaboration

Collaboration will be required between the municipalities of townships within which the villages are located and private land owners. Confirmation of the required water volume and spatial demand within the local communities is also required to ensure the appropriate sizing of the ponds.

6. Level of urgency

On average, only 30% - 40% of the rural communities within Unit Areas 5, 7 and 8 have their domestic water demands met. This measure is therefore given a high priority to ensure citizens have the access to the basic right of an accessibility and reliable water supply.

7. Effectiveness (Incl. indicators and thresholds)

This measure aims to meet the future domestic water demand of the villages with the Unit Areas 5, 7, 8. This measure is made up of a 'building block' engineering solution, which can be replicated as villages sizes increase.

8. Social and Environmental Safeguards

The acquisition of land for realization of this measure may be required to locate new ponds. This may include resettlement of local residents. However, it would be preferable to relocate new ponds on greenfield sites to avoid any resettlement.

Environmental impacts are unlikely given the relatively small size of each pond.

9. Cost estimates (CAPEX & OPEX)

The estimated CAPEX cost to achieve the unmet domestic water demand within the villages within Unit Areas 5, 7 and 8 is provided in the Table below. This considers the following:

- an average of 300 households per village
- 35% of the population within the villages will have their water demand met using existing infrastructure, based on the known census results.

Unit Area	Village No. (approx.)	Upper Bound CAPEX	Approx. CAPEX per person
Unit Area 5	50	USD 7,500,000	\$180 - \$190

Unit Area 7	10	USD 1,500,000	
Unit Area 8	150	USD 23,000,000	

CAPEX estimates can be considered to have an accuracy within the range of +/- 40%

OPEX costs are expected to be less than 5% of the estimated CAPEX cost.

10. Cost recovery indication
Cost recovery is achieved indirectly through socio-economic benefits. These benefits may include:

- A reduction of health incidences related to diseases;
- Increased economic input due to a reduction in time loss associated with fetching water, or financial loss associated with paying for water. Often profiteering can occur in situations of water scarcity, whereby water suppliers charge above reasonable market prices;
- Overall wellbeing and quality of life of those positively affected.

The costs recovered from these socio-economic benefits are difficult to quantify and further quantification may be desired in the subsequent feasibility stage.

11. Robustness & Adaptiveness
The new ponds can be designed to be durable and with a long design life. This measure is unlikely to be replaced through future developments. Further ponds may be required in the long term as village sizes grown.

12. Combinations and/or cumulative impacts
The group of ponds within the rural villages could be designed in such a way that they are integrated and water supply can be balanced across the group of ponds in the case a particular pond is depleted before the end of the dry season months. By doing so, the risk of depleting the water supply during the summer season is shared across the group of ponds and whole village. This avoids one part of the village having no water supply, while other parts of the village do have water supply.

13. Construction capacity requirements
The skills required to construct new ponds are considered to be readily available within the Yangon Region. These measures require basic civil engineering design and construction skills.

14. Suggested next steps

- Undertake baseline study for each village to confirm existing suitable water supply infrastructure capacity, including its condition.
- Confirm unmet domestic water demand for each village up to year 2040.
- Undertake conceptual design of water supply ponds and distribution network.
- Preliminary ESIA (if considered necessary)
- Detailed design development
- Tendering to market.

It is recommended to construct and operate these covered ponds on a programmatic level. This involves starting with the construction and operation of the ponds for a select number of villages. Only progress to further villages once confidence has been gained in the solution, and lessons have been learned, so as to limit the risk of any abortive work and funding.

Factsheet 3.1.U4 Sluice structures (Unit 4)

1. Description of Measure

In light of program 1 of the RWSS flood risk analysis, the fluvial and coastal flood risks have been quantified to set a conforming flood protection standard for each of the unit areas around the city of Yangon. For unit area 4, it is proposed to raise the flood protection level offered by the current flood protection system of the unit to a 1:200 protection level for fluvial and coastal flooding. In line with this goal, the following specific measures should be taken:

- Dike improvement along 66.4km of existing flood defenses.
- Construction of 3 additional sluices/hydraulic structures at the crossing of the flood defence with three small local streams. Two of these streams are approximately 5m wide, so relatively small structures are required. The last structure should be placed in an almost 50m wide river, which requires a medium sized structure.



Considering program 2, the sluice structures can serve water management purposes. In the rainy season water can be buffered for usage in the dry season.

Furthermore, there is a relation with pluvial flooding events. The sluice structures need enough capacity to drain an area within a certain period of time.

2. Purpose & targets (incl. Mainland use and unit)

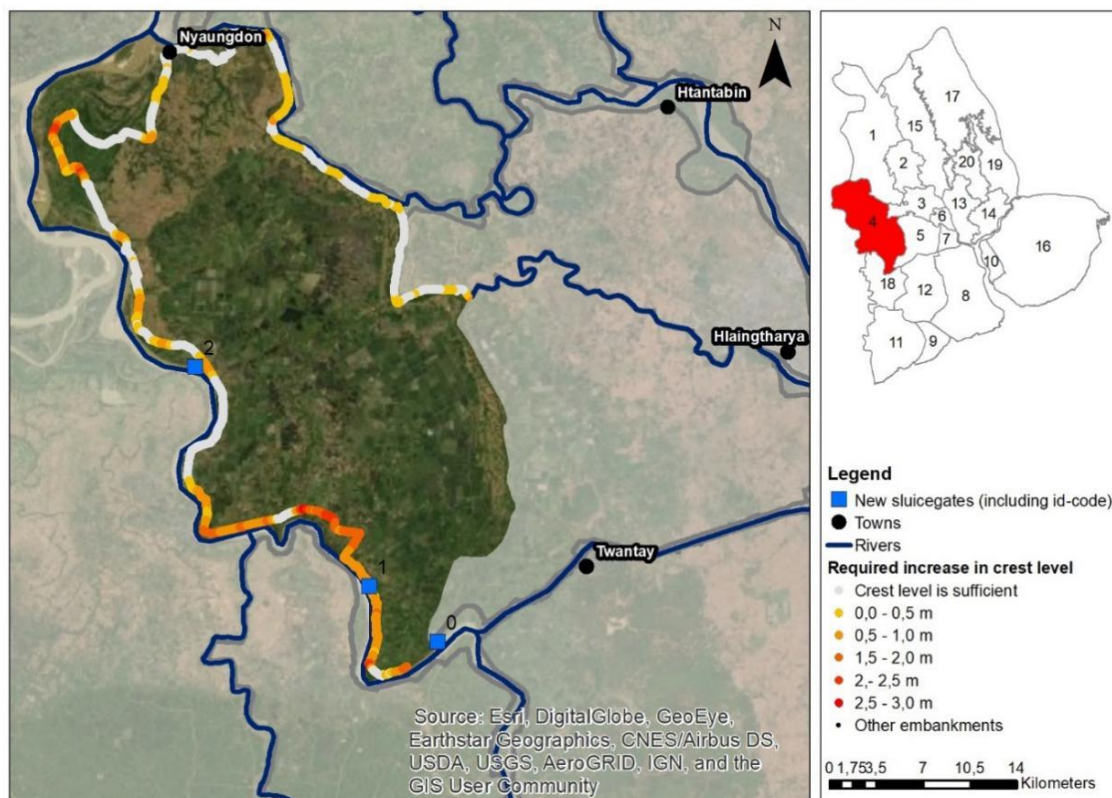
Water is required for agriculture, industry, nature and household. In the dry season there is too little fresh water and in the rainy season there is too much water. The (additional) drain capacity of the sluice structures is required to be able to drain the hinterland in a certain period.

The proposed sluices should also be part of the flood defense system, connecting embankments on both sides of a drainage channel.

The purpose of the additional hydraulic structures within the system is to prevent that flooding of the interior of unit area 4 occurs via inflow through the open channel crossings. By controlling the outflow of these streams, flooding can be prevented.

3. Location (s)

Unit 4: embankment reinforcements and additional sluices



As a result of program 1 three additional sluices are required in unit area 4. The locations of the proposed additional hydraulic structures are shown in the figure below. These are situated along the Thande river. A close capture of the local situation at the locations where these streams cross the flood defense system are included as well, in which a blue dot is placed in the channel which crosses the flood defense system of the unit area.

FID 0:



Location FID 0 is located at the south of the unit area. It is an open channel with connection to the Thande river. The larger neighboring river which makes up the border between unit areas 4 and 5 is already closed off from the Thande river by a sluice-lock system. The exact location of a new hydraulic structure is to be determined in a continued analysis.

FID 1:



Location FID 1 is located at the Southwestern side of the unit area. It's an open channel with a width of about 5 m and connected to the Thande River. For now it is assumed that a reduced 'small' building block will suffice.

FID 2:



Location FID 2 is located at the western side of the unit area. It is an open channel with a width of about 7 m and connected to the Thande River. For now it is assumed that a reduced 'small' building block will suffice. The exact location/position of the sluice structure has yet to be determined.

4. Preliminary indication of ownership

Within Myanmar the Irrigation and Water Utilization Management Department (IWUMD) is responsible for operation and maintenance of flood protection embankments and polders system all over the country. Therefore, the ownership of this intervention is expected to lie with IWUMD.

5. Preliminary indication of collaboration

IWUMD is expected to be the owner and legally responsible organization. However, before implementation further modelling, planning and a water governance structure should be in place. However, before implementation, additional analyses, further modelling, planning and a water governance structure should be in place.

6. Level of urgency

The level of urgency in relation to Program 1 is for every unit area determined based on a combination of three characteristics: The benefit-cost ratios for the current and future land use and the affected people risk reduction of the proposed measures.

Unit area 4 can be categorized as high priority. The proposed measures are very cost-effective for the current land use scenario, indicating that it is valuable to initiate these interventions on the short term. Furthermore, the affected people risk reduction value is highest for this unit, adding to the urgency to start interventions soon.

7. Effectiveness (Incl. indicators and thresholds)

Flood defense improvement is an immediate and effective way to counter flood risks in the area. The strength of the system (total flood defense system of unit area 4) is dependent on the strength of the separate components within the system. Much of the currently present flood defense system along this unit suffices already. However, due to the weak links within the system, the system as a whole does not suffice. Investing in these weak links in the system is therefore a very effective manner to decrease the overall flood risks. After adaptation of the weakest links, the full potential of the existing flood defenses can be exploited again and the system as a whole will be able to cope with the future flood threats. The open channel crossings of the flood defense system are an essential link in the system as well. Without construction of these structures, the whole system will not comprise with the proposed flood protection standards.

With regard to the drainage of area's: if the sluice structure is the limiting factor, increasing the capacity of outlet structures directly contributes to the drainage of the mainland.

8. Social and Environmental Safeguards

The acquisition of land for realization of this measure might include resettlement of local residents at locations where people reside directly next to the current flood defense and proposed location for a sluice structure. Furthermore, the construction of additional sluices in the local surface water system might affect the local water supply system and aquatic life. Aquaculture and agriculture lands require supply of fresh water, which should not be negatively impacted by the construction of these structures. This must be further analyzed. Positive social impacts of the proposed measures include a reduction of flood nuisance for residents, as well as a more stable environment for growing crops and setting up businesses, providing a more stable economic output of the area.

9. Cost estimates (CAPEX & OPEX)

CAPEX: First indication of cost per size of sluice structure. This is excluding costs for land acquisition, dike improvement and dredging works.

FID	Type	Creek Width*	Size of structure	Costs for channel closure
0	Uncontrolled intake	48	Medium	1-2.5 M USD
1	Uncontrolled intake	5	Small	0.5-1.5 M USD
2	Uncontrolled intake	7	Small	0.5-1.5 M USD
Totals				1.5-4.5 M USD

*) Creek widths based on GIS-data

Based on the assumption that installation of a penstock valve will suffice.

The OPEX is assumed to be 3-10% of the CAPEX, strongly depending on the complexity of the structure.

10. Cost recovery indication

The cost recovery indication is based on the combination of the dike strengthening and the additional sluice structures. The proposed measures will significantly reduce the total flood risk of the area, as indicated below. The investment benefits account for 11.34 times the investment costs, making the proposed measures very cost effective, regardless of future land use developments. It was assumed that the residual value of the initial investment at the end of the life cycle accounts for 50% of the initial investment.

	Current Land use scenario:	Future Land use scenario:
PV Flood risk reduction	USD 223.1 Million	USD 223.1 Million
PV Residual value investments	USD 2.9 Million	USD 2.9 Million
PV total investment benefits	USD 226 Million	USD 226 Million
Benefit/cost ratio	11.34	11.34

11. Robustness & Adaptiveness

To make use of multiple openings instead of one or a few large openings there is a certain flexibility for drainage capacity (and also potential inlet capacity). No mechanical installation is required for these gates of limited size. This contributes to a robust design and is in line with most of the existing sluices in Myanmar. The new hydraulic structures/sluices should be constructed in a robust way, as they will become an essential link in the flood protection system of this unit area. This can for instance be assured by installing both a mechanical and manual operation system to assure effectivity in case of required closure and setting up a solid operation- and maintenance program for these structures.

12. Combinations and/or cumulative impacts

There is a relation with other interventions and identified programs.

- Program 1: blocking creeks/channels is expected to result in additional sluice structures.
- The flood defense system and flood risk in the entire study area is interconnected. Flood defense improvements in one place reduce flood risks in one area, but might increase flood probabilities and flood risks in another area. This system-effect should be further quantified based on the proposed measures.
- Creating connectivity of subunit areas. This to stimulate the drainage and make use of the possible overcapacity of other structures;
- Need to introduce pumping capacity to the sluice structures. This in case the water cannot drain in time under natural conditions.
- Water storage / buffer capacity ensures there is no immediate need to adjust the size of the sluices (increase drainage capacity). This can be reached for example by reservoirs/area's for water storage or widening and deepening of existing channels.

13. Construction capacity requirements

These kind of sluice structures are already all over the country and IWUMD and local contractors are familiar with these structures. It can be constructed by local contractors.

14. Suggested next steps

- Additional data collection (amongst others for the current flood defense profiles, open channel crossings, existing hydraulic structures and surface elevation levels)
- Updated and more in-depth analysis of the effects of the proposed measures
- Preliminary ESIA
- Detailed plan and design
- Tendering

Factsheet 3.2.U5: Sluice structures (Unit 5)

1. Description of Measure

In light of program 1 of the RWSS flood risk analysis, the fluvial and coastal flood risks have been quantified to set a conforming flood protection standard for each of the unit areas around the city of Yangon. For unit area 5, it is proposed to raise the flood protection level offered by the current flood protection system of the unit to a 1:200 protection level for fluvial and coastal flooding. In line with this goal, the following specific measures should be taken:

- Dike improvement along 44.5km of existing flood defenses.
- Construction of 10 additional sluices/hydraulic structures at the crossing of the flood defense with three small local streams. 7 of these streams are less than 25m wide, so relatively small structures are required. 3 mid sized structures are required (for streams of 25 to 50m width).

Considering program 2 the sluice structure can serve for water management purposes. In the rainy season water can be buffered for the use in the dry season.

Furthermore, there is a relation with pluvial flooding events. The sluice structures need enough capacity to drain an area within a certain period of time.



2. Purpose & targets (incl. Mainland use and unit)

Water is required for agriculture, industry, nature and household. In the dry season there is too little fresh water and in the rainy season there is too much water. The (additional) drain capacity of the sluice structures is required to be able to drain the hinterland in a certain period.

