Climate change vulnerability and adaptation study for the port of Port-Louis in Mauritius

CTCN Technical Assistance Project – Ref Nb 2016000013

D3 – ADAPTATION ACTIONS REPORT

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ACRONYMS

MPA	Mauritius Ports Authority
ICZM	Integrated coastal zone management
CCD	Climate Change Division
MMS	Mauritius Meteorological Services
MOI	Mauritius Oceanography Institute
CC	Climate change
JICA	Japan International Cooperation Agency
UNDP	United Nations Development Programme
UNFCC	United Nations Framework Convention on Climate Change
GEF	Global Environment Facility
MCT	Mauritius Container Terminal
GIS	Geographic Information System
MoESDDBM	Ministry of Environment, Sustainable Development, and Disaster and Beach Management
TEU	Twenty-foot equivalent unit
CD	Chart Datum
UNCTAD	United Nations Conference on Trade and Development
IFC	International Finance Corporation
MEXA	Mauritius Export Association
NOAA	National Oceanic and Atmospheric Administration
IOWAGA	Integrated Ocean Waves for Geophysical and Other Application

1. INTRODUCTION

Mauritius, as a small island developing state, is highly vulnerable to the adverse impacts of climate change. Port Louis harbor is exposed to a number of combined risks from sea level rise including storm surge, flooding and more powerful and frequent winds, thereby challenging the resilience of the port infrastructure whilst at the same time disrupting the supply chain.

The objective of the study is to conduct a climate change vulnerability and adaptation study for the port of Port Louis and assist with the identification of adaptation options and their monitoring.

The scope and nature of the technical assistance include:

- Review existing national plans and strategies related to the port sector in the context of climate change, to identify opportunities and options to address gaps and needs ;
- Undertake a climate risk assessment for the port of Port Louis, to identify current vulnerabilities and future risks, evaluate the risks, identify and prioritize adaptation options using a multi-criteria analysis and set a monitoring baseline ;
- Formulate an action plan for the implementation of adaptation options in relation to climate change for the port sector, with specific action targets and time frames ;
- Identify capacity building needs of engineers, marine personnel and other cadres of the port sector, on climate change, vulnerability assessment monitoring and evaluation and adaptation technologies.

This report, as Deliverable 3, is the adaptation actions report, presenting adaptation measures, selecting preferential measures through a multi-criteria analysis and carrying out the prefeasibility study of selected adaptation measures.

2. RECOMMENDATION OF ADAPTATION TECHNOLOGIES

2.1. ADAPTATION MEASURES

2.1.1. Methodology

The table below identifies adaptation measures each addressing one or several of the climate hazards identified. Particular attention has been paid to properly cover the full adaptation cycle of prevision, prevention, protection and mitigation actions. Typically, the early phases of this cycle (prevision, prevention) are of a proactive nature and associated with lower cost than the latter phases, of a more reactive nature (protection, mitigation).

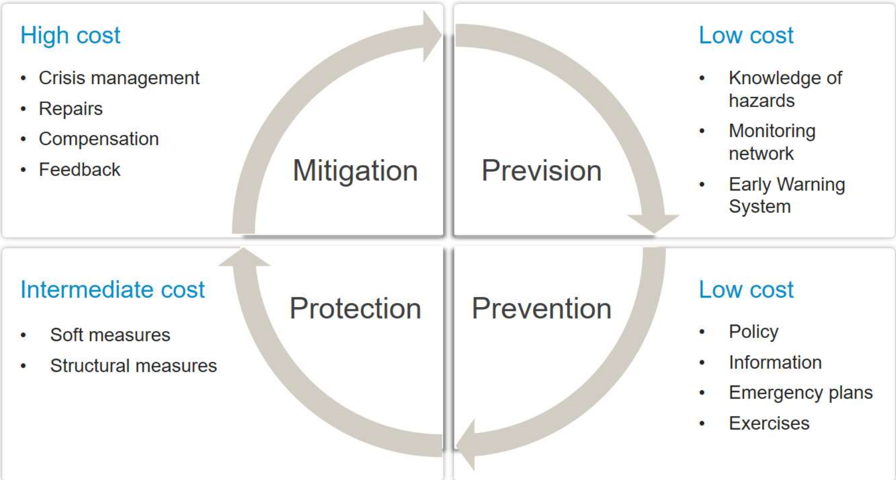


Figure 1 : Typical adaptation cycle

Measures have been further grouped into subsets corresponding to a particular adaptation objective. For each measure, the table shows whether it is already applied in Port Louis and characterizes the main nature of its benefits (EBRD, 2013):

- No regret measures: actions with benefits that outweigh their costs, whatever he extent of future climate change;
- Low regret measures: low cost measures with potentially large benefits under climate change;
- One-off measures: involve investing in one up-front adaptation measure which provides resilience against climate change throughout a certain period of time;
- Adaptive management: is an approach whereby adaptation actions are applied incrementally in response to changing conditions or new knowledge, allowing the most appropriate decisions to be made at each point in time, based on the latest evidence;
- 'Win-win' measures: contribute to climate adaptation while also delivering other benefits;
- Avoid 'maladaptive' actions: those which will make it more difficult to cope with future climate change risks.

Each adaptation measure has subsequently been qualitatively evaluated according to the criteria set out by Scott et al. (2013). As developed by Scott et al. (2013), resource constraints and conflicts between different options mean that adaptation options also need to be assessed and prioritised against numerous case specific financial and non-financial criteria. Typical assessment criteria may include:

- Effectiveness – will the adaptation option achieve the stated objective?

- Efficiency – will the benefits of the option be greater than the costs?
- Equitable – the adaptation option should not adversely affect other areas or people (i.e. gender issue)
- Priority – how high a risk is the adaptation option addressing? High or extreme risks should be addressed urgently.
- Costs – this not only refers to the immediate economic costs of the option, but also likely ongoing costs, as well as associated social and environmental costs.
- Co-benefits – adaptation options may be able to take advantage of opportunities, which lead to environmental, social or economic benefits.
- Maladaptation – does the option lock in outcomes, and limit future adaptation options, or adversely impact on other areas or people?

The scoring and weights have been validated during a multi-criteria analysis workshop with the main stakeholders. The notation method and weights used are presented below.

Table 1 - Criteria notation and weight

	Impact notation					Weight
Criteria	**0**	**1**	**2**	**3**	**4**	**Weight**
Effectiveness	Isn't effective	Nul	Slightly contributes	Moderately contributes	Highly contributes	4
Efficiency	ROI < 0	ROI = 0	ROI > 0	ROI > 50%	ROI > 2 or additional knowledge	5
Equitable	Not equitable	Nul	-	Slightly equitable	Very Equitable	1
Priority	Not applicable	Helps in a slight way	Long term issue	-	Immediate issue	5
Cost	10,000 k$	5,000 k$	1,000 k$	500 k$	100 k$ per year or less	2
Co-Benefit	Detrimental	Nul	Slightly contributes	Moderately contributes	Highly contributes	1
Maladaptation	-	-	Minor	Unimportant	No maladaptation	4

2.1.2. MCA results

The resulting list of potential adaptation measures is presented below, together with their evaluation based on the multi-criteria analysis. Adaptation measures are described in more details in the next section.

Each impact is scored based on the following calculation:

Impact notation ✖ Weight = **TOTAL SCORE**

The table below shows the scoring result for each impact.