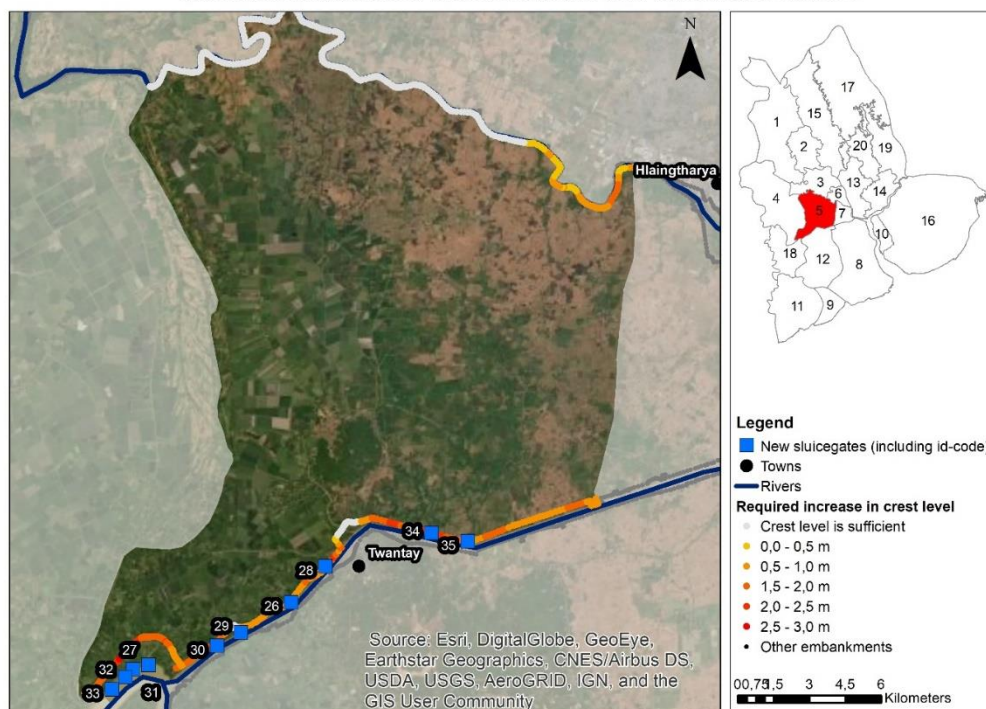
Sluices can also be part of a flood defense system, connecting embankments on both sides of a drainage channel.

The purpose of the additional hydraulic structures within the system is to prevent that flooding of the interior of unit area 5 occurs via inflow through the open channel crossings. By controlling the outflow of these streams, flooding can be prevented.

3. Location (s)

As a result of program 1 ten (10) additional sluices are required in unit area 5. The locations of the proposed additional hydraulic structures are shown in the figure below. These are all situated along the Southern side of the area, along the Twante canal or the Thande river. Additionally, for each of these locations a detail-satellite image is provided, showing the respective channel (indicated by the blue dot), relative to the flood defence (indicated by the red dots).

Unit 5: embankment reinforcements and additional sluices



FID 26:



Proposed new outlet structure (FID 26) about 6.4 km east of branch Thande river-Twante Canal. It's a creek with an open connection to the Twante Canal, width of about 30 m, where navigational activities take place. It's assumed that for the closure a building block 'medium' will suffice.

FID 27:



Location FID 27 is situated about 1 km east of branch Thande River – Twante Canal. The river has an open connection with the Thande river. The dike is located more upstream; therefore, the sluice structure should also be located more upstream. The width of the river at dike crossing is about 5-10 m width, so a building block 'small' will suffice.

FID 28:



Channel outflow at Twante Canal circa 8.5 km downstream of branch Thande River – Twante Canal. Near the connection with the Twante Canal the river has a width of about 30m and a bridge is crossing the river. There are some navigational activities in this river.

FID 29:



This river has an open connection with the Twante Canal, about 3.7 km east from branch Thande River – Twante Canal. The dike and thus also the foreseen closure are located about 350m upstream. At this point of crossing the river has a width of about 5-10 m.

FID 30:



Channel outflow at Twante Canal circa 2.5 km downstream of branch Thande River – Twante Canal. The channel flows through a township, the dike is located about 150 m upstream. The closure of the channel should therefore be realized upstream next to the bridge.

FID 31:



Location FID 31 is situated about 1-1.2 km west of branch Thande River – Twante Canal. The river has an open connection with the Thande river. The dike is located more upstream; therefore, the sluice structure should also be located more upstream. The width of the river at dike crossing is about 15-20 m width.

FID 32:



Location FID 32 is situated about 1.4-1.6 km west of branch Thande River – Twante Canal. The river has an open connection with the Thande river. The dike is located more upstream; therefore, the sluice structure should also be located more upstream. The width of the river at dike crossing is about 5-10 m width.

FID 33:



Location FID 32 is situated about 1.4-1.6 km west of branch Thande River – Twante Canal. The river has an open connection with the Thande river. The dike is located more upstream; therefore, the sluice structure should also be located more upstream. The width of the river at dike crossing is about 5-10 m width.

FID 34:



Channel outflow at Twante Canal north-east of township Twantay. The channel has a width of approx. 30-40 m at connection with Twante Canal. The dike is located about 250 m upstream. A bit more upstream a dam structure and sluice structure with gates is recently constructed. Therefore, for this specific location only some earthworks are foreseen to connect/upgrade the dike with the dam and sluice structures, if not yet constructed.

FID 35:



Channel FID 35 has an open connection to Twante Canal. The dike is located about 22m upstream, together with a river crossing (bridge). The closure of the channel should be near the bridge or could be a combination of a dike with sluice gate. The channel has a width of 35-40 m at crossing point with the dike.

4. Preliminary indication of ownership

Within Myanmar the Irrigation and Water Utilization Management Department (IWUMD) is responsible for operation and maintenance of flood protection embankments and polders system all over the country. Therefore, the ownership of this intervention is expected to be with IWUMD.

5. Preliminary indication of collaboration

IWUMD is expected to be the owner and legally responsible organization. However, before implementation further modelling, planning and a water governance structure should be in place. However, before implementation, additional analyses, further modelling, planning and a water governance structure should be in place.

6. Level of urgency

The level of urgency is determined for every unit area based on a combination of three characteristics: The benefit-cost ratios for the current and future land use and the affected people risk reduction of the proposed measures.

As part of the interconnected island consisting of unit areas 4,5 and 7, unit area 5 can be categorized as high priority, as the measures in this unit area act as prerequisite for the flood protection of the entire island. Furthermore, the affected people risk reduction value is relatively high in unit area 5 for this unit, adding to the urgency to start interventions soon.

7. Effectiveness (Incl. indicators and thresholds)

Flood defense improvement is an immediate and effective way to counter flood risks in the area. The strength of the system (total flood defense system of unit area 5) is dependent on the strength of the separate components within the system. Much of the currently present flood defense system along this unit suffices already. However, due to the weak links within the system, the system as a whole does not suffice. Investing in these weak links in the system is therefore a very effective manner to decrease the overall flood risks. After adaptation of the weakest links, the full potential of the existing flood defenses can be exploited again and the system as a whole will be able to cope with the future flood threats. The three open channel crossings of the flood defense system are an essential link in the system as well. Without construction of these structures, the whole system will not comprise with the proposed flood protection standards.

Specifically for unit area 5, the flood protection function of the Mezali sluice and the Cofferdam in the Pan Hlaing sluices are an important prerequisite for the effectiveness of the proposed investments. Mezali sluice prevents high river levels downstream along unit area 5, preventing fluvial flooding along this side of the unit area. The Cofferdam downstream prevents high storm surge levels upstream during storms. If one of these two structures cannot fulfill their flood retention function, flooding can occur within the units along the Pan Hlaing river.

8. Social and Environmental Safeguards

The acquisition of land for realization of the flood defense improvements and additional hydraulic structures might include resettlement of local residents at locations where people reside directly next to the current flood

defense. Furthermore, depending on the local configuration of the improvement strategy, agricultural lands will become occupied by the strengthened flood defenses. Local land-owners should be compensated for these losses of land.

Furthermore, the construction of additional sluices in the local surface water system might affect the local water supply system and aquatic life. Specifically relevant for this unit area is the presence of many aquaculture plots. The currently open channels crossing the flood defense play an important role in the water supply of these aquaculture plots. Further analysis of the impacts of the construction of additional sluices on the water supply system to these areas is required. Furthermore, the impact of these structures on local aquatic life should be investigated as well.

Positive social impacts of the proposed measures include a reduction of flood nuisance for residents, as well as a more stable environment for growing crops and setting up businesses, providing a more stable economic output of the area.

9. Cost estimates (CAPEX & OPEX)

CAPEX: First indication of cost per size of sluice structure. This is excluding costs for land acquisition, dike improvement and dredging works.

FID	Type	Creek Width*	Size of structure	Costs for channel closure
26	Open channel	23	Small	USD 0.5 – 1.5 million
27	Open channel	10**	Small	USD 0.5 – 1.5 million
28	Open channel	38	Medium	USD 1.0 – 2.5 million
29	Open channel	8	Small	USD 0.5 – 1.5 million
30	Open channel	12	Small	USD 0.5 – 1.5 million
31	Open channel	31	Medium	USD 1.0 – 2.5 million
32	Open channel	4	Small	USD 0.5 – 1.5 million
33	Open channel	4	Small	USD 0.5 – 1.5 million
34	Open channel	27	Medium	USD 1.0 – 2.5 million
35	Open channel	21	Small	USD 0.5 – 1.5 million
Totals				USD 8.0 – 21.5 million

*) width in accordance with (gis)model

**) Width adapted based on manual satellite imagery analysis.

The OPEX is assumed to be 3-10% of the CAPEX.

10. Cost recovery indication

Solely based on the data for unit area 5, enhanced flood protection does not pay off, as indicated by the cost-benefit ratios below 1. However, as explained in the main report, unit areas 4,5 and 7 are interconnected, which is why flood protection for unit area 5 impacts the other two unit areas as well. Therefore, given the fact that the cost- benefit ratio for unit area 5 is only slightly below 1 and for unit areas 4 and 7 are far above 1, it easily pays off to enhance flood protection along unit area 5. It was assumed that the residual value of the initial investment at the end of the life cycle accounts for 50% of the initial investment.

	Current Land use scenario:	Future Land use scenario:
PV Flood risk reduction	USD 24.67 million	USD 24.67 million
PV Residual value investments	USD 4.87 million	USD 4.87 million
PV total investment benefits	USD 29.54 million	USD 29.54 million
Benefit/cost ratio	0.88	0.88

11. Robustness & Adaptiveness

The new hydraulic structures/sluices should be constructed in a robust way, as they will become an essential link in the flood protection system of this unit area. This can for instance be assured by installing both a mechanical and manual operation system to assure effectivity in case of required closure and setting up a solid operation- and maintenance program for these structures.

To make use of multiple openings instead of one or a few large openings there is a certain flexibility for drainage capacity (and also potential inlet capacity). No mechanical installation is required for these gates of limited size. This contributes to a robust design and is in line with most of the existing sluices in Myanmar.

12. Combinations and/or cumulative impacts

There is a relation with other interventions and identified programs.

- Program 1: blocking creeks/channels is expected to result in additional sluice structures.
- The flood defense system and flood risk in the entire study area is interconnected. Flood defense improvements in one place reduce flood risks in one area, but might increase flood probabilities and flood risks in another area. This system-effect should be further quantified based on the proposed measures.
- Creating connectivity of subunit areas. This to stimulate the drainage and make use of the possible overcapacity of other structures;
- Need to introduce pumping capacity to the sluice structures. This in case the water cannot drain in time under natural conditions.

- Water storage / buffer capacity ensures there is no immediate need to adjust the size of the sluices (increase drainage capacity). This can be reached for example by reservoirs/area's for water storage or widening and deepening of existing channels.

13. Construction capacity requirements

These kind of sluice structures are already all over the country and IWUMD and local contractors are familiar with these structures. It can be constructed by local contractors.

14. Suggested next steps

- Additional data collection (amongst others for the current flood defense profiles, open channel crossings, existing hydraulic structures and surface elevation levels)
- Updated and more in-depth analysis of the effects of the proposed measures
- Preliminary ESIA
- Detailed plan and design
- Tendering

Factsheet 3.3.U6: Sluice structures (Unit 6)

1. Description of Measure

In light of program 1 of the RWSS flood risk analysis, the fluvial and coastal flood risks have been quantified to set a conforming flood protection standard for each of the unit areas around the city of Yangon. For unit area 3, it is proposed to raise the flood protection level offered by the current flood protection system of the unit to a 1:200 protection level for fluvial and coastal flooding. In line with this goal, the following specific measures should be taken:

- Dike improvement along 29.3km of existing flood defenses.
- Construction of 3 additional sluices/hydraulic structures at the crossing of the flood defence with three small local streams. Two of these streams require a small sluice structure (<25m²), and one requires a medium sized structure.



Considering program 2 the sluice structure can serve for water management purposes. In the rainy season water can be buffered for the use in the dry season.

Furthermore, there is a relation with pluvial flooding events. The sluice structures need enough capacity to drain an area within a certain period of time.

2. Purpose & targets (incl. Mainland use and unit)

Water is required for agriculture, industry, nature and household. In the dry season there is too little fresh water and in the rainy season there is too much water. The (additional) drain capacity of the sluice structures is required to be able to drain the hinterland in a certain period.

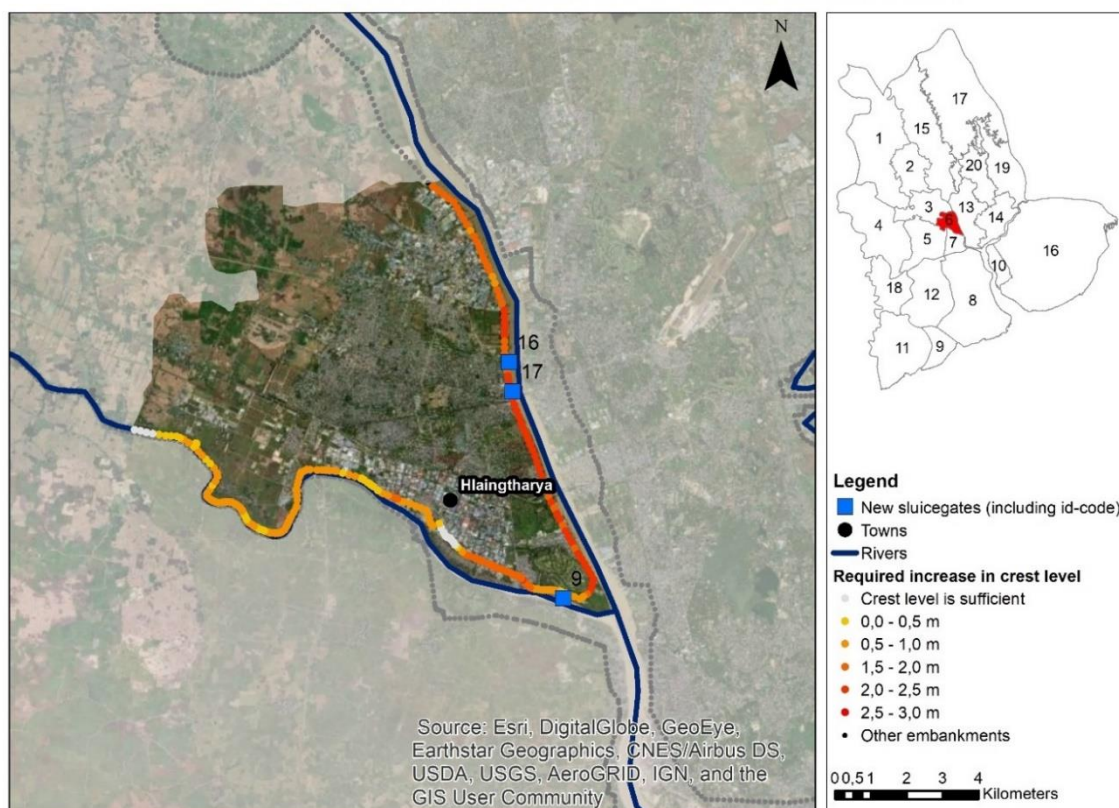
Sluices can also be part of a flood defense system, connecting embankments on both sides of a drainage channel.

The purpose of the additional hydraulic structures within the system is to prevent that flooding of the interior of unit area 6 occurs via inflow through the open channel crossings. By controlling the outflow of these streams, flooding can be prevented.