Table 2- Ranking adaptation measures according to the MCA results

Nb	Cycle phase	Adaptation measure	Type	Already in use	Fact sheet	Multicriteria analysis: Effectiveness	Efficiency	Equitable (E&S and gender)	Priority	Costs	Co-benefits	Maladaptation	Total score	RANK
Monitor hazards														
1	Prevision	Monitor climatic and environmental parameters	No regret			4	4	3	4	4	2	4	85	2
2	Prevision	Real time monitoring of waves and tides, Early Warning System	No regret			3	4	3	2	4	2	4	71	20
3	Prevision	Measure and account the carbon footprint of port activities (IAPH Guidance for Carbon Footprinting for Ports)	Win-win	X	yes	3	4	4	2	4	3	4	73	14
Quantify climate impacts														
4	Prevision	Identify the exact cause of overtopping during South-West swell events and its recent increase (capital dredging works, strong local wind waves etc)	Low regret			3	4	3	4	4	2	4	81	8
5	Prevision	Develop a flood risk management plan for Port Louis	Low regret			0	0	2	1	4	2	4	33	42
6	Prevision	Refine knowledge of climate risks	Low regret	X		3	4	3	2	4	4	4	73	14
7	Prevision	Monitor impacts of climate change on supply and demand for traded products	No regret			0	0	**3**	1	4	4	**4**	**36**	36
Plan with climate change in mind														
8	Prevision	Appoint an expert in charge of the overall coordination of climate adaptation (for instance the HSE expert)	No regret			4	4	2	4	4	2	4	84	4
9	Prevision	Allow for increased downtime in financial predictions	No regret			1	0	1	1	4	1	4	35	39
10	Prevision	Climate adaptation funded as a specific item in the budget	Low regret			1	0	1	1	4	1	4	35	39
Adapt operations to climate hazards														
11	Prevention	Include climate adaptation in key policy and operational documents of the port, for instance through the IFC standard Environmental and Social Monitoring System (general policy, environmental monitoring plan, emergency response procedures, port asset management plan, construction standards, inspection forms etc)	No regret			4	4	2	4	4	2	4	84	4
12	Prevention	Include the pandemic risk in emergency management plans	No regret			1	0	3	1	4	4	4	40	34
13	Prevention	Periodically review and update the climate component of key policy and operational documents of the port (continuous improvement process)	Low regret			4	4	2	4	4	2	4	84	4
14	Prevention	Increase inspection, repair and maintenance frequency	Adaptive			1	1	2	1	3	3	4	41	32
15	Prevention	Adapt operational procedures (minimize disruption of supply chain, maximize operational wind and wave thresholds etc)	Adaptive		yes	3	4	2	4	4	3	4	81	8
16	Prevention	Adapt storage procedures (height of exposed container and bulk stacks, above ground storage etc)	Adaptive			2	1	1	4	3	2	4	58	26
Capitalize on opportunities linked to climate adaptation														
17	Prevention	Promote the use of renewable energies within the port (water, solar, wind)	Win-win	X		4	4	3	2	3	3	4	74	13
18	Prevention	Promote the use of electric equipment (e-RTG, hybrid straddle carriers etc)	Win-win	X	yes	4	4	3	2	2	3	4	72	18
19	Prevention	Promote the use of clean fuels (LNG powered ships, low sulphur)	Win-win			3	4	3	2	4	3	4	72	18
20	Prevention	Promote the use of IAPH sustainabiliy standards (IAPH Lease Agreement Template, ESI clean ship incentive scheme, Toolbox for Port Clean Air Program etc)	Win-win		yes	4	4	3	2	4	4	4	77	11
42	Prevention	Install storm water collection tanks as renewable water source	Win-win			1	4	3	2	3	2	4	61	24
21	Prevention	Diversify trade into climate-resilient commodities	Adaptive		yes	2	3	4	1	4	4	4	60	25
Strengthen climate preparedness														
22	Prevention	Implement a climate adaptation capacity building program	No regret		yes	4	4	3	4	4	3	4	86	1
23	Prevention	Conduct regular emergency drills for climate events to minimize disruption	Low regret			3	4	3	4	4	2	4	81	8
24	Prevention	Strengthen functional requirements of future infrastructure	Adaptive			4	3	3	4	1	1	4	73	14

						Multicriteria analysis								
Nb	Cycle phase	Adaptation measure	Type	Already in use	Fact sheet	Effectiveness	Efficiency	Equitable (E&S and gender)	Priority	Costs	Co-benefits	Maladaptation	Total score	RANK
Hard protection measures														
25	Protection	Build a breakwater to reduce wave action at the MCT and oil jetties	One-off		yes	4	3	2	4	0	2	3	67	22
26	Protection	Build coastal defenses such dikes or sea walls (potentially of retractable or temporary nature)	One-off		yes	4	2	3	0	0	2	3	43	31
27	Protection	Raise the working platform, critical transport links and equipment (or any combination thereof)	One-off			4	0	3	0	0	1	4	36	36
28	Protection	Consider floating developments for future infratructure	Adaptive	X	yes	4	1	3	0	0	1	4	41	32
29	Protection	Build storm water retention basins against flash floods	One-off			1	4	3	0	1	3	4	48	28
30	Protection	Increase capacity of drainage system against flash floods and excessive rain	One-off			3	2	3	0	1	3	4	46	30
31	Mitigation	Install green roofs	Win-win			3	4	2	2	2	2	4	66	23
Soft protection measures														
32	Protection	Dry-proof construction of critical infrastructure	Adaptive	X	yes	4	3	3	4	2	1	4	75	12
33	Protection	Wet-proof construction of non-critical infrastructure	Adaptive	X	yes	3	3	3	4	2	1	4	71	20
34	Protection	Relocate critical infrastructure	One-off			4	0	2	0	1	0	4	36	36
Increase equipment efficiency and operability														
35	Protection	Automate logistics procedures	One-off		yes	4	3	2	4	1	2	4	73	14
36	Protection	Install active motion damping systems for moored ships	One-off		yes	4	2	2	0	1	1	4	47	29
37	Protection	Install cranes that can safely operate under strong winds	One-off		yes	4	1	2	0	0	1	4	40	34
38	Protection	Install high efficiency refrigerated storage	One-off			3	4	3	0	2	1	4	56	27
39	Protection	Install waterproof electrical infratructure	One-off			2	1	2	0	1	1	4	34	41
Mitigate future impacts														
40	Mitigation	Keep track of all climate-related incidents and events affecting the port, and lessons learnt	No regret			4	4	3	4	4	2	4	85	2
41	Mitigation	Manage the costs of climate change risks through insurance contracts (a proactive climate change adaptation policy may decrease insurance costs)	Low regret		yes	4	4	2	4	4	1	4	83	7

While the weighting and associated ranking are to some extent subjective, some trends can be observed. Adaptation measures which are less costly, easy to implement (soft rather than hard measures) and/or corresponding to early phases of the adaptation cycle (prevision, prevention), tend to rank higher than hard measures. Among hard protection measures, a breakwater ranks the highest.

2.2. ADAPTATION MEASURE DESCRIPTION

2.2.1. General description

The table below presents a short description of each adaptation measure.

Table 3 - Short description of each adaptation measure

Nb	Cycle phase	Adaptation measure	Short description
Monitor hazards			
1	Prevision	Monitor climatic and environmental parameters	Monitoring enables to set up a historical database and use that data for statistics, trends, thresholds and variations. The most relevant parameters to monitor for the port are : the wind climate (permanent wind sensor), the wave climate (permanent wave buoy), water levels (permanent tide gauge), the topography (high resolution drone survey), the bathymetry (regular monitoring where erosion-sedimentation occurs), water parameters (conductivity, temperature and pressure; permanent CTD sensor on the wave buoy), atmospheric parameters (permanent sensor for temperature, pressure, CO2 and other GHG; record of all cyclonic data), rainfall (permanent station). A more detailed list of environmental parameters has been defined by the Climate Technology Center Network (CTCN - UN Environement program).
2	Prevision	Real time monitoring of waves and tides, Early Warning System	Real time monitoring coupled with data analysis trends and statistics enables port users to set up an early Warning System for any climatic effect threshold overrun. Appropriate measures and procedures can be deployed according to the risk level to be proactive rather than reactive (operation shutdown, evacuation, emergency measures...).
3	Prevision	Measure and account the carbon footprint of port activities (IAPH Guidance for Carbon Footprinting for Ports)	According to the World Port Sustainability Program (IAPH) : "Carbon footprinting is used by ports to determine emissions sources, track emission trends, and provides data that allows ports to focus efforts to reduce their greenhouse gas (GHG) emissions. A carbon footprint is the given amount of GHG emissions an individual, organisation or event directly or indirectly releases over a measured period of time". The IAPH proposes a guide for port wanting to develop the inventory of its greenhouse gaz (GHG). Additional information and methodology are available on the official website : https://sustainableworldports.org/carbon-footprinting/
Quantify climate impacts			
4	Prevision	Identify the exact cause of overtopping during South-West swell events and its recent increase (capital dredging works, strong local wind waves etc)	Overtopping is identfied as a major climate impact for the port (current cost and cost of climate change). Knowing and understanding the causes and roots of its occurrence is essential to efficiently deal with the impact.
5	Prevision	Develop a flood risk management plan for Port Louis	It is not necessary at this stage to set up a flood risk management plant for Port Louis as recent flooding (from land) didn't impact the port area of Port Louis. However It could be interesting to get information on previous flash floods and assess the risk of flash floods impacting the port in the future. The climate seems less to blame than the insufficient dimensions of the overland drainage network of canals and streams.
6	Prevision	Refine knowledge of climate risks	Understanding climate risks is a necessary foundation to adapt to climate change. Some useful publications may include: - PIACN - https://www.pianc.org/about - IPCC - Climate change report - https://www.ipcc.ch/ - NCCARF - Climate change adaptation guidelines for ports, Enhancing the resilience of seaports to a changing climate report series - https://www.nccarf.edu.au - EBRD Guidebook - Development of guidance for optimising resilience to climate change in investments in sea ports and other coastal infrastructure - www.ebrd.com
7	Prevision	Monitor impacts of climate change on supply and demand for traded products	The port organisation and revenues are highly dependent on the product typology and transportation mode (bulk, container, breakbulk). Climate change may have a medium to long term impact on traded product volumes, typology and transport mode. it can affect the port structure and organisation. By monitoring CC impacts on traded products, the port will be better prepared for operational adjustment. That being said, it may be difficult to distinguish the effect of climate change from the constantly changing competitive landscape.