3. Location (s)

As a result of program 1 three additional sluices are required in unit area 6. The locations of the proposed additional hydraulic structures are shown in the figure below. These are situated both along the Hlaing and Pan Hlaing rivers, directly next to urbanized areas. A detail satellite image snap shot of the individual channels is shown as well, in which the location of the flood defense is shown by the red dots.

Unit 6: embankment reinforcements and additional sluices



FID 9:



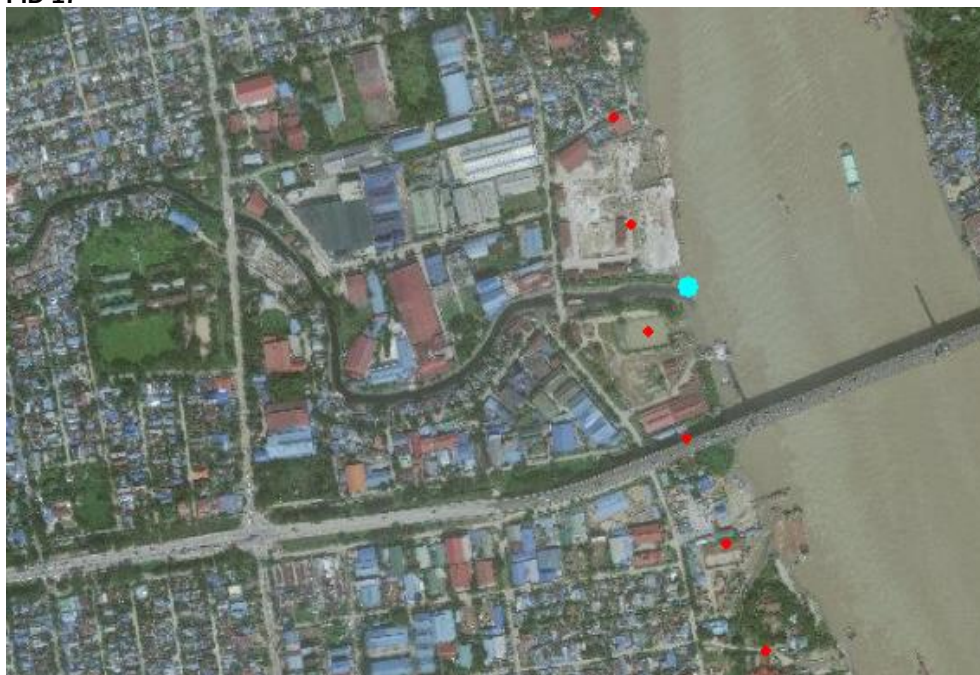
Location FID 9 is located at the south-western corner of unit area 6, south of Pan Hlaing Golf Estate. The open channel flows into the Pan Hlaing River. At the mouth, the channel is about 31m wide, a bit more upstream at location of the dike the channel is only 10 meters width. It is assumed that a small sized structure will suffice here.

FID 16



Location FID 16 is situated at the eastern side of unit area 6, approx. 1 km north of the Aung Zeya Bridge. At the crossing with the dike, the channel has a width of approx. 25 m. The channel is used for local navigational purposes as well. For now, it is assumed that this channel could be blocked by a medium-sized sluice structure without any possibilities for crossing by ships.

FID 17



Location FID 17 is situated at the eastern side of unit area 6, approx. 200 m north of the Aung Zeya Bridge. At the crossing with the dike, the channel has a width of approx. 15 m. This channel is not in use for navigational activities. It is assumed that a small-sized sluice system will suffice to control this channel.

4. Preliminary indication of ownership

Within Myanmar the Irrigation and Water Utilization Management Department (IWUMD) is responsible for operation and maintenance of flood protection embankments and polders system all over the country. Therefore, the ownership of this intervention is expected to be with IWUMD.

5. Preliminary indication of collaboration

IWUMD is expected to be the owner and legally responsible organization. However, before implementation, additional analyses, further modelling, planning and a water governance structure should be in place.

6. Level of urgency

The level of urgency in relation to Program 1 is for every unit area determined based on a combination of three characteristics: The benefit-cost ratios for the current and future land use and the affected people risk reduction of the proposed measures.

Unit area 6 can be categorized as medium priority. The proposed measures are cost-efficient in both the current and (especially) the future land use situation. The affected people risk reduction is however slightly lower than in other unit areas. The measures in Unit 6 should therefore be categorized among the interventions with a medium priority.

7. Effectiveness (Incl. indicators and thresholds)

Flood defense improvement is an immediate and effective way to counter flood risks in the area. The strength of the system (total flood defense system of unit area 6) is dependent on the strength of the separate components within the system. Much of the currently present flood defense system along this unit suffices already. However, due to the weak links within the system, the system as a whole does not suffice. Investing in these weak links in the system is therefore a very effective manner to decrease the overall flood risks. After adaptation of the weakest links, the full potential of the existing flood defenses can be exploited again and the system as a whole will be able to cope with the future flood threats. The open channel crossings of the flood defense system are an essential link in the system as well. Without construction of these structures, the whole system will not comprise with the proposed flood protection standards.

With regard to the drainage of area's: if the sluice structure is the limiting factor, increasing the capacity of outlet structures directly contributes to the drainage of the mainland.

8. Social and Environmental Safeguards

The acquisition of land for realization of the flood defense improvements and additional hydraulic structures might include resettlement of local residents at locations where people reside directly next to the current flood defense. Furthermore, depending on the local configuration of the improvement strategy, agricultural lands will become occupied by the strengthened flood defenses. Local landowners should be compensated for these losses of land.

Also, the construction of additional sluices in the local surface water system might affect the local water supply system and aquatic life. Specifically, relevant for this unit area is the fact that some of these streams are currently used for local shipping as well. The impacts of additional hydraulic structures on these shipping activities should be further analyzed. Furthermore, the impact of these structures on local aquatic life should be investigated as well.

Positive social impacts of the proposed measures include a reduction of flood nuisance for residents, as well as a more stable environment for growing crops and setting up businesses, providing a more stable economic output of the area.

9. Cost estimates (CAPEX & OPEX)

CAPEX: First indication of cost per size of sluice structure. This is excluding costs for land acquisition, dike improvement and dredging works.

FID	Type	Creek Width*	Size of structure	Costs for channel closure
9	Open channel	31 (10**)	Small	0.5-1.5 M USD
16	Open channel	19 (25**)	Medium	1.0-2.5 M USD
17	Open channel	9	Small	0.5-1.5 M USD
Totals				2.0-5.5 M USD

*) width in accordance with (gis)model

**) width manually adapted based on satellite imagery analysis

The OPEX is assumed to be 3-10% of the CAPEX.

10. Cost recovery indication

The cost recovery indication is based on the combination of the dike strengthening and the additional sluice structures. The proposed measures will significantly reduce the total flood risk of the area, as indicated below. The effectiveness is strongly dependent on the future land use developments. Under current land use, the benefit/cost ratio is 1.83, but based on the current land use projections in 2040, the benefit/cost ratio would be 9.65. This does however indicate that the proposed measures are effective regardless of the future land use development. It was assumed that the residual value of the initial investment at the end of the life cycle accounts for 50% of the initial investment.

	Current Land use scenario:	Future Land use scenario:
PV Flood risk reduction	USD 15.1 Million	USD 85.1 Million
PV Residual value investments	USD 1.3 Million	USD 2.0 Million
PV total investment benefits	USD 16.4 Million	USD 77.4 Million
Benefit/cost ratio	1.83	9.65

11. Robustness & Adaptiveness

The new hydraulic structures/sluices should be constructed in a robust way, as they will become an essential link in the flood protection system of this unit area. This can for instance be assured by installing both a mechanical and manual operation system to assure effectivity in case of required closure and setting up a solid operation- and maintenance program for these structures.

To make use of multiple openings instead of one or a few large openings there is a certain flexibility for drainage capacity (and also potential inlet capacity). No mechanical installation is required for these gates of limited size. This contributes to a robust design and is in line with most of the existing sluices in Myanmar.

12. Combinations and/or cumulative impacts

There is a relation with other interventions and identified programs.

- Program 1: blocking creeks/channels is expected to result in additional sluice structures.
- The flood defense system and flood risk in the entire study area is interconnected. Flood defense improvements in one place reduce flood risks in one area, but might increase flood probabilities and flood risks in another area. This system-effect should be further quantified based on the proposed measures.
- Creating connectivity of subunit areas. This to stimulate the drainage and make use of the possible overcapacity of other structures;
- Need to introduce pumping capacity to the sluice structures. This in case the water cannot drain in time under natural conditions.
- Water storage / buffer capacity ensures there is no immediate need to adjust the size of the sluices (increase drainage capacity). This can be reached for example by reservoirs/area's for water storage or widening and deepening of existing channels.
- Location FID 9 has a relationship with any realization of the Pan Hlaing (navigational) sluice structure complex.

13. Construction capacity requirements

These kind of sluice structures are already all over the country and IWUMD and local contractors are familiar with these structures. It can be constructed by local contractors.

14. Suggested next steps

- Additional data collection (amongst others for the current flood defense profiles, open channel crossings, existing hydraulic structures and surface elevation levels)
- Updated and more in-depth analysis of the effects of the proposed measures
- Preliminary ESIA
- Detailed plan and design
- Tendering

Factsheet 3.4.U7: Sluice structures (Unit 7)

1. Description of Measure

In light of program 1 of the RWSS flood risk analysis, the fluvial and coastal flood risks have been quantified to set a conforming flood protection standard for each of the unit areas around the city of Yangon. For unit area 3, it is proposed to raise the flood protection level offered by the current flood protection system of the unit to a 1:200 protection level for fluvial and coastal flooding. In line with this goal, the following specific measures should be taken:

- Dike improvement along 27,9km of existing flood defenses.
- Construction of 11 additional sluices/hydraulic structures at the crossing of the flood defence with 11 small local streams. 10 of these streams are <25m wide, which requires small sized sluices, while one is between 25 and 50m wide, requiring a medium sized structure.



Considering program 2 the sluice structure can serve for water management purposes. In the rainy season water can be buffered for the use in the dry season.

Furthermore, there is a relation with pluvial flooding events. The sluice structures need enough capacity to drain an area within a certain period of time.

2. Purpose & targets (incl. Mainland use and unit)

Water is required for agriculture, industry, nature and household. In the dry season there is too little fresh water and in the rainy season there is too much water. The (additional) drain capacity of the sluice structures is required to be able to drain the hinterland in a certain period.

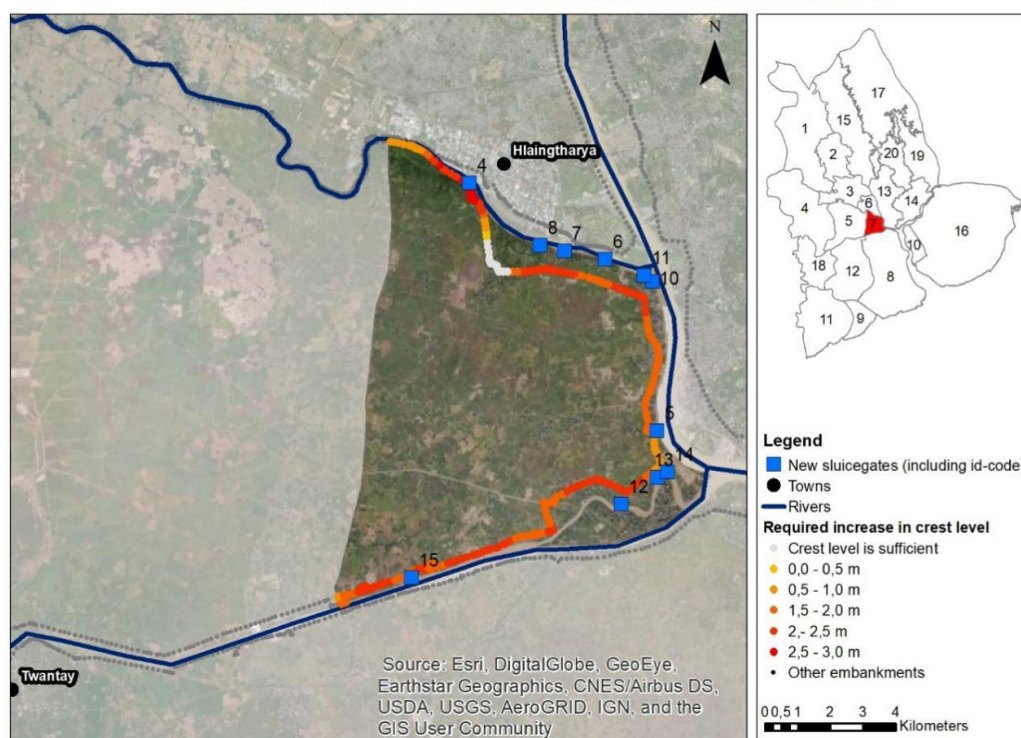
Sluices can also be part of a flood defense system, connecting embankments on both sides of a drainage channel.

The purpose of the additional hydraulic structures within the system is to prevent that flooding of the interior of unit area 7 occurs via inflow through the open channel crossings. By controlling the outflow of these streams, flooding can be prevented.

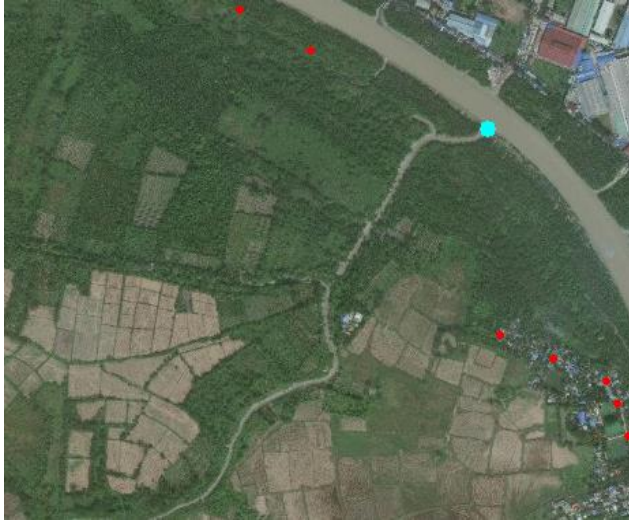
3. Location (s)

As a result of program 1, 11 additional sluices are required in unit area 7. The locations of the proposed additional hydraulic structures are shown in the figure below. These are situated both along the Hlaing river, Pun Hlaing river and the Twante canal. Details of the confluence of the local streams are provided as well, along with the location of the flood defence (shown by the red dots).

Unit 7: embankment reinforcements and additional sluices

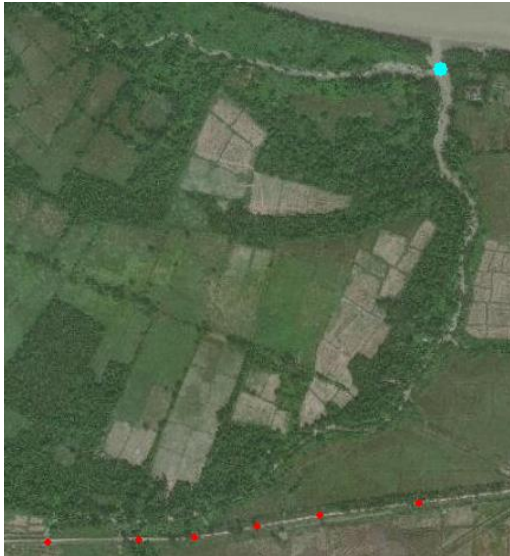


FID-4:



Channel FID-4 is situated along the Northern side of unit area 7. The channel is approximately 20m wide and is not used for navigational purposes. It is assumed that a small sized structure will suffice to close this channel.