Plan with climate change in mind			
8	Prevision	Appoint an expert in charge of the overall coordination of climate adaptation (for instance the HSE expert)	Initiating a "climate change" reflexion within the port organisation has to be led by a dedicated service or branch, reporting directly at the highest decision level and being intergrated into any strategic development reflexion. The Climate Change officer can be integrated into the HSE branch. Having a dedicated Climate Change officer is one of the earliest steps to integrate climate change into the development strategy of the port.
9	Prevision	Allow for increased downtime in financial predictions	The cost of climate change has been estimated in the previous report, and directly correlates with the number of days of inactivity of the port due to climate hazards. Climate hazard impacts on port performance can be monetarized to be integrated into the financial analysis. The objective is to assess the climate hazard cost (or loss) and see it as a potential item to be optimized. The efficiency of climate change investment programs can then be assessed from a financial perspective (Return On Investment).
10	Prevision	Climate adaptation funded as a specific item in the budget	Funding climate adaptation as a specific item in the budget would be a direct ackowledgement of its importance.
Adapt operations to climate hazards			
11	Prevention	Include climate adaptation in key policy and operational documents of the port, for instance through the IFC standard Environmental and Social Monitoring System (general policy, environmental monitoring plan, emergency response procedures, port asset management plan, construction standards, inspection forms etc)	Climate and climate change has to be at the core of any company values and policies. According to IFC, "An environmental and social management system (ESMS) helps companies to integrate the rules and objectives into core business operations, through a set of clearly defined, repeatable processes". This early step of considering climate, climate change, and more generally environnement, is necessary for a company willing to fight against climate change. IFC provides various tools (Implementation Handbook, Self assessment & improvement guide, toolkit) to help companies set up an efficient ESMS. *Source :* *https://www.ifc.org/wps/wcm/connect/topics_ext_content/ifc_external_corporate_site/sustainability-at-ifc/publications/publications_handbook_esms-general*
12	Prevention	Include the pandemic risk in emergency management plans	The current sanitary crisis related to the covid 19 epidemic is considered by some people as a byproduct of climate change. Its effect has been greater on the economy than many extreme climatic events. The risk of pandemic should hence also be added in the emergency plan of the port.
13	Prevention	Periodically review and update the climate component of key policy and operational documents of the port (continuous improvement process)	Continuous improvement (through PDCA - Deming wheel process) is recognized as an efficient methodology to improve processes within an organisation. Originally used for production processes, continous improvement has proven to be also efficient for environmental management and was included into the ISO1400 norm. It can easily be applied with the same efficiency for climate issues and integrated into organization processes, monitoring and reports. This measure is an early step to integrate Climate Change into port management systems and goes hand in hand with other measures of this table (appointing an expert on climate change, monitoring data, etc).
14	Prevention	Increase inspection, repair and mainten	Climate change can lead to early wear and tear on exposed equipment and infrastructures (maritime infrastructure, quay side equipment as cranes). Higher temperatures, more frequent extreme events, more saline water and a higher CO2 concentration all subtly contribute to an increased deterioration of equipment and infrastructure. R&D level studies indicate that the life expectancy of structures may decrease by more than a decade due to climate change, compared to what they would have withstood without climate change. Because the change is so slow, it may not require immediate action but should nonetheless be followed up closely with a regular return on experience.
15	Prevention	Adapt operational procedures (minimize disruption of supply chain, maximize operational wind and wave thresholds etc)	Adapting operational procedures is a response to climate hazards to maximize port productivity and performance while keeping the same level of security. It is best addressed by identifying operations which may continue despite certain climate hazards (i.e. not closing the entire port when only part of the operations is impacted).
16	Prevention	Adapt storage procedures (height of exposed container and bulk stacks, above ground storage etc)	Adapting storage procedures prevents sensitive goods to be affected by a sudden water surge into the storage area (indoor or outdoor). Adapating storage procedures can consist in elevating stored goods or protecting them against a water surge (walls or drainage system). Adapting storage procedures can also consist in relocating sensitive goods to areas not exposed to a water surge. Relocating bulk storage areas can be more problematic (volume, transportation process, H&S measures or restrictions). The regular flooding due to wave overtopping on the MCT does so far not justify to adapt storage procedures, but a more extreme event may.

Capitalize on opportunities linked to climate adaptation			
17	Prevention	Promote the use of renewable energies within the port (water, solar, wind)	Mauritius is now 79% dependent on fossil fuels for electricity generation. Renewable energy (RE) use for the port should be consistent with the national strategy "RENEWABLE ENERGY ROADMAP 2030" which sets a target of 60% of RE for 2060 (35% in 2025). Multinational organizations (IREAN, UNDP) are now providing support to reach this target. Mauritius has several opportunities for RE use. In 2020, the renewable energy mix (and share in ER mix) is composed of onshore wind (2.1%), solar (8%), biomass (11.3%), landfill gas (0.8%) and hydropower (3%) (data: Ministry of Energy and public utilities - 2019). In the port, solar panels could - among other solutions - easily be installed on administrative buildings, warehouse rooftops and undevelopped steep land.
18	Prevention	Promote the use of electric equipment (e-RTG, hybrid straddle carriers etc)	Switching to electric equipment is a "must be" for any port willing to fight climate change. Operators can access this technology either by acquiring new equipment or by retrofiting its equipment into hybrid or full electric power supply. RTG cranes highly contribute to diesel emissions in a port and can easily be switched to electric or hybrid. Hybrid RTGs can reduce CO2 emissions by 60% and NOX emissions by 90%, fuel consumption can be lowered by 60%. Recent technology even allows RTGs to use regenerative breaking energy when a container is lowered. Straddle carriers, stackers and most other handling equipment can be powered electrically. https://www.greenport.com/news101/energy-and-technology/the-benefits-of-battery-hybrid-powered-port-equipment
19	Prevention	Promote the use of clean fuels (LNG powered ships, low sulphur)	The maritime sector emits more than 940 million tons of CO2 per year and accounts for 2.5% of global greenhouse gas (GHG) emissions. Theses emissions could grow from 50% to 250% by 2050 under a "business as usual" scenario. Some options are currently available to tackle this emissions problem, such as slow steaming (decrease speed), weather routing (optimum ship routing) or counter-rotating propellers. As for the clean fuel issue, LNG is currently considered one of the greenest fossil energy, allowing a reduction of 99% of sulphur emissions, 80% of nitrogen oxides and 20% of carbon dioxide. LNG use is in line with the lastest 2020 regulations of the International Maritime Organization (IMO) stating that vessel owners should collectively not exceed 0.5% of worldwide sulphur oxide emissions (compared to 3.5% previously). Other solutions are possible to promote the use of clean fuels. Cleantech companies have recently developped a technology to recycle ship oil residues into new fuel and light bitumen (Ecoslops). Some other solutions are under development to provide efficient and low GHG emissions solutions (hybrid, wind and solar powered solutions). (*source : https://ec.europa.eu/clima/policies/transport/shipping_en)*
20	Prevention	Promote the use of IAPH sustainabiliy standards (IAPH Lease Agreement Template, ESI clean ship incentive scheme, Toolbox for Port Clean Air Program etc)	The International Association of Port Harbour (IAPH) set up in 2017 the World Port Sustainability Program (WPSP). The goals are to enhance the sustainability of the ports and encourage the participation of supply chain members. The Program is based on the 17 UN Sustainable Development Goals (https://sustainabledevelopment.un.org/) and addresses five main topics: - Climate and Energy - Community outreach and port-city dialogue - Governance and Ethics - Resilient Infrastructure - Safety and Security WPSP works as a think tank and can provide various tools and share experience on port sustainability projects.
42	Prevention	Install storm water collection tanks as renewable water source	Storm water has an impact on port productivity and cost as it can damage sensitive goods and reduce or stop port activity. In addition, storm water runoff has been recently identified as source of pollution for receiving water ecosystems. For these two reasons, a storm water collection and treatment system can be installed, improving productivity and reducing ecosystem pollution. Treated storm water can either be discharged into the ecosystem or be reused for other purposes. *https://fr.calameo.com/read/001454317491cf72c2f35*

21	Prevention	Diversify trade into climate-resilient commodities	Port Louis is organized to handle a wide mix of products and volumes that slighlty change from year to year. Climate Change may change the product mix and lead to a decrease in volume to be handled or a mismatch between demand (products) and supply (services). Supply being driven by assets (infrastructures and equipment) and knowledge (operation processes, expertise), the sustainability and competitivity of the port on the medium to long term relies on its capacity to adapt to the supply. On the other hand, the port can also prepare the future by putting incentives on trade diversification. This diversification will have to be driven by climate change effects. This reflexion will have to be taken for both import and export products and considering the port as part of an overall suppply chain.
Strengthen climate preparedness			
22	Prevention	Implement a climate adaptation capacity building program	According to the UNDP, capacity building is "the process through which individuals, organizations and societies obtain, strengthen and maintain the capabilities to set and achieve their own development objectives over time". This kind of program shall be set up as early as possible in the process of climate adaptation. The program will have to consider 1) the enabling environement 2) the organisation and 3) the individual. This long term approach, based on continual improvement, can be divided into 5 steps : - engage stakeholders ; - assess capacity assets and needs ; - formulate a capacity development program ; - implement a capacity development response ; - evaluate capacity development. *source : https://www.undp.org/content/undp/en/home/librarypage/capacity-building/capacity-development-a-undp-primer.html*
23	Prevention	Conduct regular emergency drills for climate events to minimize disruption	As for any emergency situation, an emergency drill is an efficient method to validate an emergency procedure as well as the ability of the organisation (manpower, operation, assets, QHSE) to efficently respond to it. Drills stakes are mainly : - to assess emergency processes (through measures) and their achievability, - to identifiy shortcomings and improvements - to inform, train and educate people - to adjust processes For the port, the objectives are to maintain the port operability and productivity while controlling as much as possible the risks (human, environmental, financial...) related to climate events.
24	Prevention	Strengthen functional requirements of future infrastructure	Climate factors are changing and impact infrastructure construction. Future infrastrucutre will have to be designed to cope with these changes, in terms of dimensions (higher quay level), resilience (stronger resistance to increased wave loads), and duration over time (increased maintenance costs).

Hard protection measures			
25	Protection	Build a breakwater to reduce wave action at the MCT and oil jetties	Breakwaters are pretty much the standard engineering solution to protect a port against wave action, for navigation, mooring and wave overtopping on the quay.
26	Protection	Build coastal defenses such as dikes or sea walls (potentially of retractable or temporary nature)	Various types of coastal defences exist, depending on the objective. Seawalls and levees are typical hard protection measures to protect against overtopping. Soft measures such as reefs, mangroves, dunes, and salt marshes are often preferred for coastal protection due to their "building with nature" nature, but such solutions are not easily applicable in a port environment. Alternatively, retractable seawalls, of temporary nature and raised following an extreme event warning, are cheaper and integrate better in the urban environment. Such a solution would be particularly suitable for the Caudan waterfront, and a similar solution has been installed on the MCT.
27	Protection	Raise the working platform, critical transport links and equipment (or any combination thereof)	Raising the working platform is a typical "accommodation strategy" solution. Raising the platform will solve the problem of overtopping caused by the combination of waves and sea level rise, instead of trying to address the cause of overtopping. This solution does not seem practical from our point of view for the port of Port Louis, in view of its cost and impact on operations.
28	Protection	Consider floating developments for future infratructure	Floating platform solutions are still at R&D level, but are considered for a few projects around the world. Chittagong port is considering this solution as a response to the current port congestion, inability to extend operations overland and the necessity to reduce the excessive dredging maintenance costs that the port is currently facing. In French Guyana, the port authority is also considering this solution for a deep sea port offshore, in order to create a regional hub complementing the existing low draught port. Floating developments naturally adapt to a rising sea level rise.
29	Protection	Build storm water retention basins against flash floods	A retention basin, also called wet pond, is a permanent pool of water that provides an efficient solution to manage stormwater runoff and delay the flood peak. It is different from a detention basin, also called dry pond, that stores water temporarly and slowly empties out. The port of Port Louis isn't directly facing flash floods, but the neighbouring port areas impacted in 2013 may consider this solution.
30	Protection	Increase capacity of drainage system against flash floods and excessive rain	Climate projections indicate that rain volumes will decrease over the year but extreme rain (storms, cyclones) will be more frequent. The drainage system capacity may need to be increased where water tends to accumulate and impact either port productivity or deteriorate port infrastructure.
31	Mitigation	Install green roofs	Green roofs are a common and efficient measure to fight against rising temperatures and heavy rain. Green roofs provide a natural heat protection for buildings, limiting impact of high external temperatures and retaining water during heavy rain, lowering the impact on outdoor working areas. Turning a roof into a green roof depends mainly on the building capacity to support the extra weight of earth and vegetation, and on the roof slope (a 3% to 5% slope being the most adequate, green roofs can be installed on up to an 18% slope).

Soft protection measures			
32	Protection	Dry-proof construction of critical infrastructure	Dryproofing is a construction method consisting of making a buiding watertight. Dryproofing techniques include putting sealants to the walls, shields to any sensitive openings (doors, ventilation…) and installing a water pumping system to remove the water that would still enter inside the building. According to current analysis and projected climate hazards on the port, there does not seem to be any critical infrastructure affected in the short to middle term. The MCT terminal, logistics areas as well as the Indian Oil and the bulk terminals seem to be the most exposed areas for which such an approach may make sense, where applicable (electrical stations, etc).
33	Protection	Wet-proof construction of non-critical infrastructure	By contrast to dryproofing, wetproofing allows water to enter the building or the structure. Infrastructure is designed to resist flooding (resistant materials, elevated storage, etc) until water drains. Wetproofing is a cheaper solution than dryproofing but can be more problematic in case of serious or recurrent flooding of a building. Like for dryproofing, the MCT terminal, logistics areas as well as the Indian Oil and the bulk terminals seem to be the most exposed areas for which such an approach may make sense, where applicable (storehouses, administrative buildings). *https://www.dewberry.com/news/blog/post/blog/2018/10/18/five-prominent-flood-resistant-building-techniques*
34	Protection	Relocate critical infrastructure	Relocating infrastructure appears to be the most effective solution but not necessarly the most efficient, considering the cost of relocation. Port Louis port is surrounded by the city and space available for relocation appears to be difficult to find (area behind the ferry terminal south-west of the port to be considered).
Increase equipment efficiency and operability			
35	Protection	Automate logistics procedures	Automating logistics processes increases the competitivity and reliability of port operations. It will probably have a positive side effect with less "human caused" downtime such as poor visilibility. Automating (fully or not) a port has to be strongly weighted and prepared in order to reach expected objectives (higher productivity, lower OPEX) to cover a rather high investment cost. Major barriers to successfully switch to automation are capability, data quality, siloed operations and the handling of exceptions (source : Mc Kinsey study - 2018). *https://www.mckinsey.com/industries/travel-logistics-and-transport-infrastructure/our-insights/the-future-of-automated-ports#*
36	Protection	Install active motion damping systems for moored ships	Active motion damping systems for moored ships are an example of a smart port application. Among other mooring operations and safety benefits, this system increases accessibility and operability of the ship (mooring, loading/unloading) when the port is facing severe weather conditions. Active motion damping systems can be a cheaper and more environmentally friendly solution to reduce wave and surge impacts on the terminal than a hard structure. The current knowledge level of climate hazards may be insufficient to confirm the applicability of such a system at Port Louis.
37	Protection	Install cranes that can safely operate under strong winds	Under strong wind, cranes can face serious issues to efficiently and safely operate. Combined with waves and vessel movements, operating under these conditions can quickly become problematic. It is advised to assess the benefits of installing higher efficiency cranes or upgrading current cranes to be able to operate under stronger winds. This may also be combined with a push to further automate container port operations.
38	Protection	Install high efficiency refrigerated storage	Refrigerated storage costs may increase in the future with higher air temperatures. When changing refrigerated storage equipment, or earlier if cost savings justify it, preference should be given to higher efficiency storage. Alternatively other low cost solutions exist, such as installing a roof shade above the reefer area (depending on the compatibility with handling equipment).
39	Protection	Install waterproof electrical infratructure	As projected for 2100, the sea level rise combined to the wave climate will cause increased overtopping on the quay and other logistic areas. The present study did not identify any critical and sensitive installation likely to be impacted in the short to medium term (the power plant in particular is located sufficiently far from the quay side). However it is advised to conduct a more detailed diagnostic of secondary electrical equipment likely to be impacted (such as the reefers on the MCT), in order to take where needed the proper protective measures (heightening, waterproofing, etc).

Mitigate future impacts			
40	Mitigation	Keep track of all climate-related incidents and events affecting the port, and lessons learnt	Keeping track of all climate related incident ties in closely with the prevention measures related to monitoring climate hazards. It is of fundamental importance in order to set up a continuous improvement process, as illustrated by the fact that the cause of overtopping on the MCT is not fully understood yet despite its repeated nature. This regular activity will improve the understanding of actual climate hazards and allow to quantify their occurrence. It will allow to adapt progressively to climate change by taking ground-tested measures.
41	Mitigation	Manage the costs of climate change risks through insurance contracts (a proactive climate change adaptation policy may decrease insurance costs)	Climate change will affect the port on many levels (operations, efficiency, wear and tear, damage ….). Refining knowledge on climate change and impacts is a major step for the port authority to understand the futur risks and assess the insurance coverage and cost associated. Regarding insurance, it is important for the port to focus on two directions : - making sure all climate change related risks are insured at a correct level; - setting up a climate change related policy that will decrease insurance costs.

2.2.2. Technology fact sheets

A subset of 15 adaptation measures identified have been further investigated to include information about:

- Technology description ;
- Climate change adaptation benefits ;
- Environmental and social benefits ;
- Knowledge/capacity building requirements ;
- Cost ;
- Opportunities and barriers ;
- Sustainable construction standards and codes of practice ;
- References to case studies where the technology has been applied.