FID 8



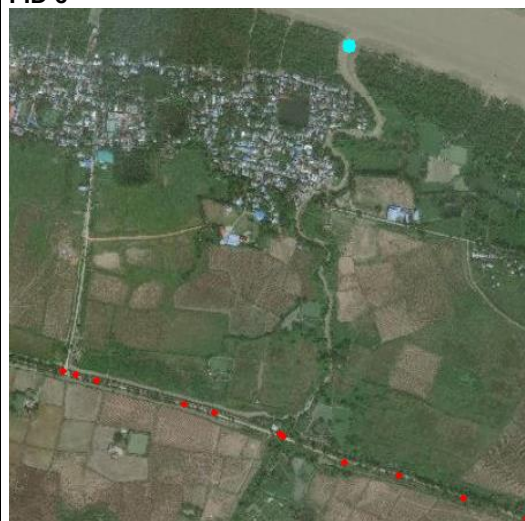
Channel FID-8 is situated along the Northern side of unit area 7. The channel is approximately 20m wide at the confluence and is not used for navigational purposes. Upstream the channel quickly becomes less wide. It is assumed that a small sized structure will suffice to close this channel approximately 1 km upstream of the confluence, where the channel crosses the flood defense.

FID 7



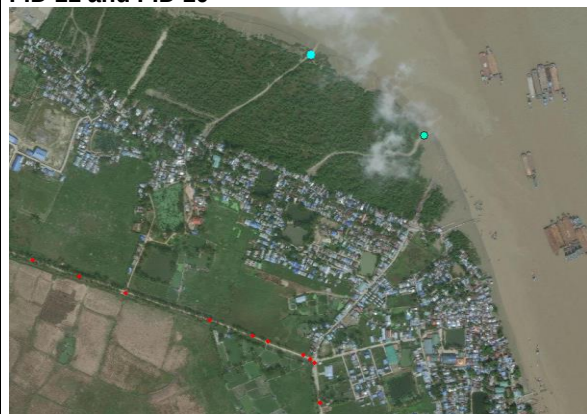
Channel FID-8 is situated along the Northern side of unit area 7. The channel is approximately 20m wide at the confluence and is not used for navigational purposes. It is assumed that a small sized structure will suffice to close this channel, especially since the channel decreases in width quickly further upstream where it crosses the flood defense. The channel is approximately 5m wide at the crossing with the flood defense.

FID 6



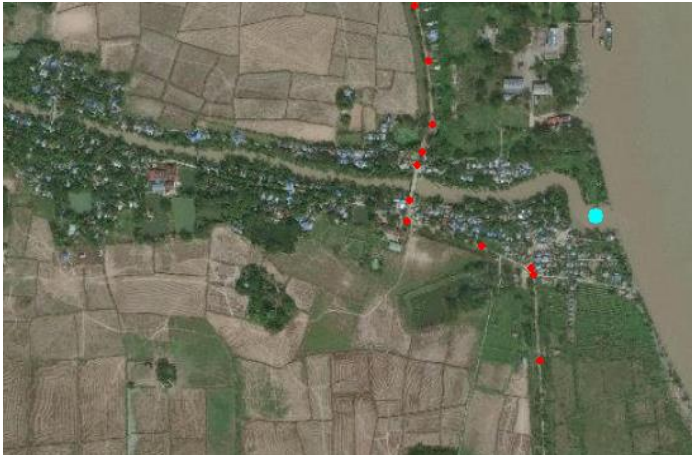
Channel FID 6 is situated along the Northern side of the area along the Pan Hlaing river. It flows alongside a small village, where some navigational activity takes place as well. However, upstream at the location where the channel crosses the flood defense, navigational activity stops and it is therefore assumed that a simple small 'building block' will suffice to shut this channel locally at the crossing with the flood defense.

FID 11 and FID 10



Channels FID 11 and FID 10 are situated at the confluence of the Pan Hlaing and Kokkowa rivers. These channels are both very small and a small structure will therefore suffice to close the gaps in the flood defense system.

FID 5



Channel ID-5 is the widest open channel crossing the flood defenses of unit area 7. The channel is approximately 30m wide and will require a medium sized structure. This channel is used for small-scale navigational purposes as well.

FID 14 and FID 13



Channel FID 14 and FID 13 are situated at the Southeastern side of Unit area 7. Both are relatively small (between 10 and 20 m wide) at the river mouths and decrease in width quickly further upstream. No navigation takes place at these rivers and a small sized structure will suffice to close these channels.

FID 12



Channel FID-12 is situated along the Southern side of unit area 7. The channel is small and not used for navigational purposes. It is assumed that a small sized structure will suffice to close this channel.

FID15



Channel FID-15 is situated along the Southern side of unit area 7. The channel flows alongside the flood defense North of a small village before crossing the flood defense. It is not used for navigation purposes. Upstream the channel becomes less wide. It is assumed that a small sized structure will suffice to close this channel.

4. Preliminary indication of ownership

Within Myanmar the Irrigation and Water Utilization Management Department (IWUMD) is responsible for operation and maintenance of flood protection embankments and polders system all over the country. Therefore, the ownership of this intervention is expected to lie with IWUMD.

5. Preliminary indication of collaboration

IWUMD is expected to be the owner and legally responsible organization. However, before implementation further modelling, planning and a water governance structure should be in place. However, before implementation, additional analyses, further modelling, planning and a water governance structure should be in place.

6. Level of urgency

The level of urgency in relation to Program 1 is for every unit area determined based on a combination of three characteristics: The benefit-cost ratios for the current and future land use and the affected people risk reduction of the proposed measures.

The measures in unit 7 can be categorized as medium priority. The cost-effectiveness is highly dependent on the future development of the area. Under the current land use scenario, the measures are not cost-efficient. It is therefore recommended to assure first that the foreseen developments within this unit will become a reality, before implementing the proposed measures. If so, these measures are however very cost-efficient, which is why it is important to install these interventions before the area is urbanized. This will also prevent that construction within urbanized areas results in additional costs and efforts.

7. Effectiveness (Incl. indicators and thresholds)

Flood defense improvement is an immediate and effective way to counter flood risks in the area. The strength of the system (total flood defense system of unit area 7) is dependent on the strength of the separate components within the system. Much of the currently present flood defense system along this unit suffices already. However, due to the weak links within the system, the system as a whole does not suffice. Investing in these weak links in the system is therefore a very effective manner to decrease the overall flood risks. After adaptation of the weakest links, the full potential of the existing flood defenses can be exploited again and the system as a whole will be able to cope with the future flood threats. The open channel crossings of the flood defense system are an essential link in the system as well. Without construction of these structures, the whole system will not comprise with the proposed flood protection standards.

With regard to the drainage of area's: if the sluice structure is the limiting factor, increasing the capacity of outlet structures directly contributes to the drainage of the mainland.

8. Social and Environmental Safeguards

The acquisition of land for realization of this measure might include resettlement of local residents at locations where people reside directly next to the current flood defense and proposed location for a sluice structure.

Furthermore, the construction of additional sluices in the local surface water system might affect the local water supply system and aquatic life. Aquaculture and agriculture lands require supply of fresh water, which should not be negatively impacted by the construction of these structures. This must be further analyzed. Positive social impacts of the proposed measures include a reduction of flood nuisance for residents, as well as a more stable environment for growing crops and setting up businesses, providing a more stable economic output of the area.

9. Cost estimates (CAPEX & OPEX)

CAPEX: First indication of cost per size of sluice structure. This is excluding costs for land acquisition, dike improvement and dredging works.

FID	Type	Creek Width*	Size of structure	Costs for channel closure
4	Open channel	23	Small	0.5-1.5 M USD
5	Open channel	29	Medium	1.0-2.5 M USD
6	Open channel	21 (5**)	Small	0.5-1.5 M USD
7	Open channel	20 (5**)	Small	0.5-1.5 M USD
8	Open channel	19 (5**)	Small	0.5-1.5 M USD
10	Open channel	2	Small	0.5-1.5 M USD
11	Open channel	2	Small	0.5-1.5 M USD
12	Open channel	11	Small	0.5-1.5 M USD
13	Open channel	13 (5**)	Small	0.5-1.5 M USD
14	Open channel	20 (10**)	Small	0.5-1.5 M USD
15	Open channel	17	Small	0.5-1.5 M USD
Totals				6.0-17.5 M USD

*) Widths according to GIS-data

**) Widths corrected based on manual satellite imagery analysis at the crossing location with the flood defence.

The OPEX is assumed to be 3-10% of the CAPEX, strongly depending on the complexity of the structure.

10. Cost recovery indication

The cost recovery indication is based on the combination of the dike strengthening and the additional sluice structures. The proposed measures will significantly reduce the total flood risk of the area, as indicated below. The effectiveness is strongly dependent on the future land use developments. Under current land use, the benefit/cost ratio is 0.18, but based on the current land use projections in 2040, the benefit/cost ratio would be 20.97. It was assumed that the residual value of the initial investment at the end of the life cycle accounts for 50% of the initial investment.

	Current Land use scenario:	Future Land use scenario:
PV Flood risk reduction	1.0M USD	518M USD
PV Residual value investments	3.6M USD	3.6M USD
PV total investment benefits	4.6M USD	521.6M USD
Benefit/cost ratio	0.18	20.97

11. Robustness & Adaptiveness

The new hydraulic structures/sluices should be constructed in a robust way, as they will become an essential link in the flood protection system of this unit area. This can for instance be assured by installing both a mechanical and manual operation system to assure effectivity in case of required closure and setting up a solid operation- and maintenance program for these structures.

For the two specific location in unit area 3 there can be chosen for an stainless steel penstock valve to reduce the maintenance.

12. Combinations and/or cumulative impacts

There is a relation with other interventions and identified programs.

- Program 1: blocking creeks/channels is expected to result in additional sluice structures.
- The flood defense system and flood risk in the entire study area is interconnected. Flood defense improvements in one place reduce flood risks in one area, but might increase flood probabilities and flood risks in another area. This system-effect should be further quantified based on the proposed measures.
- Creating connectivity of subunit areas. This to stimulate the drainage and make use of the possible overcapacity of other structures;
- Need to introduce pumping capacity to the sluice structures. This in case the water cannot drain in time under natural conditions.

- Water storage / buffer capacity ensures there is no immediate need to adjust the size of the sluices (increase drainage capacity). This can be reached for example by reservoirs/area's for water storage or widening and deepening of existing channels.
- Locations FID 4, 6, 7 and 8 are related to the realization of the Pan Hlaing (navigational) sluice structure complex project.

13. Construction capacity requirements

These kind of sluice structures are already all over the country and IWUMD and local contractors are familiar with these structures. It can be constructed by local contractors.

14. Suggested next steps

- Additional data collection (amongst others for the current flood defense profiles, open channel crossings, existing hydraulic structures and surface elevation levels)
- Updated and more in-depth analysis of the effects of the proposed measures
- Preliminary ESIA
- Detailed plan and design
- Tendering

Factsheet 3.5.U8: Sluice structures (Unit 8)

1. Description of Measure

In light of program 1 of the RWSS flood risk analysis, the fluvial and coastal flood risks have been quantified to set a conforming flood protection standard for each of the unit areas around the city of Yangon. For unit area 8, it is proposed to raise the flood protection level offered by the current flood protection system of the unit to a 1:200 protection level for fluvial and coastal flooding. In line with this goal, the following specific measures should be taken:

- Dike improvement along 64.7km of existing flood defenses.
- Construction of 9 additional sluices/hydraulic structures at the crossing of the flood defence with 9 smaller local streams. 7 of these are <25m wide, requiring a small sized structure. One requires a medium sized structure, and there is also one large river requiring a large hydraulic structure.



Considering program 2 the sluice structure can serve for water management purposes. In the rainy season water can be buffered for the use in the dry season.

Furthermore, there is a relation with pluvial flooding events. The sluice structures need enough capacity to drain an area within a certain period of time.

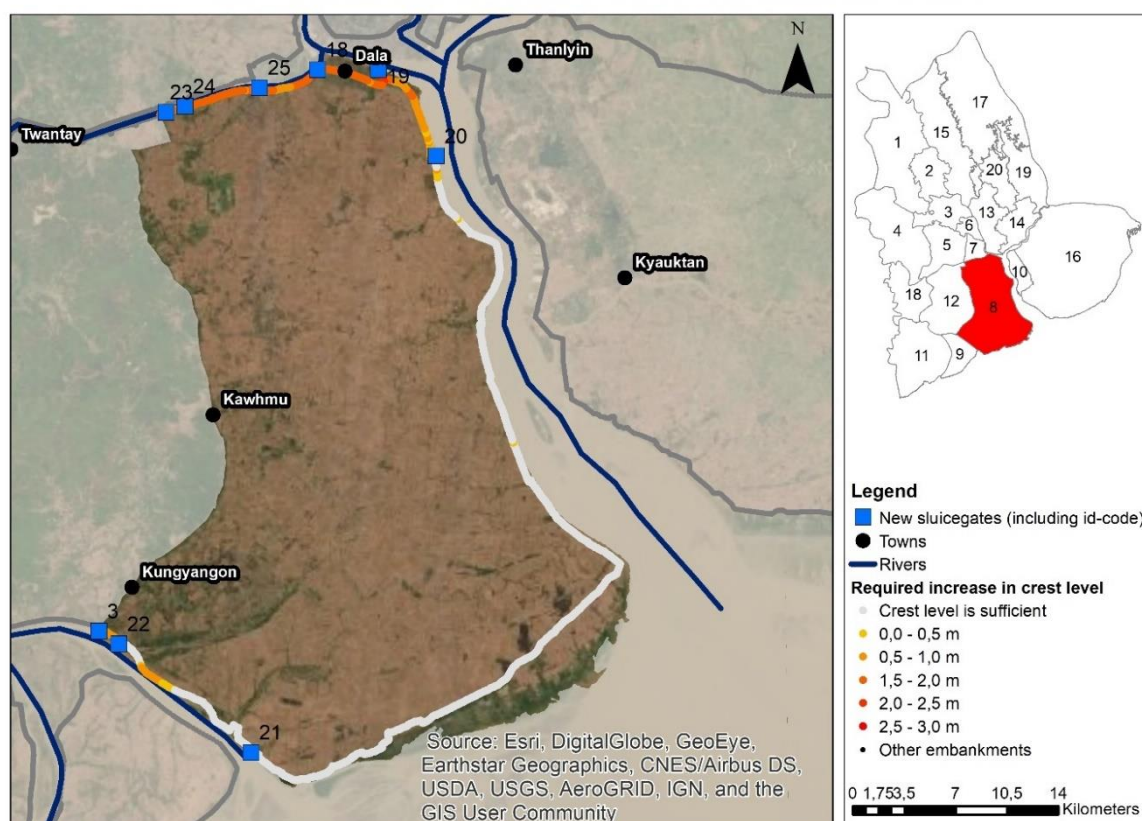
2. Purpose & targets (incl. Mainland use and unit)

Water is required for agriculture, industry, nature and household. In the dry season there is too little fresh water and in the rainy season there is too much water. The (additional) drain capacity of the sluice structures is required to be able to drain the hinterland in a certain period.

Sluices can also be part of a flood defense system, connecting embankments on both sides of a drainage channel.

3. Location (s)

Unit 8: embankment reinforcements and additional sluices



The location of the proposed additional hydraulic structures is shown in the figure as well. These are situated both along the Northern and Southwestern sides of the unit area. Hydraulic structure ID-3 is situated at the ca. 100m wide confluence of a relatively large local river with the Thande river.

FID 23:



Proposed new outlet structure (FID 23) about 420 m east of Twantay Bridge. It's a relatively small creek with an open connection to the Twante Canal, width of about 10 m. It's assumed that for the closure a building block 'small', with an open drain area of 10 m² will suffice.

FID 24:



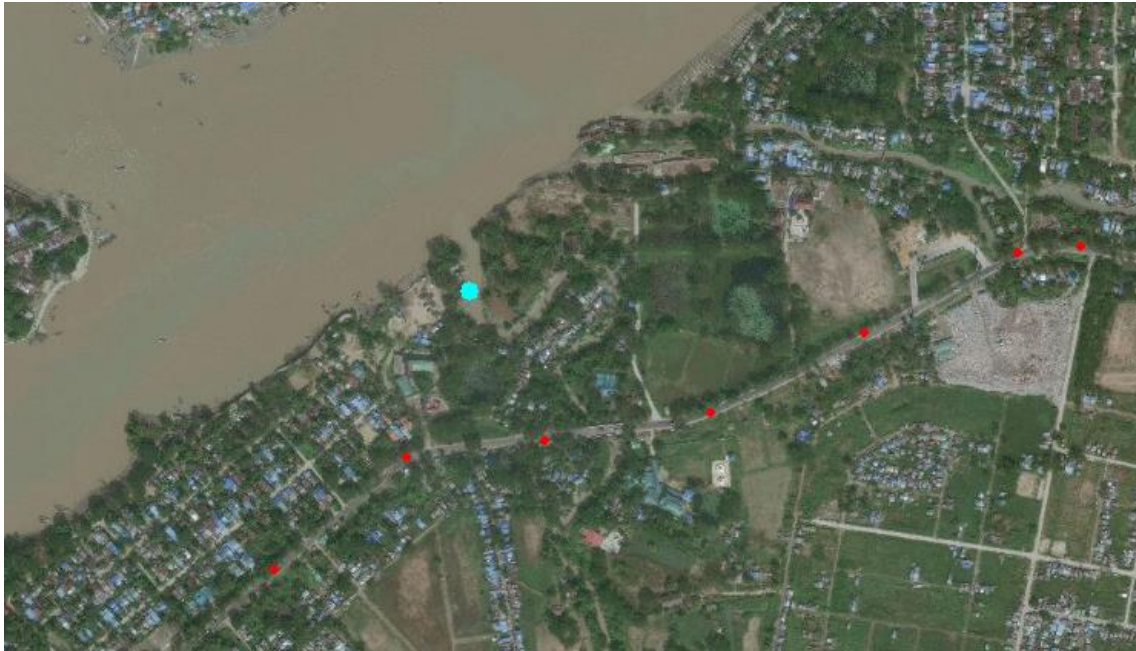
The existing channel is located about 1.8 km east of Twantay Bridge. It's a channel with a width of about 15 meters and has an open connection with the Twante Canal.

FID 25:



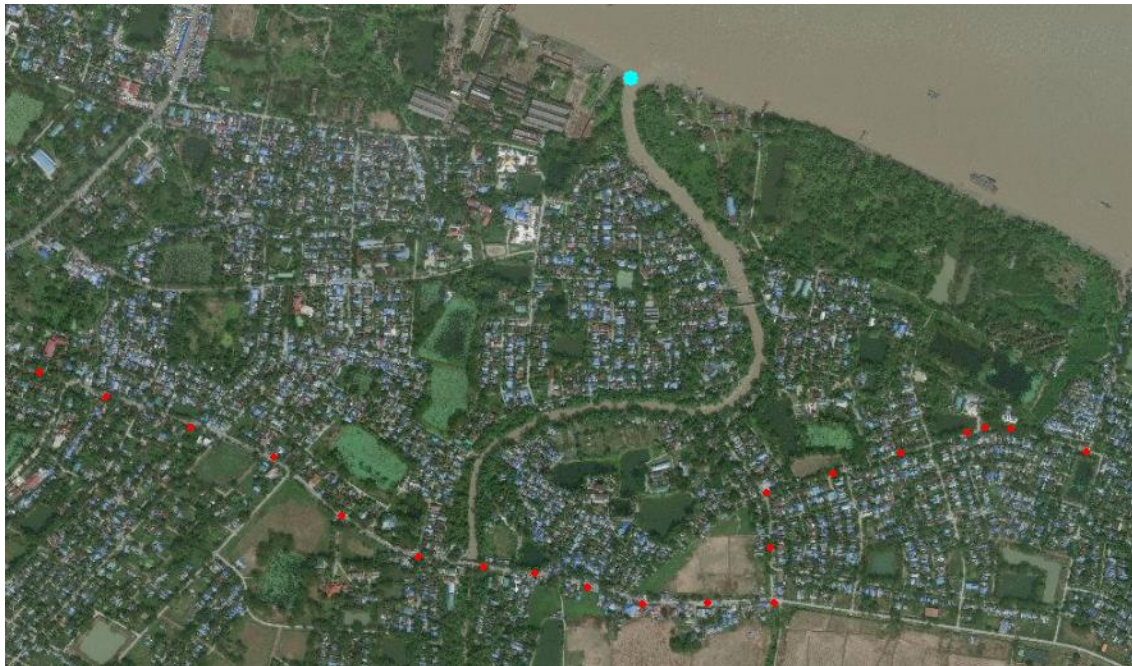
Channel outflow at Twante Canal circa 1 km downstream of Khanaungto Creek intake. The channel flows through a township, the dike is located about 380 m upstream. The closure of the channel should therefore be realised upstream next to the bridge.

FID 18:



Channel outflow at Twante Canal opposite of outflow Khanaungto Creek and west of Dala. The channel, with an average width of about 18 m, flows through a township the dike is located about 500 m upstream. The closure of the channel will therefore also not at the mouth of the channel but a bit upstream, next to the bridge.

FID 19:



Channel through Dala and an open connection with the Yangon River. The channel, with an average width of about 23 m, flows through a township, the dike is located about 1.5 km upstream. The closure of the channel will therefore also not at the mouth of the channel but a bit upstream, next to the bridge. As a result, the first 1.5 km from the mouth upstream can still be used for navigational purposes.

FID 20:



Location FID 20 is situated between Dala and Yakainggyaung, opposite of Gwa-ywa and has an open connection with Yangon River. The channel, with an average width of 21 meter, is situated at the north of a township and at the mouth is a small channel crossing created. The dike is located more inland and as a result of that the sluice structure will also be situated 400 m upstream.

FID 21:



Location FID 21 is located at the Southwestern side of the unit area, almost at the mouth of the Thande River. The channel at location of closure has a width of about 23 m.

FID 22:



Channel FID 22 consists of two separate streams crossing the flood defence close to each other. A sluice structure is in place already in the left stream (slightly upstream of the image), so it is assumed that only a new structure is required in the right stream. The stream is approximately 15m wide, so a small structure will likely suffice.

FID 3:



Location FID 3 is located at the mouth of the river coming from Kungyangon and further upstream. There is an open connection with the Thande River and at location of the (ring)dike the width of the river is about 100 meters. Due to the navigational activities in this river it's not an option to close the river with an outlet structure. It should be considered in combination with a navigational sluice, with large investment costs as a result. Economically this might not be an attractive solution, and it might be economically more efficient to invest in dike reinforcement along this river up to Kungyangon. At Kungyangon there are already (large) sluice structures like Kungyan Gone to protect the mainland against flooding, so it might be possible to invest in additional dike construction up to these existing sluice-structures.

4. Preliminary indication of ownership

Within Myanmar the Irrigation and Water Utilization Management Department (IWUMD) is responsible for operation and maintenance of flood protection embankments and polders system all over the country. Therefore, the ownership of this intervention is expected to lie with IWUMD.

5. Preliminary indication of collaboration

IWUMD is expected to be the owner and legally responsible organization. However, before implementation further modelling, planning and a water governance structure should be in place.

6. Level of urgency

The level of urgency in relation to Program 1 is for every unit area determined based on a combination of three characteristics: The benefit-cost ratios for the current and future land use and the affected people risk reduction of the proposed measures.

The measures in unit 8 can be categorized as low priority. The cost-efficiency of the proposed measures is dependent on future land use development, and even under the foreseen future land use of the area, there are many other unit areas where the cost-efficiency of the proposed measures is higher. Furthermore, the affected people reduction value appointed to the measures in unit 8 is limited compared to other unit areas around Yangon city.

7. Effectiveness (Incl. indicators and thresholds)

Flood defense improvement is an immediate and effective way to counter flood risks in the area. The strength of the system (total flood defense system of unit area 8) is dependent on the strength of the separate components within the system. Much of the currently present flood defense system along this unit suffices already. However, due to the weak links within the system, the system as a whole does not suffice. Investing in these weak links in the system is therefore a very effective manner to decrease the overall flood risks. After adaptation of the weakest links, the full potential of the existing flood defenses can be exploited again and the system as a whole will be able to cope with the future flood threats. The open channel crossings of the flood defense system are an essential link in the system as well. Without construction of these structures, the whole system will not comprise with the proposed flood protection standards

With regard to the drainage of area's: if the sluice structure is the limiting factor, increasing the capacity of outlet structures directly contributes to the drainage of the mainland.

8. Social and Environmental Safeguards

The acquisition of land for realization of this measure might include resettlement of local residents at locations where people reside directly next to the current flood defense and proposed location for a sluice structure.

Furthermore, the construction of additional sluices in the local surface water system might affect the local water supply system and aquatic life. Specifically, relevant for this unit area is the presence of many agriculture plots. The currently open channels crossing the flood defense might be used as water supply source by the agriculture plots. Further analysis of the impacts of the construction of additional sluices on the water supply system to these areas is required. Furthermore, the impact of these structures on local aquatic life should be investigated as well. Also, the large open channel which should at location FID-3, connects to several villages upstream. This river is used as local transport mode. This aspect should also be further investigated to minimize negative impacts on local shipping conditions.

Positive social impacts of the proposed measures include a reduction of flood nuisance for residents, as well as a more stable environment for growing crops and setting up businesses, providing a more stable economic output of the area. The possibility to faster drain the area can also have a positive effect on the agriculture, more change of successful harvests.

9. Cost estimates (CAPEX & OPEX)

CAPEX: First indication of cost per size of sluice structure. This is excluding costs for land acquisition, dike improvement and dredging works.

FID	Type	Creek Width*	Size of structure	Costs for channel closure
3	uncontrolled intake	94m	Large**	2.0-5.0 M USD
18	Open channel	18m	Small	0.5-1.5 M USD
19	Open channel	28m	Medium	1.0-2.5 M USD
20	Open channel	21m	Small	0.5-1.5 M USD
21	Open channel	23m	Small	0.5-1.5 M USD
22	Open channel	15m	Small	0.5-1.5 M USD
23	Open channel	6m	Small	0.5-1.5 M USD
24	Open channel	15m	Small	0.5-1.5 M USD
25	Open channel	11m	Small	0.5-1.5 M USD
Totals				6.5-18.0 M USD

*) Widths based on GIS-data

**) Location FID-3 is a large channel with navigational activities. For the CAPEX it is assumed that dike strengthening until the village Kungyangon will suffice, assumed dike length 3 km. This in combination with some small inlet/outlet structures in the dike. Data for current dike is not available, therefore the average cost for strengthening the dike with 0.5-1.0 m in Unit 8 is considered (USD 200/m).

The OPEX costs for the civil works of a sluice structure is limited. Concrete works doesn't need a lot of maintenance. However, removal of rubbish to avoid blocking the system and inspections of the structure needs to take place and the steel gates needs some maintenance. For now its assumed that this is about 3-10% of the CAPEX costs, strongly depending on the complexity of the structure.

10. Cost recovery indication

The cost recovery indication is based on the combination of the dike strengthening and the additional sluice structures. The proposed measures will significantly reduce the total flood risk of the area, as indicated below. The effectiveness is strongly dependent on the future landuse developments. Under current landuse, the benefit/cost ratio is 0.19, but based on the current landuse projections in 2040, the benefit/cost ratio would be 1.25. It was assumed that the residual value of the initial investment at the end of the life cycle accounts for 50% of the initial investment.

	Current Land use scenario:	Future Land use scenario:
PV Flood risk reduction	USD 1.65 million	USD 38.84 million
PV Residual value investments	USD 5.11 million	USD 5.11million
PV total investment benefits	USD 6.76 million	USD 43.95 million
Benefit/cost ratio	0.19	1.25

11. Robustness & Adaptiveness

To make use of multiple openings instead of one or a few large openings there is a certain flexibility for drainage capacity (and also potential inlet capacity). No mechanical installation is required for these gates of limited size. This contributes to a robust design and is in line with most of the existing sluices in Myanmar.

The new hydraulic structures/sluices should be constructed in a robust way, as they will become an essential link in the flood protection system of this unit area. This can for instance be assured by installing both a mechanical and manual operation system to assure effectivity in case of required closure and setting up a solid operation- and maintenance program for these structures.

12. Combinations and/or cumulative impacts

There is a relation with other interventions and identified programs.

- Program 1: blocking creeks/channels is expected to result in additional sluice structures.
- The flood defense system and flood risk in the entire study area is interconnected. Flood defense improvements in one place reduce flood risks in one area, but might increase flood probabilities and flood risks in another area. This system-effect should be further quantified based on the proposed measures.
- Creating connectivity of subunit areas. This to stimulate the drainage and make use of the possible overcapacity of other structures;
- Need to introduce pumping capacity to the sluice structures. This in case the water cannot drain in time under natural conditions.
- Water storage / buffer capacity ensures there is no immediate need to adjust the size of the sluices (increase drainage capacity). This can be reached for example by reservoirs/area's for water storage or widening and deepening of existing channels.

13. Construction capacity requirements

These kind of sluice structures are already all over the country and IWUMD and local contractors are familiar with these structures. It can be constructed by local contractors.

14. Suggested next steps

- Additional data collection (amongst others for the current flood defense profiles, open channel crossings, existing hydraulic structures and surface elevation levels)
- Updated and more in-depth analysis of the effects of the proposed measures
- Preliminary ESIA
- Detailed plan and design
- Tendering

APPENDIX D INVENTORY OF INTERVENTIONS

Inventory of interventions and developments with expected impact on the regional water system

Code	Project name	Project owner	Project funder	Source	Expected regional impact	Adaptability
INT_006	Pan Hlaing Sluice	IWUMD	WB / NL	IWUMD / NL	Experience from IADS-B: Minor change in tidal flows (low and high-water levels) in Yangon River and Toe River.	No influence
INT_007	New Yangon City	New Yangon Development Company	New Yangon Development Company	New Yangon Development Company	Different land use: larger water demand and need for flood protection	No influence
INT_008	Kokkowa Water Supply Project	YCDC	JICA	JICA / YCDC	Experience from IADS-B: minor changes in freshwater distribution, but freshwater availability is important in relation to saltwater intrusion in the Yangon River and Kokkowa River.	No influence. Phase 1 is in implementation stage. Project is expected to be finished in 2025. The capacity is expected to be 60mgd.
INT_009	Twante Canal Improvement Project	DWIR	Korea	KOICA / DWIR	Experience from IADS-B: Significant change in tidal flows (low and high-water levels) in the Yangon River and Toe River	Project design is not fix yet. Prefeasibility study has done in 2014 and implementation haven't started yet.
INT_011	Toe Water Supply Project	YCDC	JICA	JICA / YCDC	Experience from IADS-B: minor changes in freshwater distribution, but freshwater availability is important in relation to saltwater intrusion in the Toe River.	Prefeasibility study is already done. Currently planning to make FS with JICA. It is adaptable as it can be started only after Kokkowa Water Supply Project is finished.
INT_012	Thilawa Special Economic Zone	Thilawa Special Economic Zone Management Committee	JICA / investors / Myanmar	Thilawa Special Economic Zone Management Committee	Different land use: larger water demand and need for flood protection	To contact Thilawa Special Economic Zone Management Committee.