The guiding idea is to provide extra insights about some of the less common measures proposed, based on a literature study. These fact sheets are presented in Annex 1 of this document according to the following template:

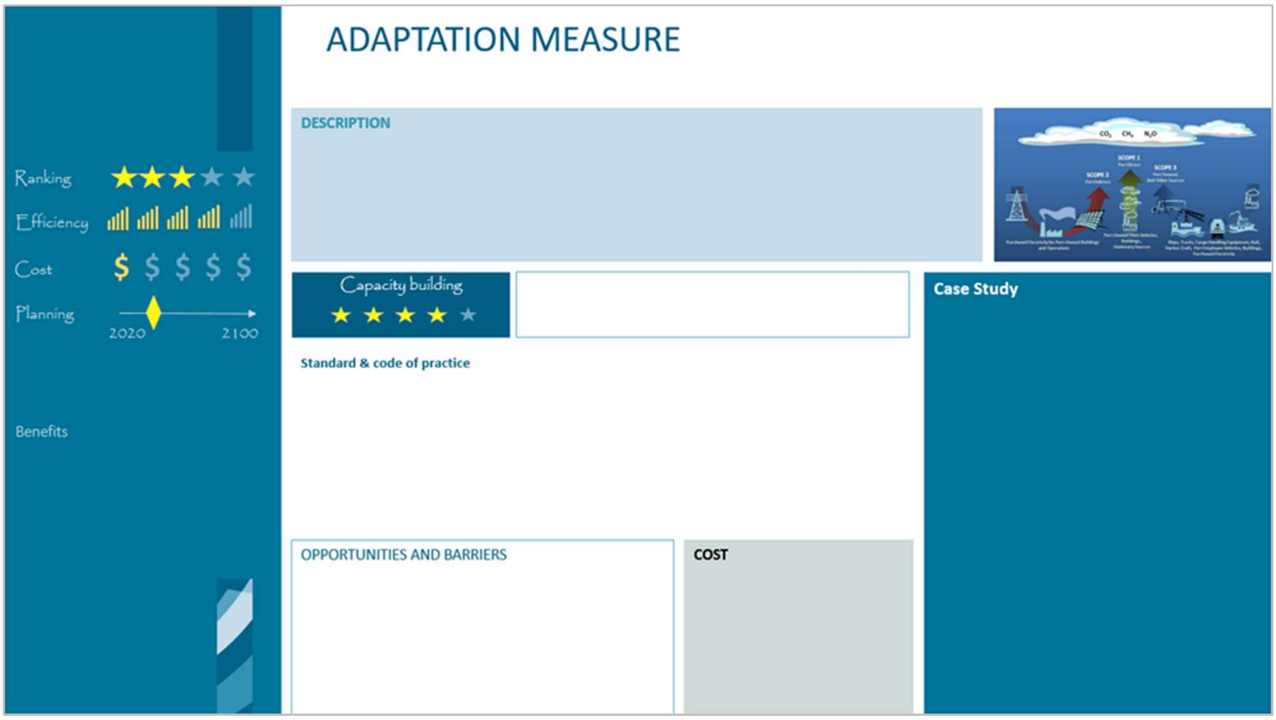


Figure 2 - Fact sheet template

2.3. INCLUSION OF GENDER IN PLANNING ADAPTATION

Gender mainstreaming is a concept that has been implemented in different sectors of activity in Mauritius, including the public sector where gender equality is promoted increasingly in line with the Platform for Action adopted **at the UN Fourth World Conference on Women held in Beijing in 1995.**

Demographic data gathered at the last population census in 2019 are not yet available. As per the 2011 data, the population of Mauritius (island) was 1.2 million, with 50.6% being Female. The resident population for the district of Port Louis was 118,431 (50.5% Female). The population of Ward 6 alone that includes the localities of Mer Rouge, Roche Bois and Camp Yoloff was 30,619 in 2011 (50.5% being female). Statistics pertaining to the number of people working in the port area are not available. Labour statistics per sector however indicate there are 15,498 people employed in 'transport and storage' which encompasses shipping and logistics.

	March 2017[1]			March 2018[2]		
	Male	Female	**Both Sexes**	Male	Female	**Both Sexes**
Transport and Storage	**12,754**	**2,934**	**15,688**	**12,549**	**2,949**	**15,498**
Passenger land transport	5,100	431	**5,531**	4,973	472	**5,445**
Freight transport by road	723	26	**749**	649	27	**676**
Water and air transport	1,576	829	**2,405**	1,608	812	**2,420**
Warehousing and storage	837	106	**943**	857	127	**984**
Support activities for transportation	3,528	965	**4,493**	3,500	966	**4,466**
Postal and courier activities	990	577	**1,567**	962	545	**1,507**

Table - 1 - MPA - Labour statistics per sector - Source: Statistics Mauritius, Labour Statistics 2018

In 2000, Mauritius together with 188 other UN member states, signed the Millennium Declaration setting out the eight Millennium Development Goals (MDGs). One of the goals was to promote gender equity and empower women, with the target date set at 2015.

Over the years, Governments in Mauritius have introduced several legislations and measures with a view to moving away from a patriarchal society dating from pre-independence days, to a fairer and unbiased democratic society, where gender discrimination no longer exist, as is the case with modern societies around the world. These measures include:

- The setting up of a specific Ministry in the Government of Mauritius, namely the Ministry of Gender Equality, Child Development and Family Welfare, for promoting gender equality in Mauritius ;
- Acceding in July 1984 to the Convention on the Elimination of all forms of Discrimination against Women (CEDAW) ;
- Being a party to the 1995 Platform of Action adopted at the Fourth World Conference on Women in Beijing regarding the advancement of women ;
- Signing in 1997 the SADC Declaration on Gender and Development ;
- Signing in 1998 of the Addendum to the Declaration on the Prevention and Eradication of Violence against Women ;
- Signing in November 2001 the Optional Protocol to the CEDAW, which was ratified in October 2008 ;
- Enactment of Sex Discrimination Act (SDA 2002), passed in 2002 which gives effect to provisions of the Convention on the Elimination of All Forms of Discrimination Against Women ;
- Enactment of Equal Right to Employment entitling the right to the same employment opportunities between men and women is ensured by Section 5 (1) of the Sex Discrimination Act (2002) ;
- The Sexual Offences Act 2003 reinforcing the sanctions associated with sexual offences ;

- Protection from Domestic Violence Act, enacted in 1997 and proclaimed in 1998, provides for the issue of Protection Orders, Occupation Orders and Tenancy Orders. to have introduced a comprehensive law to combat domestic violence.

- Employment Rights Act 2008, which protects the right of women to several maternity benefits.

Moreover, with a view to transforming Mauritius in a modern democratic society, ensuring equal rights and opportunities for all its citizens, an equal opportunities act was introduced in year 2008. This legislation provides for the implementation of a policy for equal opportunity in employment and education. The Equal Opportunities Commission, a body corporate, established under the Equal Opportunities Act, became operational in April 2012. Its main objective is to eradicate all forms of discriminatory practices in employment and ensuring fair and equal treatment for everyone, tackling discrimination wherever it exists and in whatever form and which may be grounded on race, colour, ethnic origin, sex and sexual orientations, religious beliefs, political opinion, social or economic status, disability etc.

More recently in September 2015, Mauritius adopted the 2030 Agenda for Sustainable Development: Transforming our world – *ending poverty, protecting our planet and ensuring that all people enjoy peace and prosperity*. The SDGs is a global action plan comprising 17 Goals and 169 Targets, together with 232 indicators, to be reached by 2030. SDG no. 5 specifically addresses 'Achieve gender equality and empower all women and girls. Data on the progress of the subgoals are monitored every year.

Selected indicators	**Men**	**Women**
Number of cases on violence reported by female - 2019	N.A	3,318 v/s 7,882 in 2011
Proportion of women holding senior positions in Government services - 2019	N.A	39.1%
Share of women working as own account worker and employer over total own account workers and employers - 2019	N.A	22.1%
Proportion of individuals who own a mobile telephone, by sex - 2019	88.9% in 2019	82.7%
Human Development Index (HDI) - 2018	0.803	0.782
Mean years of schooling (years) - 2018	9.5	9.3
Life expectancy at birth (years) - 2018	71.5	78.4
Gender Development Index (GDI) - 2018	0.803	0.782
Labour force participation rate - 2018	71.8 %	45%

Table - 2 - SDG – Gender Equality indicators. Source: Statistics Mauritius, SDGs & Human Development report

A 2017 report on the Gender Status of Mauritius indicates that Mauritius scores an index of 0.674 on the Gender Status Index (GSI). This index takes into account Education, Health, Income, Time-use and employment as well as access to resources, public sector and civil society. Overall the country scores 1.033 for the social power block, 0.656 for economic power and lowest for political power with a score of 0.333.