Code	Project name	Project owner	Project funder	Source	Expected regional impact	Adaptability
						Water and Energy supply from Japan and water treatment plant in that zone. YCDC ask to check the source of water intake for project.
INT_034	Mezali 3 sluice	t.b.d.	t.b.d.	Pan Hlaing Vision report	More water extraction into the Pan Hlaing River. The expected regional impact is small. Only possible in combination with INT_006 Pan Hlaing Sluice.	Planning stage.
INT_035	Changing river profile of Pan Hlaing River	t.b.d.	t.b.d.	Pan Hlaing Vision report	More water extraction into the Pan Hlaing River. The expected regional impact is small. Only possible in combination with INT_006 Pan Hlaing Sluice and INT_034 Mezali 3 sluice.	Planning stage
INT_036	River shortcuts Pan Hlaing River	t.b.d.	t.b.d.	Pan Hlaing Vision report	More water extraction into the Pan Hlaing River. The expected regional impact is small. Only possible in combination with INT_006 Pan Hlaing Sluice and INT_034 Mezali 3 sluice.	Planning stage
INT_037	Raw Water Retention Reservoirs	t.b.d.	t.b.d.	Pan Hlaing Vision report	More water extraction into the Pan Hlaing River. The expected regional impact is small. Only possible in combination with INT_006 Pan Hlaing Sluice and INT_034 Mezali 3 sluice.	Planning stage

Code	Project name	Project owner	Project funder	Source	Expected regional impact	Adaptability
INT_041	Pumps for irrigation Pan Hlaing	t.b.d.	t.b.d.	Pan Hlaing Vision report	More water extraction into the Pan Hlaing River. The expected regional impact is small. Only possible in combination with INT_006 Pan Hlaing Sluice and INT_034 Mezali 3 sluice.	Planning stage
INT_044	Lowering irrigation sluices Pan Hlaing River	t.b.d.	t.b.d.	Pan Hlaing Vision report	More water extraction into the Pan Hlaing River. The expected regional impact is small. Only possible in combination with INT_006 Pan Hlaing Sluice and INT_034 Mezali 3 sluice.	Planning stage
INT_045	KOICA Industrial Zone	YCDC	KOICA	YCDC / KOICA	Different land use: larger water demand and need for flood protection	Planning stage
INT_050	Yangon Outer Ring Road & Inner Ring Road	MOC	JICA	Strategic Urban Development Plan of Greater Yangon	Potential effect on pluvial flooding scenario, depending on how the drainage system will be designed. Usually the drainage system will be considered in the design of new roads. Worst case scenario (no consideration of the drainage system) can be simulated to determine potential bottlenecks.	Planning stage

Inventory of interventions and developments relevant for strategy development

Code	Project name	Project owner	Project funder	Source	Expected regional impact	Adaptability
INT_001	Nyaungdon Bank Protection River Bifurcation	DWIR	WB / NL		Very limited. No significant change in river profile / hydraulic resistance expected by this intervention.	Implementation planned
INT_002	Ayeyarwady Agriculture Development Plan	IWUMD / DOA	KOICA		Very limited. Potentially an increase in water extraction for irrigation.	Planning stage. To contact Agriculture Department.
INT_003	Saline agriculture	DOA	NL		Very limited. Small scale changes in water extraction, no significant impact expected.	Planning stage. To contact Agriculture Department.
INT_004	Thalyin Bridge	MOC			Very limited. Only very local effects expected caused by bridge pillars.	Project design is fixed and it is under construction.
INT_005	Thilawa Port				Very limited. Limited changes expected to river profile and the hinterland.	No information.
INT_013	Wastewater Treatment Plant MyaSeinYaung Industrial Zone	YCDC		YCDC	Very limited. Only expert judgement on water quality.	No information.
INT_014	Yangon-Ngayokekaung Expressway Project	MOC		MOC	Very limited. The road won't increase in elevation.	No impact. To contact Ministry of Construction.
INT_015	Drainage Infrastructure Improvements for the 6 Downtown Townships of Yangon	YCDC		YCDC	Very limited. Too detailed for RWSS model.	Planning stage. Project is to construct retention ponds and water pumping stations in 6 downtown townships of Yangon.
INT_016	Yangon Sewerage System Development Project	YCDC		YCDC	Very limited. Too detailed for RWSS model.	Unknown
INT_017	Sewage Water Treatment Plant Than Lyet Soon	YCDC		YCDC	Very limited. Only expert judgement on water quality.	Unknown

Code	Project name	Project owner	Project funder	Source	Expected regional impact	Adaptability
INT_018	Canal Expansion in Bago-Sittaung Canal (Masterplan Bago)		JICA		Outside model boundaries, so expert judgement.	Unknown
INT_019	Retarting Pond (Masterplan Bago)		JICA		Outside model boundaries, so expert judgement.	Unknown
INT_020	Embankment along Bago (Masterplan Bago)		JICA		Outside model boundaries, so expert judgement.	Unknown
INT_022	Yangon CAD Drainage Channel Improvement Works	YCDC		YCDC	Very limited. Too detailed for RWSS model.	Unknown
INT_023	Dam Safety Assessment for Reservoirs in Phugyi, Hlawga, GyoePhyu	YCDC	WB	YCDC	Non-structural measure.	Fixed. Project is to start in 2020. Proposal for the project is already submitted and proposal evaluation stage will be in next week.
INT_025	Waste Management Facility	YCDC		YCDC	Very limited. No direct impact in model output. Cleaner drainage systems will impact the drainage capacity positively (expert judgement).	To contact Pollution Control and Cleansing Department, YCDC.
INT_026	Road Widening Thilawa	MOC		MOC	No impact on drainage capacity expected when the drainage system is maintained. When the road becomes also an embankment effects are expected (<i>need for a check</i>).	Project is finished and contact to Ministry of construction.
INT_027	Water Treatment Plant Project at Hlawga Reservoir	YCDC	AFD	YCDC	Reservoirs are excluded from the model.	Already received a grant from CDIA funding for FS which will be finished in coming 5 or 6 months. AFD together with CDIA have already evaluated consultants.
INT_028	Greater Yangon Water Supply Improvement Project (Lagunbyin)	YCDC	JICA	YCDC	Reservoirs are excluded from the model.	Implementing stage. Expected to finish in 2022.

Code	Project name	Project owner	Project funder	Source	Expected regional impact	Adaptability
INT_030	Improvement Flood Prevention Capabilities in Yangon City	YCDC		YCDC	Very limited. Most likely the scale is too small for the model (<i>need for a check</i>).	Project is to construct retention ponds and water pumping stations in 6 downtown townships of Yangon. Only planning stage. Same with INT015.
INT_032	Weather Observation and Forecasting Capacity Development	DMH		DMH	Non-structural measure.	Collaboration with AIRBM. Project is under construction and 80% completed. To set up weather station, measure river water level by server integration method in Ayeyawaddy and Chindwin river basin.
INT_033	Non-revenue water management in Tamwe	YCDC	AFD	YCDC	Non-structural measure.	Project is to start this year – probably next month and it will take for 2 years. Consultants are already selected.
INT_042	Improving urban drainage Hlaing Thar Yar	YCDC		YCDC	Very limited. Too detailed for RWSS model.	To contact drainage and wastewater management department.
INT_043	Helophyte filter system Pan Hlaing River				Very limited. Too detailed for RWSS model.	. Unknown

APPENDIX E AGRICULTURE OPTIMIZATION

This appendix provides more background with regard to the location analysis to increase agriculture potential in the RWSS project. The agriculture water demands to optimize agriculture production.

The land use image below has been created by RHDHV for the report 'Regional Water Security Study - 1D Hydrodynamic Model South East Ayeyarwady delta' from 2019 (Results of workshop irrigation and drainage analysis, 2019). The image shows that a lot of rainfed agriculture areas are scattered throughout the Yangon region. Implying that still only rainfed agriculture is being performed in locations that appear to be suitable for irrigation-based agriculture.

The area is divided in agricultural zones that show differences in land use distinguishing between irrigated land, rainfed-only land, aquaculture, post-monsoon storage water fed crops and forest. It should be noted that as this image is derived from satellite data and field tested that it gives a good estimation of the areas but is not 100% accurate and can be improved. This line of thought should be carried through in the following analysis. The values given are estimates based on this classification.



Figure a: Land use classification indicating irrigated and rainfed areas

According to this land use map around 200.000 ha of agricultural land is currently subjected to only rainfed agriculture. This amounts to about a third of the area in the identified agricultural zones. The largest part of this is because there are no alternative fresh water sources when salinity intrusion increases in the dry season.

The image below indicates for each controlled area the percentage of land that is only rainfed agriculture. These controlled areas are the areas that are estimated to drain towards the relevant sluices or open connections with the main river system. They can receive water when the sluice or open connection allows water in during the dry season. Those areas located south of Yangon near to the sea and river mouth are clearly subjected to salinity intrusion and the large majority practices

rainfed agriculture. The areas to the South and South-West of Yangon around Kungyangon and Kwahmu are located around the part of the Toe River that is affected by salinity in the dry season. It is largely regulated by sluiceways which close entirely during the dry season to keep the fresh water in the system as long as possible. Some irrigation is taking place here along the canals. A bit more North, to the West of Yangon around Maubin and a large part of Twante the area is less affected by salinity in the dry season. However, still 20%-40% of the agricultural land in those areas is identified as using rainfed agriculture. A large part of the land is according to Myanmar experts used for aquaculture because of the presence of Nitosol rather than the Gleysols that occur in much of the surrounding regions, allegedly making the area more suitable for aquaculture.

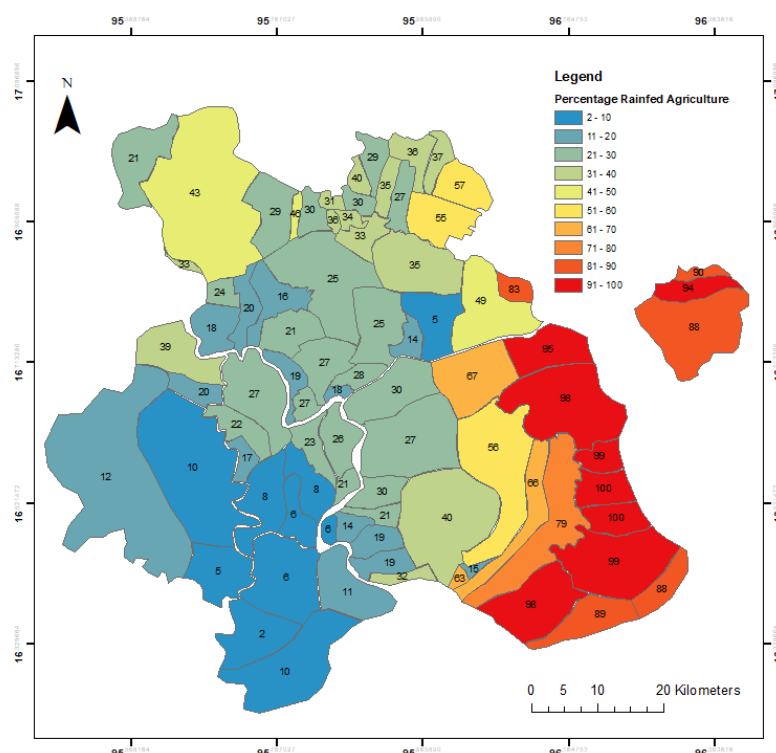


Figure b: Zones indicating the percentage of rainfed-only agriculture per controlled area

The map shows the surface area percentage of agricultural land that is only growing crops through the use of rainfed agriculture. Irrigated agriculture, Irrigated + rainfed agriculture, aquaculture and forest make up the rest of the land.

Based on assessing above maps, a total of 7 areas were selected for further analysis. See chapter 4.6.2 of the RWSS Report for the conclusions of these analysis. The steps in the analysis are elaborated below.

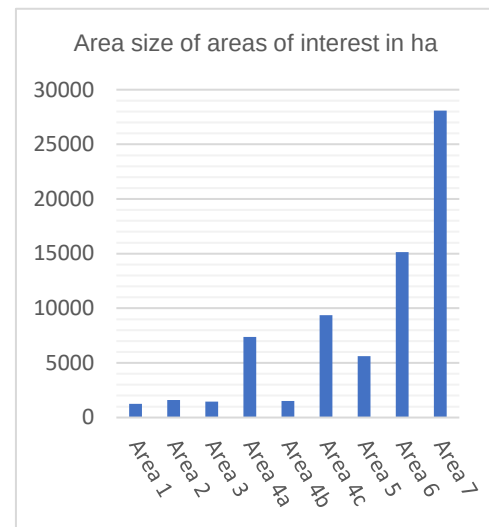
Area size

The areas discussed in chapter 4.6.2 were studied to identify their size in order to make estimations about water use and income increase in the case that these areas are developed with irrigation agriculture.

Due to the nature of the land use image used in this assessment multiple small and scattered areas indicated as using only rainfed agriculture can be identified. Creating designated investment plans or infrastructure for these small plots of land is not considered viable within the scope of this project. Therefore rainfed areas with an area larger than 10 ha were filtered out of the land use map in order to discount the 'too small' areas in the surface area calculations. These larger areas were combined for each of the 7 identified locations to give an indication of the total areas of rainfed agriculture with sufficient surface area to justify possible investments. The table below shows the surface areas as depicted in the related image underneath it.

Table a: Area Size of the different identified areas

Area no.	Area location	Area size (m2)	Area size (ha)
Area 1	South of Nyaungdon	12.571.604	1257
Area 2	East of Maubin	15.893.097	1589
Area 3	Southeast of Maubin	14.437.042	1444
Area 4a	Pan Hlaing Island and Nyaungdon Island	73.784.892	7378
Area 4b		15.267.877	1527
Area 4c		93.741.490	9374
Area 5	East of Twante river	56.092.230	5609
Area 6	East of Thanlyn	151.436.274	15144
Area 7	Yangon South (West)	280.897.019	28090



Area 4 was split into A, B and C to better align with the RWSS Unit borders.

The figure below shows the detailed locations of the areas in different colors.

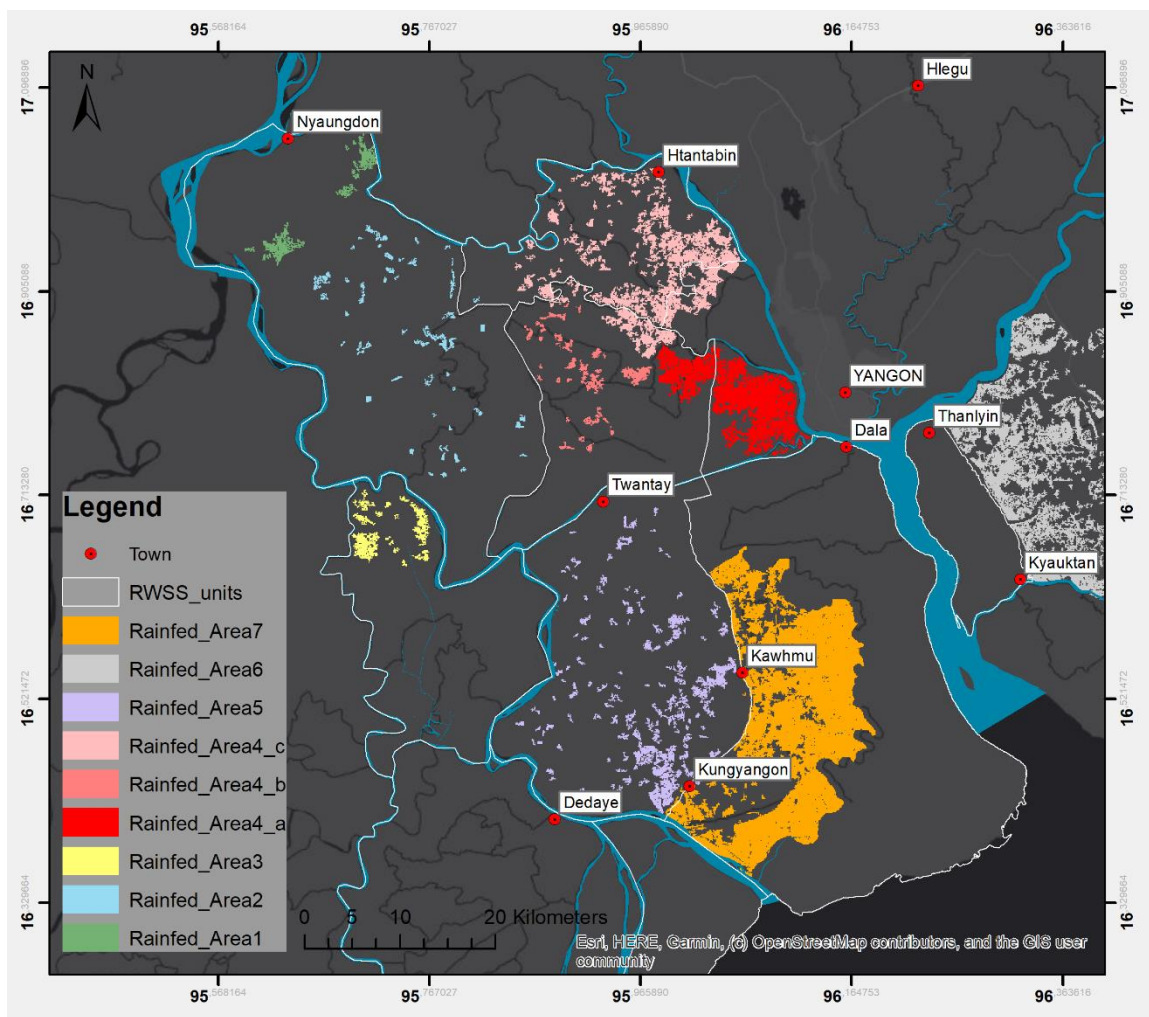


Figure c: Detailed map on areas included in the analysis.