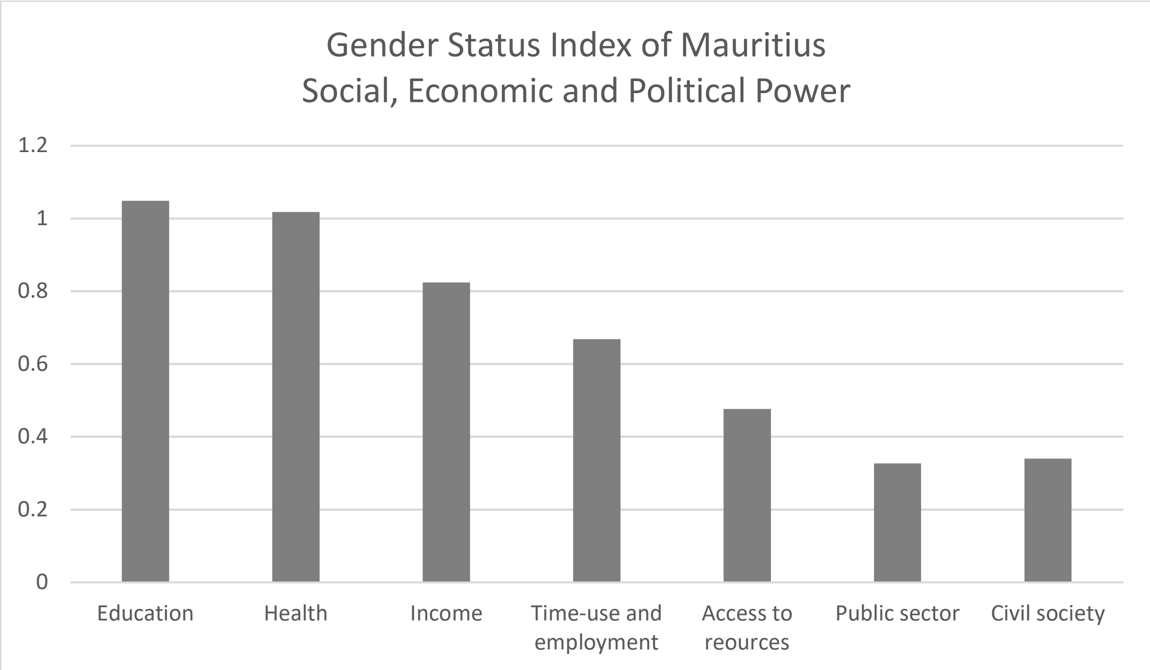


Figure 3 - Source: The African Gender and Development Index (AGDI) Report for Mauritius, 2017

In line with the Government's policy regarding equitable treatment and opportunities for all of its citizens, the Mauritius Ports Authority (MPA) has publicly communicated that it adheres to the provisions of the Equal Opportunities Act 2008 and endeavours to follow the recommendations of the Equal Opportunities Commission regarding employment policies, procedures and practices. It is thus an equal opportunity employer, who ensures, through the implementation of policies and practices, that its employees feel respected and valued, and can achieve their potential regardless of their status, namely: age, caste, colour, creed, ethnic origin, impairment, marital status, place of origin, political opinion, race, sex, sexual orientation.

While there is sufficient legislation and policies in place to safeguard against discrimination on basis of gender as to roles and responsibilities, power for decision-making, participation and representation at various levels within organisations in Mauritius, it is noted from the MPA's corporate plan 2016 to 2018 that as at 4th November 2015, the age and gender composition of the Human Capital of the MPA was as follows:

Age Range	Total Number of Employees	
	Male	Female
Below 30 Years	22	9
30 – 34 Years	32	7
35 – 39 Years	52	5
40 – 44 Years	42	7
45 – 49 Years	47	8
50 – 54 Years	95	6
55 – 59 Years	88	21
60 Years and Above	85	4
Total by Gender	463	67
TOTAL	530	

Table - 3 : Age & gender composition of human capital in MPA (2017)

CHCL Ltd (Cargo Handling Corporation), another major port operator employs some 1,370 people in different categories.. In the private sector, there is no publicly available information and in the absence of a survey, figures can only be estimated. Companies with quay operations tend to be less labour intensive (e.g. Les Moulins de la Concorde) except for fish processing activities that involve significantly more manual labour.

Gender inequality regarding employment at the MPA is considered to be an issue, from the objective of attaining gender parity in the organisation. Though figures for other operators in the sector and within the port area are not readily available, it may be considered that the same situation prevails, i.e. much less women are in employment than their counterparts. Gender integration and targeted gender activities are therefore necessary to realising the objective of a fairer representation of women at all levels of employment. A balanced representation at the Board of Directors and Senior Executives level would be the right signal towards moving in the right direction. As at end December 2015, out of seven Directors of MPA's Board, one was a woman. Similarly, out of thirteen Senior Executives, only two were women.

Gender tool analysis frameworks suggest that in many societies gender defines roles and responsibilities and in the case of climate change, both genders may not be equally prepared to cope with the situation. In Mauritius, there are 320,340 people who are employed, the proportion being 61.2% for men and 38.8%% for women as of March 2018. Within the perimeter of the port area and in economic activities, it may be inferred that the lower skilled may be less prepared to adapt or face climate change but not really on account of gender. A lower representation of women as revealed by statistics available in the port area also implies that there is a lower number of women that may not be informed about the consequences of climate change on their lives or on their work.

Recommendations

Women should also be encouraged to join MPA and other port operators/organisations, with the MPA setting the trend. New positions will have to be created to meet the new challenges posed by climate change at the port and existing ones, albeit partly filled as part of these organisations' succession planning strategy. This would be a golden opportunity for reversing the trend, as far as parity of employment is concerned. For example, positions such as crane operators and forklift drivers at Cargo Handling Corporation Ltd when advertised should carry a note to the effect that women are encouraged to apply and that once selected, all successful applicants will be properly trained on the job and in workshops, for carrying out works assigned to them, and will also be active participants to climate change adaptation and climate technology measures. Some may eventually be trained to become trainers themselves.

Progress regarding the above actions need to be monitored so that the impact of women participation in decision-making at various levels for preparing all those concerned by climate change in the port to be conversant with adaptation measures and trained for optimum use of new technology to face the change. Continuous training and technical assistance are essential parts of course of action for living up to the challenges posed by climate change. Both genders should be identical beneficiaries of such training. The quality of training imparted, its relevance, perception and impact on each gender should be evaluated by the concerned organisations.

Suggested KPIs for monitoring and evaluation of gender equality may include the following:

Decision-making related to climate technology implementation or use

- Number and percentage of women and men who attend participatory planning and consultation meetings ;
- Number of men and women in decision making and or leadership positions in project planning process ;
- Number and percentage of men and women in climate technology user groups, cooperatives, committees, utilities etc.

Technical assistance and project-related training

- Number and percentage of women and men who receive some form of leadership or technical training from the program ;
- Number and type of training sessions targeted specifically at women or men.

3. SELECTED ADAPTATION MEASURE

The adaptation measures presented in section 2.1.2. are, in general, not mutually exclusive except for hard protection measures such as for instance choosing between a breakwater or raising the working platform. A few measures with limited applicability to the port have been removed from the list of selected measures developed in the action plan. The reduced list is presented in report D4.

Following a workshop with MPA and the main stakeholders, it has been decided to select the most appropriate hard protection measure to be developed further at pre-feasibility level. This concerns measure #25 “Build a breakwater to reduce wave action at the MCT and the Oil jetties”.

Since the previous report showed that waves and storm surges were also impacting the Caudan basin area, the pre-feasibility study targets a breakwater aiming to protect both industrials areas (MCT and Oil Jetties) as well as the Caudan basin. Two layouts have been evaluated:

- One long breakwater, protecting the MCT and the Caudan basin;
- One short breakwater, to evaluate whether the level of protection would still be acceptable if the long breakwater is shortened on its north-eastern section.

4. NUMERICAL MODELLING OF THE IMPACT OF SELECTED ADAPTATION MEASURES

The objective of the modelling study is to verify the efficiency of the adaptation measure selected in chapter 3, namely "Build a breakwater to reduce wave action at the MCT and the Oil jetties".

To this end, the two breakwater configurations (the long and short versions) have been modelled for the T100 cyclone defined in report D3, in the present situation and with climate change (mean scenario).

4.1. MODEL UPDATE

The numerical model developed to evaluate the flood risk linked to climate change and presented in report D2 is used. Two new mesh grids have been set up, for each breakwater configuration.

The long breakwater is positioned approximately 1150 m off the MCT, protecting it from North and North-West waves. The western half of the breakwater partly shields the port basin. The position is constrained by the presence of the navigation channels towards the MCT and the Caudan basin. The MCT approach channel has been slightly offset in order to increase the protection offered by the breakwater.

In its short version, the eastern part of the breakwater is shortened by about 400 m. The exact location and length of the breakwater shall be optimized in view of the level of protection offered (this section), but also of the expected impact on – among other factors – navigation, currents, erosion-sedimentation and coastline dynamics (not part of the present study).

Figure 4 and Figure 5 below show a view of the model with breakwater.