Water demands for irrigation

Knowing the respective water requirements for the relevant areas is needed in order to determine what measures might be required to develop the areas into irrigated agriculture. The water required to irrigate the different areas can be calculated from the crop water requirements of the crops that are most common in the area. Looking at rice varieties 4 types are often used. 2 monsoon paddies with respectively a 150 and 130 day crop cycle. These are grown during the monsoon season and are rainfed. 2 summer paddies with respectively 130 and 90 day crop cycles. These last two are grown using irrigation and can be used to estimate the additional water use in case the areas are developed. The table below gives more information about these rice varieties.

Table b: Crop Water Requirement (CWR) in the area of Nyaungdon and Htantabin

Season	Crop cycle (days)	Name of rice	CWR /month (only dry season)	Irrigation Efficiency	Yield basket /acre	Yield Kg/ha	Price USD 1 kg	Price (USD) per ha
Monsoon Paddy	150	Paw San Hmwe			50	2577.25	0.33	838
Summer Paddy	130	Sin Thu Kha	70-150 mm	45%	95	4896.78	0.19	922
Summer Paddy	90	A Nyar Thar	70-150 mm	45%	90	4639.06	0.17	795
Monsoon Paddy	135	Sin Thu Kha			70	3608.15	0.19	680

Source: Data from NEPS

1 basket of paddy = 20.86 Kg

Other relevant crops for the region:

- Chickpea CWR- 450mm for total cropping period (cropped in January, Feb and March)
- Greengram (type of pulses) CWR- 595mm for total cropping period

The irrigation requirements were also derived from the RHDHV report, Regional Water Security Study - 1D Hydrodynamic Model South East Ayeyarwady delta, 2019. From these the water requirements in m3/day can be calculated for each defined area. The table below shows the average crop water requirements that were measured for the region. The irrigation period naturally spans the dry season when irrigation is required. However the amount of irrigation required changes related to the climate and crop stages. The table divides each month into three decades (period of 10 days) to distinguish the different crop water requirements over time.

Table c: Average Crop Water Requirements per decade

Month	Decade	Gross irr req.	
		l/s/ha	m3/day/ha
Nov	3	0,22	19,008
Dec	1	0,58	50,112
Dec	2	0,93	80,352
Dec	3	1,3	112,32
Jan	1	1,47	127,008
Jan	2	1,5	129,6
Jan	3	1,54	133,056
Feb	1	1,57	135,648
Feb	2	1,28	110,592
Feb	3	0,89	76,896
Mar	1	0,5	43,2
Mar	2	0,1	8,64

From these figures the water requirements in m3/day can be calculated for each defined area. The results in the table below show the gross irrigation requirements for each area of interest over the duration of the irrigation season per period of 10 days (decade). It gives an indication about the amount of water that will be required to irrigate the respective areas.

Table d: Irrigation volumes required per day for each defined area

Month	Decade	Areas (m3/day)						
		1	2	4a	4b	4c	5	7
Nov	3	23893,1	30203,7	140241	29025,2	178181	106616	533935
Dec	1	62990,8	79628	369726	76521	469750	281078	1407646
Dec	2	101002	127679	592837	122698	753220	450694	2257088
Dec	3	141186	178476	828697	171513	1052888	630003	3155069
Jan	1	159649	201816	937065	193941	1190573	712388	3567655
Jan	2	162907	205934	956189	197899	1214870	726926	3640464
Jan	3	167251	211426	981687	203177	1247267	746311	3737543
Feb	1	170510	215545	1000811	207134	1271564	760850	3810352
Feb	2	139014	175731	815948	168874	1036689	620311	3106529
Feb	3	96658,3	122188	567339	117420	720823	431310	2160009
Mar	1	54302,4	68644,8	318730	65966,4	404957	242309	1213488
Mar	2	10860,5	13729	63745,9	13193,3	80991,4	48461,8	242698

Table e: This amounts to the following total gross irrigation requirements per year:

Areas (m3/year)*1000						
1	2	4a	4b	4c	5	7
12902	16310	75730	15674	96218	57573	288325

Based on the demands a further analysis could be executed to estimate the scale of the measures that would be required in terms of water storage requirements, pumping and/or lowering of irrigation sluices and drainage.

The main obstacles are analyzed and suggestions are given about how to overcome them for the five remaining areas of interest.

Area 1 - Elevation

- This area has a fairly small surface area but is mainly condensed in two areas. The areas are located on elevated ground between 2m and 3m above MSL. Through pumping and improved drainage these areas should be able to be developed into rainfed agriculture. – The area is considered to have high potential.

Area 2 - Elevation

- One of the smaller sized areas and the individual identified plots are small and spread out far and wide in between the aquaculture fields. These plots are located 2m and 3m above MSL according to local experts an seem to be practicing rainfed agriculture as smaller pumps cannot reach the canals. Upgrading and expanding the drainage and supply canals with increased pumping facilities would make development to irrigated agriculture or aquaculture possible – However, due to the small size and haphazard distribution of the plots this area is of Medium interest.

Area 4 - Planned Development

- Area four is of specific interest as it is located on both Pan Hlaing Island and Nyaungdon Island. Some of area 4 is planned for New Yangon City (NYC) with modernized irrigation agriculture to the North West adjecting to the new city. Most of the currently available water is saline or polluted from industrial wastewater. However, the development of Pan Hlaing sluice and a water treatment facility will result in more fresh water availability for NYC, the industrial zone and irrigation development. The area is divided in 3 parts (A, B & C) to better align with the RWSS Unit borders.

- Area A is for about 2/3 planned to develop into New Yangon City the remaining agricultural areas to the north west will be able to upgrade to irrigation agriculture – It is of medium interest as the remaining agricultural areas are fairly small.
- Areas B and C will be able to receive more fresh water after the planned developments around Pan Hlaing river are finished. This will allow the areas to upgrade the agriculture to irrigated agriculture. Additional measures apart from Pan Hlaing sluice which increases storage include pumping, lowering of irrigation sluices and potentially expanding the supply and drainage infrastructure.

Area 5 - Elevation & Soil type

- This area has a higher elevation (3 to 4 meter above MSL) than the surrounding areas and the soil may be unsuitable for agriculture due to the poor soil type (Lateritic soil). In addition, the plots that are currently practicing only rainfed agriculture are spread out and potentially hard to reach with canals or pumping due to the topography. To develop irrigation agriculture in this area field observation about the viability of pumping and improved infrastructure would be needed in the area as well as a more in depth study of the potential in terms of crop types that can grow on lateritic soils. – Due to these limitation this area is of medium interest.

Area 7 - Water Supply

- Area 7 consists of large swaths of land which are currently rainfed agriculture and could be developed to irrigated agricultural lands. The main limiting factor is freshwater availability in the area. The area is serviced by multiple sluice gates located around the south of Toe River. Due to salinity intrusion these sluices are closed to stop saline water from flowing into the area around the middle of the dry season. Irrigation therefore only happens along the canals. In the remainder of the area, only one crop of monsoon paddy is grown. Increased water storage and/or increased fresh water supply in the dry season would allow for the development of irrigation agriculture for many of those areas – Due to the large size of the area with development potential this area is considered of high interest.

Agricultural Development Plans

- For the agricultural lands of Area 3 aquaculture developments are planned. Additional assessments for irrigation developments in the area are therefore not required.
- KOICA is working on the agricultural masterplan for the Ayeyarwady Delta, details of this masterplan are still unavailable.
- The general 20-year development plan for the Myanmar agricultural sector (2011-2012 to 2030-2031) mentions the enhancement of agriculture productivity and technology of extension of the services. For example the reformation from conventional farming to mechanized farming and, relevant for this project, the promotion of irrigated farming systems by reforming rainfed conventional farming to irrigated farming.

Bankability

In order to further assess the development viability of the selected areas to irrigation agriculture and the potential benefits related to the development the monetary benefits are estimated. The prices given in the table below are derived from the prices indicated by NEPS.

Table f: Yield for monsoon and summer paddy rice varieties

Season	Duration (days)	Name of rice	Yield basket/ ha	Price basket (USD)	Price/ha (USD)
Monsoon Paddy	150	Paw San Hmwe	123,55	7.12	879
Summer Paddy	130	Sin Thu Kha	234,75	4.12	969

Considering the total areas of rainfed crops and the current estimated income from 1 ha of rainfed monsoon paddy the income for the 150 day variety is about USD 879/ha. Introducing irrigation to those areas would also allow for the growing of an irrigated rice crop with the estimated income for 1 ha of summer paddy equal to about USD 969, more than doubling the farmers' income.

Table g: Total earnings for each area depending on rice variety.

Season	Total income Areas USD						
	1	2	4a	4b	4c	5	7
Monsoon Paddy	1107141	1399561	6498402	1344953	8256442	4940301	24741140
Summer Paddy	1217856	1539517	7148243	1479448	9082086	5434331	27215254

The table above shows the earnings for each area if irrigation were to be developed. The Monsoon paddy is also what they currently earn, the summer paddy would be added due to the irrigation. In other words the income from the summer paddy is the potential increased earnings for the selected areas.

Summary table

The combination of above information result in the following table showing the total area of each identified area that was deemed of interest during the analysis in combination with the total irrigation requirements and the total potential increase in earnings in those areas if they are upgraded to irrigation agriculture and grow Sin Thu Kha during the dry season, a 130 day summer paddy variety.

Table h: Summary table indicating for each identified area the area size irrigation requirements and income increase.

Area location		Area size (m2)	Total irr. Req. (m3)	Total Income increase /year USD
South of Nyaungdon		12.571.604	12.902.250	1,217,855
East of Maubin		15.893.097	16.310.004	1,539,517
Pan Hlaing Island and Nyaungdon Island	A	73.784.892	7148243,2	6,382,360
	B	15.267.877	1479448,32	1,320,936
	C	93.741.490	9082085,6	8,109,005
East of Twante river		56.092.230	57.572.571	5,434,330
Yangon South (West)		280.897.019	288.324.749	27,215,254

Furthermore, a more in depth analysis took place towards potential measures to optimize agriculture by looking at RWSS Unit 8. Mainly Yangon South (West), rainfed-area 7, is located in Unit 8.

RWSS Unit 8 - Baseline situation

Unit 8 consists primarily of agricultural land even though it suffers in most of the area from a lack of fresh water in the dry season. Many drainage canals on the south and southeast, flowing into the Yangon river and the ocean, have no control structures able to block out the salt water from flowing into the channels in the dry season. As a result most of the agricultural area in Unit 8 is limited to rainfed irrigation only, especially in the southeast. Moving more to the north and to the west the drainage canals are controlled through sluice gates. These are being closed at the beginning of the dry season in order to store fresh water in the canals to be used for irrigation. This is currently enough to irrigate around 7660 ha of land. This equals to around only 7% of the total agricultural area in Unit 8.

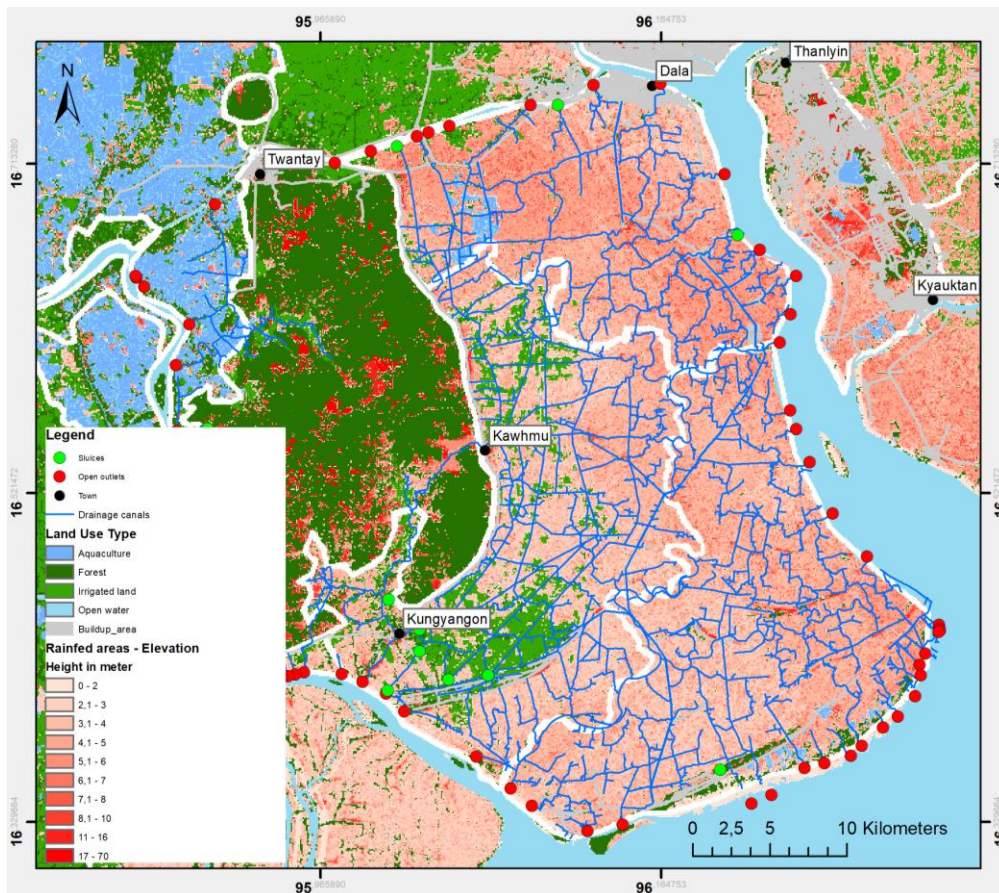


Figure d: Map indicating land use, rainfed areas and elevation in Unit 8

An analysis has been performed to confirm that the shortage of fresh water is indeed the cause for the lack of irrigation in the area instead of other possible limiting factors. The available water was estimated to be around 90 million m³ which equals the total storage capacity of the drainage channels in unit 8. Evaporation rates and gross irrigation requirements were adapted from the RHDHV report “Regional Water Security Study - 1D Hydrodynamic Model South East Ayeyarwady delta, 2019”. The resulting change in water availability versus the total water used is depicted in the chart below.