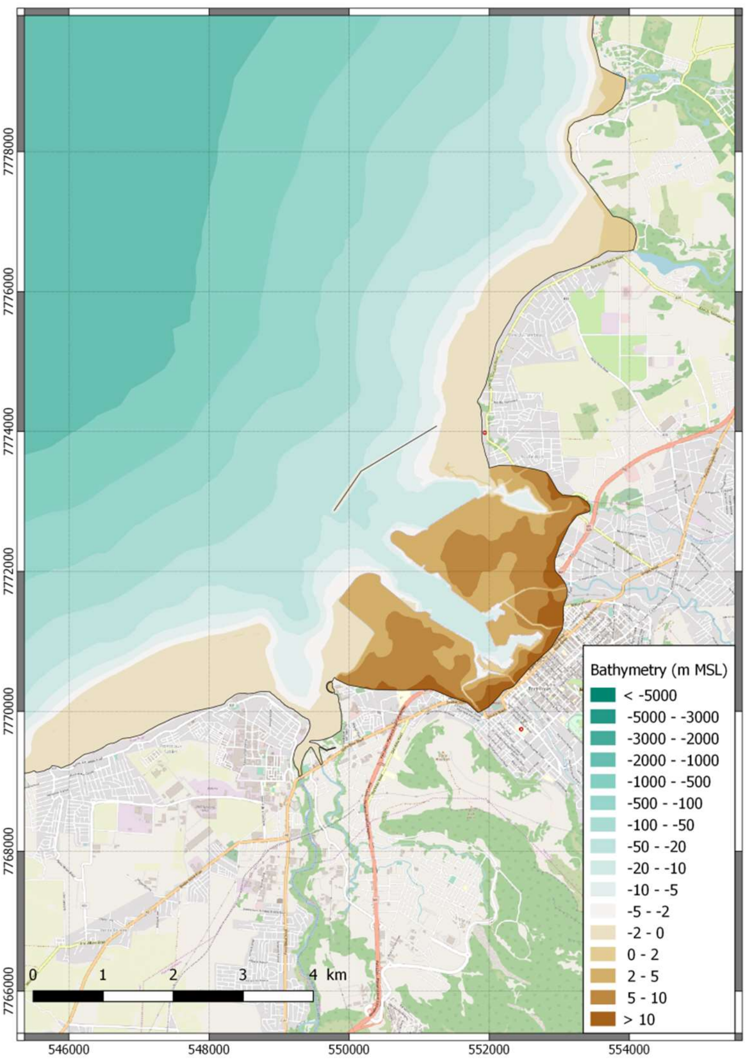


Figure 4. Model bathymetry – Configuration with a long breakwater

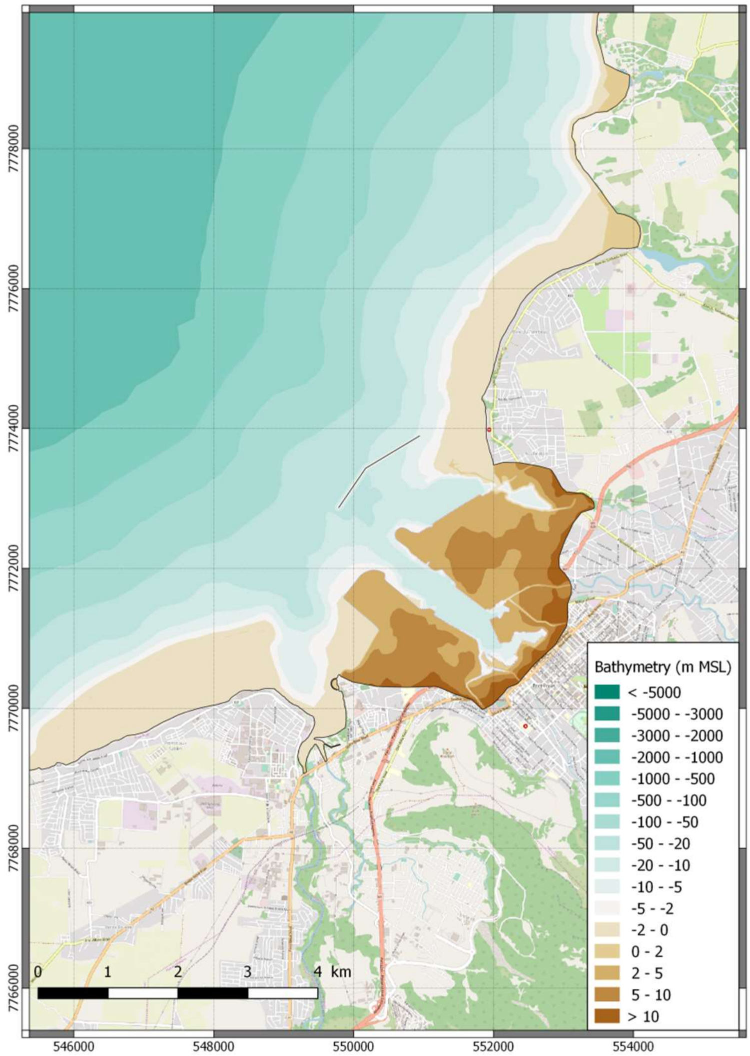


Figure 5. Model bathymetry – Configuration with a short breakwater

4.2. MODEL EXPLOITATION

4.2.1. Scenarios

For each breakwater configuration, two simulations are carried out, with the following hydro-meteorological scenarios:

- T100 actual,
- T100 mean future.

The T100 event represents the passage of a cyclone over Mauritius. It is described in detail in report D2.

Table 4 recalls the characteristics of the two scenarios.

Table 4: Hydro-meteorological scenarios

NAME	WIND	ATMOSPHERIC PRESSURE	WAVES	SEA LEVEL RISE
T100 actual	Reference hazard [1]	Reference hazard	Calculated in the model	0 m
T100 mean future	Reference hazard +3.3% on extreme wind speed	Reference hazard -3.3% on minimum cyclone pressure	Calculated in the model	+0.47 m

[1] *The T100 reference hazard is based on the track of cyclone Chantelle-Daniella, shifted to the northeast so that the eye of the cyclone passes over Port-Louis. The wind and pressure values are those of cyclone Cilida.*

4.2.2. Results for the long breakwater

The results of the simulations are presented in the form of:

- Map of the maximum significant wave height ;
- Map of the maximum water level at sea;
- Map of the maximum water height (inundation depth) on land.

4.2.2.1. T100 actual

Figure 6 shows the maximum significant wave height reached during the simulation.

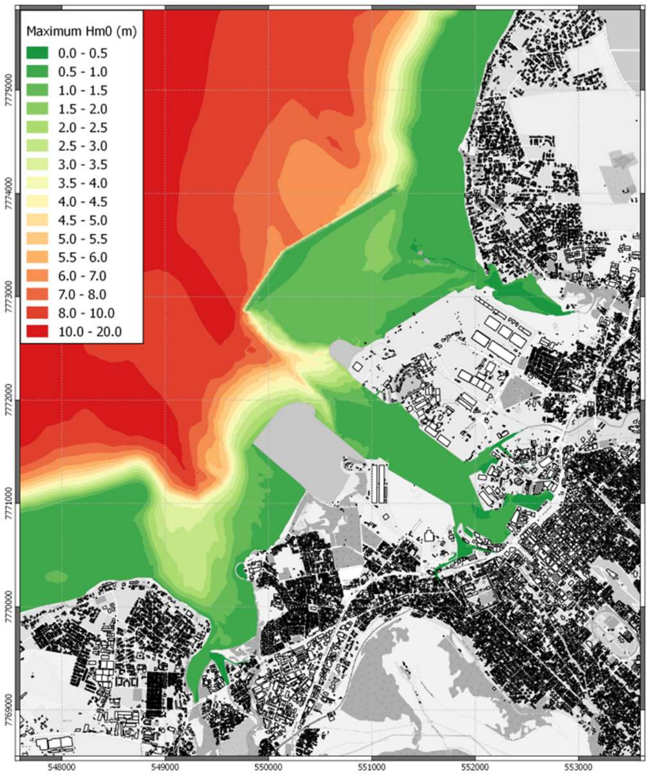


Figure 6. Maximum significant wave height – T100 actual – Long breakwater

For this calculation, the wave height at the foot of the MCT remains less than 1 m. The areas of the port which are the most impacted are the reclaimed area west of the port (which is not protected by the breakwater) and the Indian Oil Terminal (waves bypass the western end of the breakwater and strike the quay almost perpendicularly).

Figure 7 shows the maximum water level reached in the port of Port-Louis during the simulation and the maximum water height calculated on the quays.