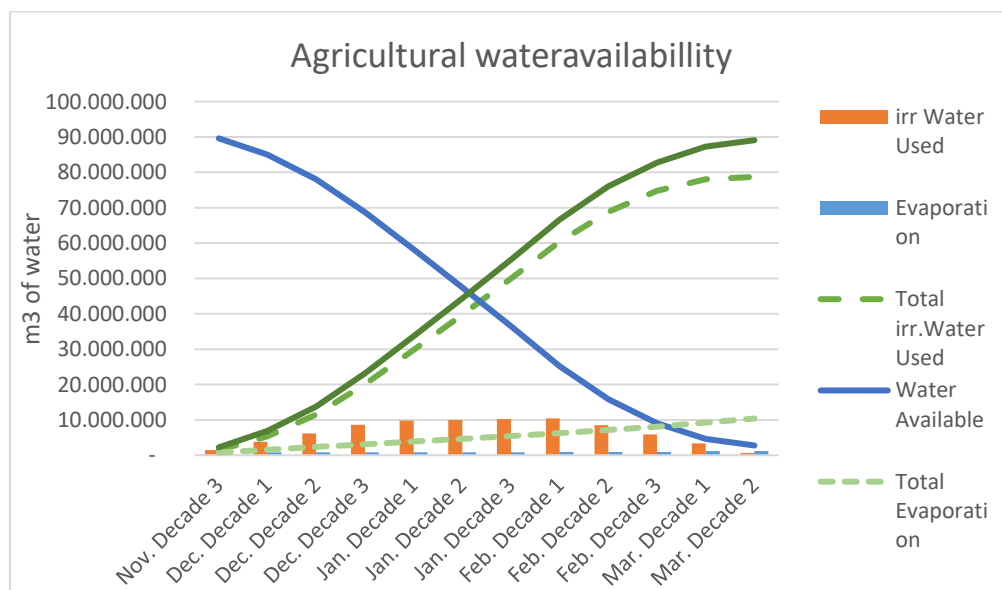


Figure e: Change in water availability versus the total water used

This supports the idea that the current amount of irrigation agriculture in Unit 8 is limited by the available fresh water.

RWSS Unit 8 - objectives

Transforming the agricultural land from rainfed-only to irrigated agriculture would support the growing of a second or even a third crop. Taking into account the difference in price for monsoon paddy rice versus irrigated dry season paddy rice the income of farmers would more than double. Going from around 879 to 1840 USD per hectare according to Myanmar experts.

Looking at Unit 8 and considering that currently the south and southeast side has no flow regulating structures at the outlets of the channels, the northern and western side of the unit can be considered as most suitable for further irrigation development. The east and south side on the other hand have very large potential due to the large area that could be converted to irrigation agriculture, but would also require very sizable investments to make it possible due to the lack of any outlet sluices.

In order to develop parts of this area more fresh water needs to be made available. This can be done in three ways, or a combination of these.

- 1) Increasing storage capacity:
 - a. by increasing the drain size
 - b. by extending the current drainage network
 - c. by implementing control structures along the drainage canals to keep water available in more upstream part of the drainage system

This would result in the ability to store more monsoon water for use in the dry season. Additionally, extending the drainage network could make water available to areas that are currently un-served.

- 2) Bringing fresh water from elsewhere
 - a. By tapping water from the Twante canal.

The Twante canal, located along the northern border of Unit 8, is undergoing measures that will make more fresh water available in the river. Part of this water can be diverted into Unit 8 and used for irrigation purposes.

- 3) Using the natural tidal changes to let in fresh water into certain channels during the low tide when fresh water is available in the channels due to the retreat of the salinity front.

It has been observed in the field that certain farmers are already implementing this on a small scale. They own their own EC meter and measure the salinity levels in the larger drainage canals. They have constructed small barriers in the drainage canals surrounding their fields and once the salinity levels are low enough, they allow fresh water to fill up their canals, after which they close them again with the small barriers.

RWSS Unit 8 - Indicative extraction volumes

In order to considering supplying fresh water from the Twante canal the following irrigation requirements need to be considered during the dry season for each day. The requirements are split per decade (period of 10 days) to account for the increase and decrease in crop water requirements according to the crop stages. This amounts to a total of 10.260 m³ of water that is needed to irrigate 1 hectare. Depending on the surface size of the irrigation canals and the distance to the fields a certain amount of evaporation needs to be accounted for and added to this total water demand.

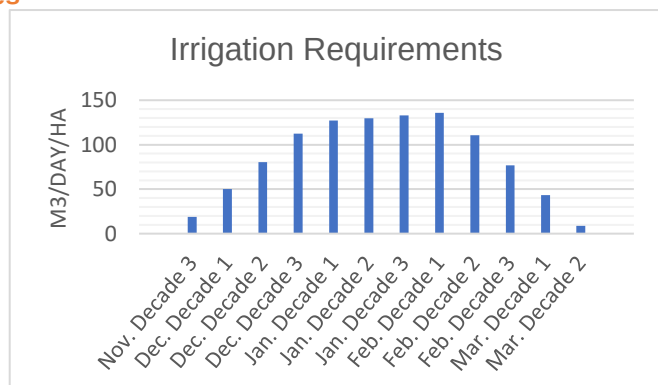


Figure f: Irrigation requirements

Taking into account the natural lay of the land, the consequential flow directions and accumulation points, the following area is suggested for irrigation development as depicted in the image below. This area is estimated to be inside several control areas that are currently regulated by sluice gates. The majority of the other areas have unregulated outlets through which salt intrusion is possible while

the control areas where irrigation expansion is suggested are currently already being closed off to store water during the dry season.

The area shown in the image for irrigation expansion in the west totals around 28.000 hectares. Resulting in the following required extraction volumes in m3 x1000.

Table i: Required extraction volumes in m3 x1000 to irrigate the western expansion area

Nov. D 3	Dec. D 1	Dec. D 2	Dec. D 3	Jan. D 1	Jan. D 2	Jan. D 3	Feb. D 1	Feb. D 2	Feb. D 3	Mar. D 1	Mar. D 2
534	1.408	2.257	3.155	3.568	3.640	3.738	3.810	3.107	2.160	1.213	243

This amounts to a total estimated extraction volume for the suggested scenario of 288.324.748 m3 for purely the gross irrigation requirements excluding the evaporation losses.

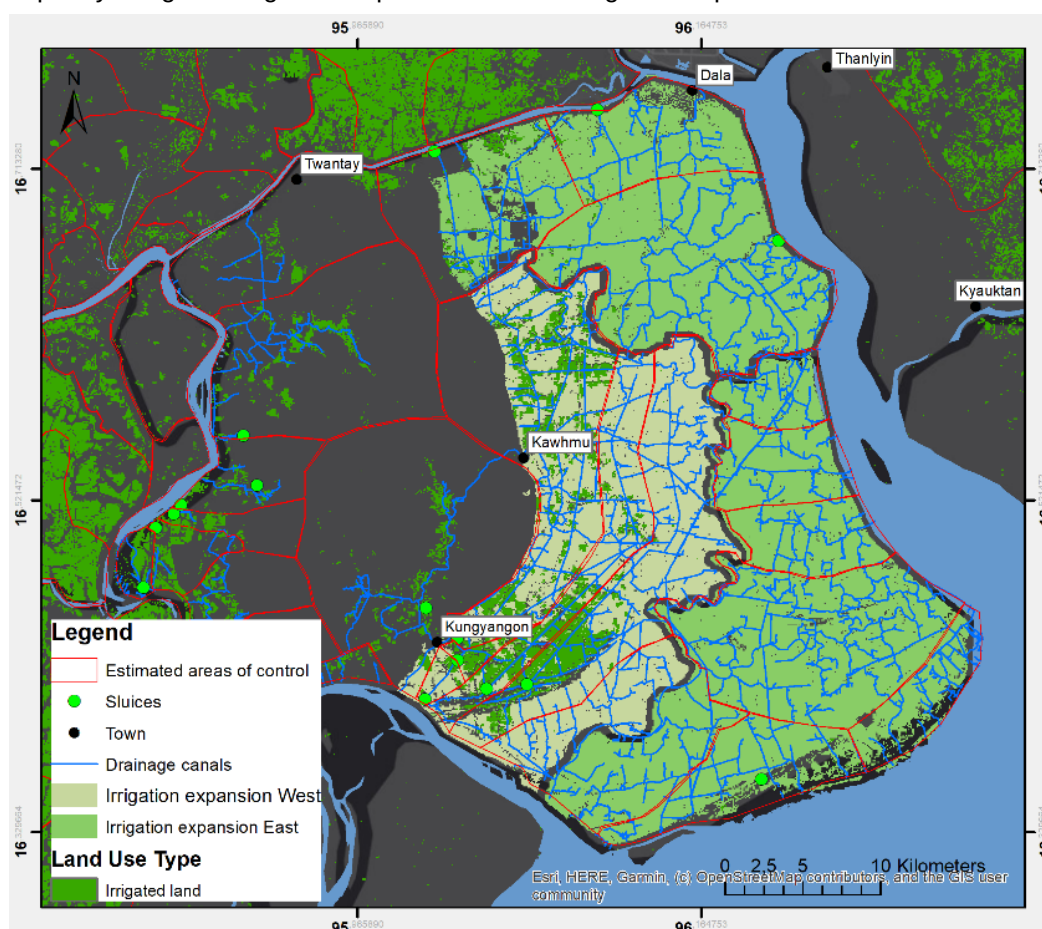


Figure g: Potential expansion areas and estimated areas of control

For the east part of Unit 8 an additional 67000ha of agricultural land van be developed from rainfed-only to irrigated. This results in the following extraction volumes for each decade needed to irrigate this area (in m3/day x1000).

Table j: Required extraction volumes in m3 x1000 to irrigate the eastern expansion area

Nov. D 3	Dec. D 1	Dec. D 2	Dec. D 3	Jan. D 1	Jan. D 2	Jan. D 3	Feb. D 1	Feb. D 2	Feb. D 3	Mar. D 1	Mar. D 2
1.274	3.358	5.384	7.525	8.510	8.683	8.915	9.088	7.410	5.152	2.894	579

In total this equals 687.709.440 m³ of water (excluding in-channel evaporation losses) to irrigate the whole eastern area of Unit 8. Besides a location of fresh water, there is also a requirement that it can be used efficiently. Currently most of the eastern and southern borders of Unit 8 have no regulative structures. This results in saltwater intrusion and makes it impossible to store any monsoon rainfall water in the area. Over 30 additional sluice gates would be required to regulate all the outlets in order to block out the salt water and store the fresh water. Furthermore, a lot of additional fresh water would have to be extracted from up north. Whether or not the Twante canal has enough capacity for this would have to be investigated.

RWSS Unit 8 - Internal control structures

Certain areas that are currently suffering from salt intrusion in the drainage canals can be instructed to the functioning of tidal effects and EC meters. With incentives to build their own small regulative structures schemes could be developed to store the available fresh water on a small scale throughout the drainage canals. Due to the smaller scale of these types of interventions it is suggested that further analysis is needed for a more in-depth plan.

Suggested next steps

- An detailed assessment of the available fresh water in the Twante canal available for irrigation is needed in order to be able to estimate the actual size of the irrigation expansion and whether or not the suggested area is feasible, to large, or can be expanded further.
- The area just south of Twante canal knows some irrigation and aquaculture but is also mainly rainfed. This agricultural area could also be further developed into irrigation.
- More in-depth analysis of the lower limits of the salt front in order to develop small scale community based fresh water management during low tide events.

Insights from Myanmar experts on Unit 8 drainage and irrigation

Myanmar input was collected through NEPS in order to field-test certain results and assumptions. The SOBEK model indicates that flooding occurs in Unit 8 in the west as roughly shown by the red circle in the image below. This was confirmed stating that shallow to medium flooding occurs in those areas during the monsoon season. It is indicated that the main reason for this is that the number of gates in the outlet sluice is not big enough to drain the excess amount of water.

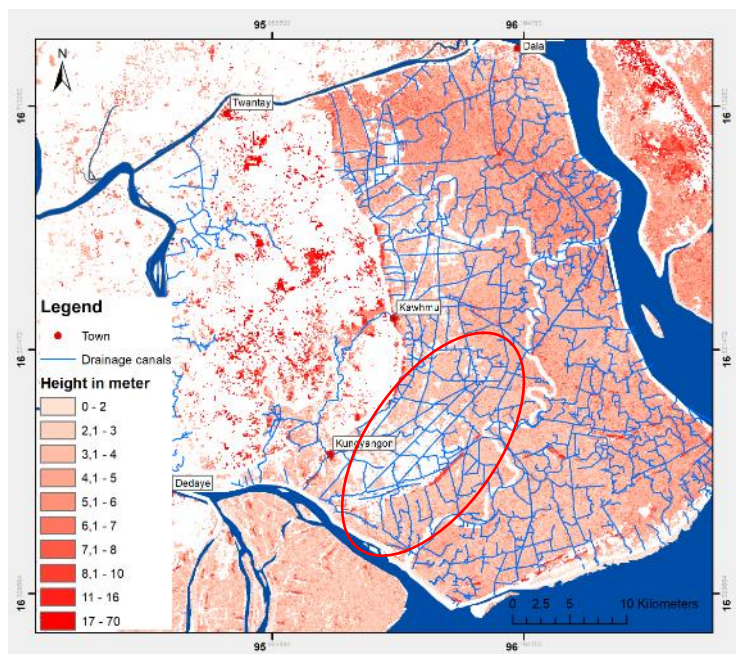


Figure h: Indicating flooding area in red circle based on Myanmar expert insights

In order to understand where the flood water is coming from and which areas drain in what direction the following schematic was drawn.

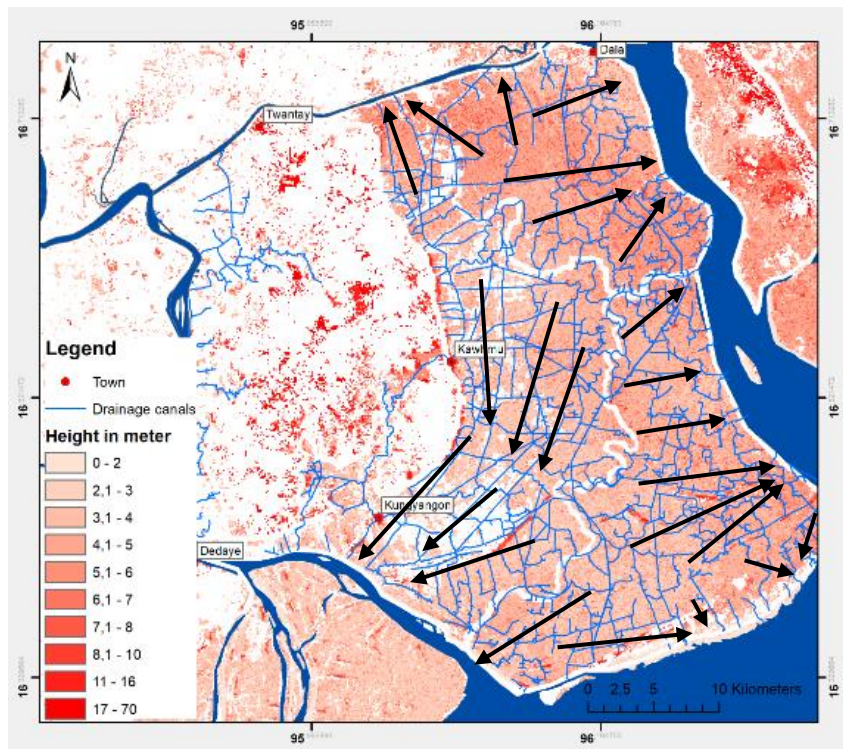


Figure i: Flow directions in the drainage system

This schematic of flow directions in the drainage system is in line with the estimations in both models used in this research. Additional to flow directions the size of the drains was estimated at an average size of around 50 meters in width and 2.5 meters deep. Concluding, the dimensions are slightly different from the estimations of the drainage channels in the models, however this is alleviated as the resulting capacity of the estimations is similar.

Myanmar experts confirm that the south and southeast side of Unit 8 has no irrigation due to a shortage in fresh water while the western side does have some irrigation as they are able to store monsoon water for during the dry season there. The shortage in the east is caused by salt intrusion, as there are no regulative structures in those locations, and possibly because a large part of the water drains to the west.

When asked if storage would be possible in the east the local experts mentioned that it could be possible if the salt water intrusion could be controlled in those areas. It is however suggested that it would be easier to upgrade the agriculture in the West using water from Twante Canal for example, proper flood management and tidal irrigation.

COLOPHON

REGIONAL WATER SECURITY STUDY (RWSS) GREATER YANGON REGION - FINAL REPORT

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