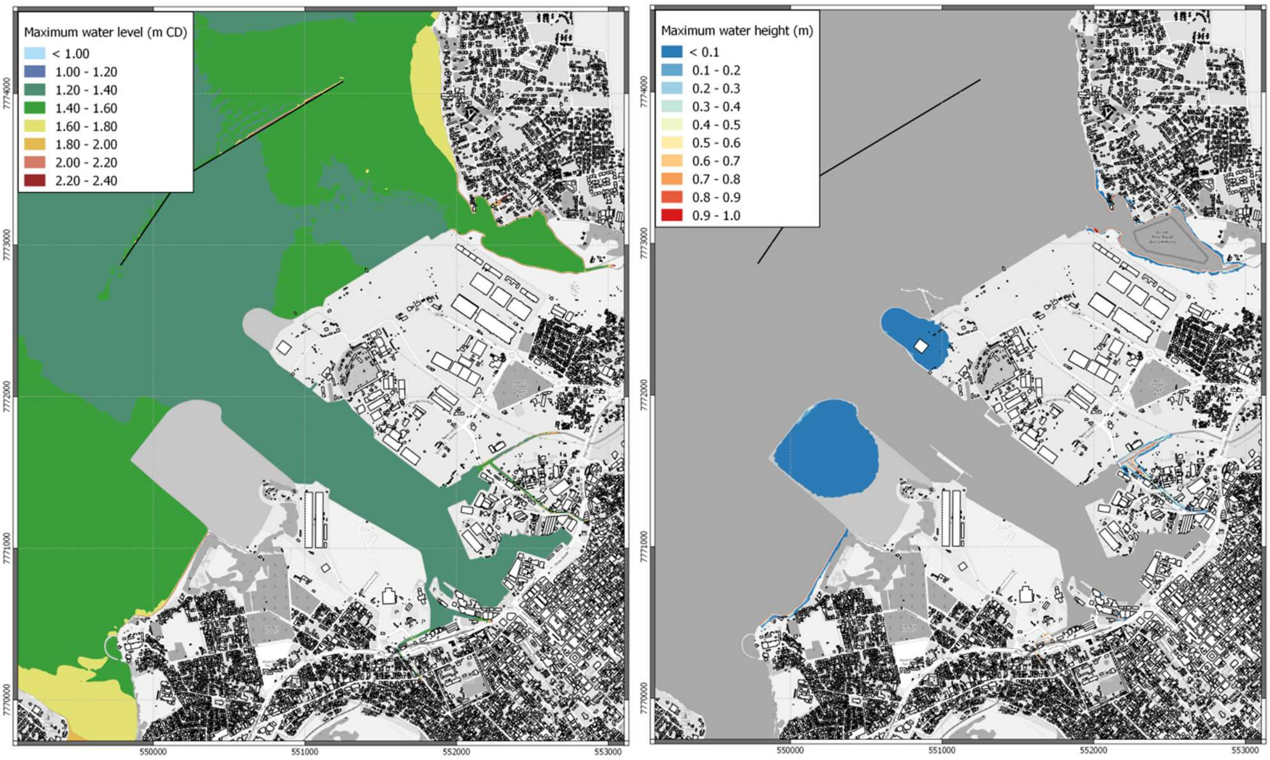


Figure 7. Maximum water level (left) and maximum water height (right) – T100 actual - Long breakwater

Like in the current port configuration (without breakwater), the maximum water level is about 1.40 m CD. The map on the right shows that for this scenario, two areas of the port are flooded: the reclaimed area west of the port and the Indian Oil terminal. The maximum water height on these areas is now less than 10 cm (against about 15 cm in the current configuration).

It should however be noted that the model is not able to take into account wave agitation inside the port due to refraction and reflection off structures. The wave height calculated at the end of the basin is therefore probably underestimated.

4.2.2.1. T100 mean future

Figure 8 shows the maximum significant wave height reached during the simulation.

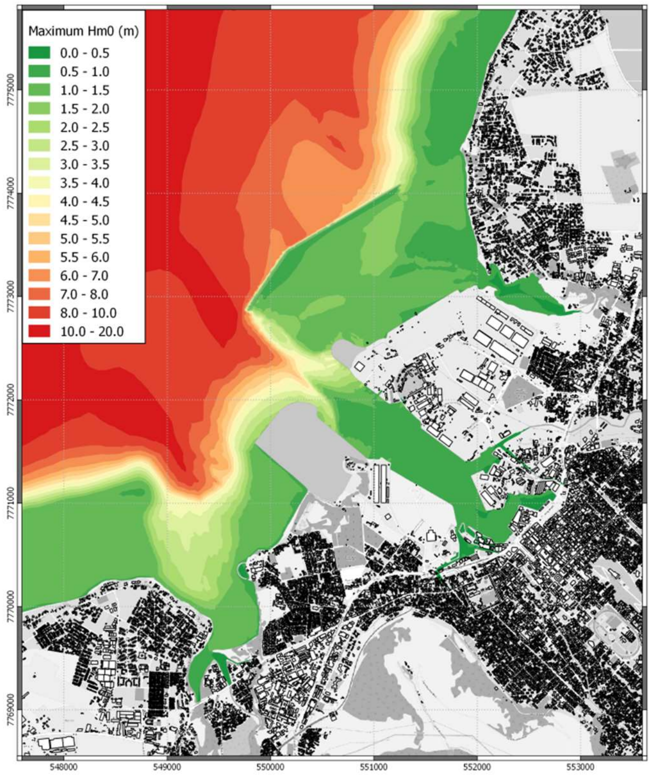


Figure 8. Maximum swell significant height – T100 mean future – Long breakwater

Like in the previous meteorological scenario, the significant wave height at the foot of the MCT remains less than 1 m. The reclaimed area west of the port and the Indian Oil Terminal are still the areas most impacted by waves.

Figure 9 shows the maximum water level reached in the port of Port-Louis during the simulation and the maximum water height calculated on the quays.

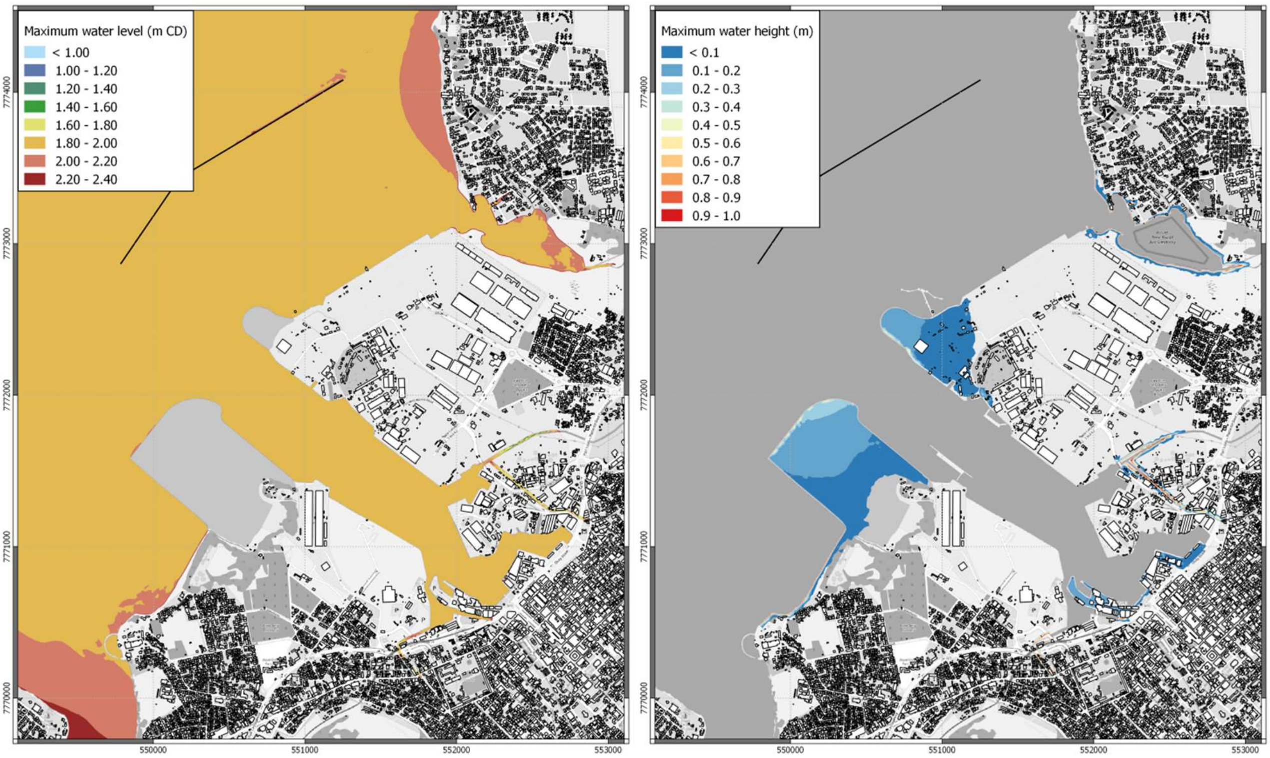


Figure 9. Maximum water level (left) and maximum water height (right) – T100 mean future - Long breakwater

The maximum water level is about 1.9 m CD, which is very close to the quay level at the Caudan waterfront and at the fishing port (+2 m CD). The map on the right shows that for this scenario, the reclaimed area west of the port, the Oil Indian terminal, the Caudan waterfront and the fishing port are flooded. All the quays between the Caudan waterfront and the fishing port are also flooded.

The MCT is not flooded and the maximum water height on the Oil Indian terminal is approximately 10 cm (against almost 30 cm in the current configuration).

Note that for this scenario (+0.47 m of mean sea level rise), the freeboard at the Caudan waterfront and at the fishing port is very low (10 cm). The construction of a breakwater to limit the height of the waves entering the port will not be enough to prevent submersion in these areas.

4.2.3. Results for the short breakwater

4.2.3.1. T100 actual

Figure 10 shows the maximum significant wave height reached during the simulation with a shorter breakwater.

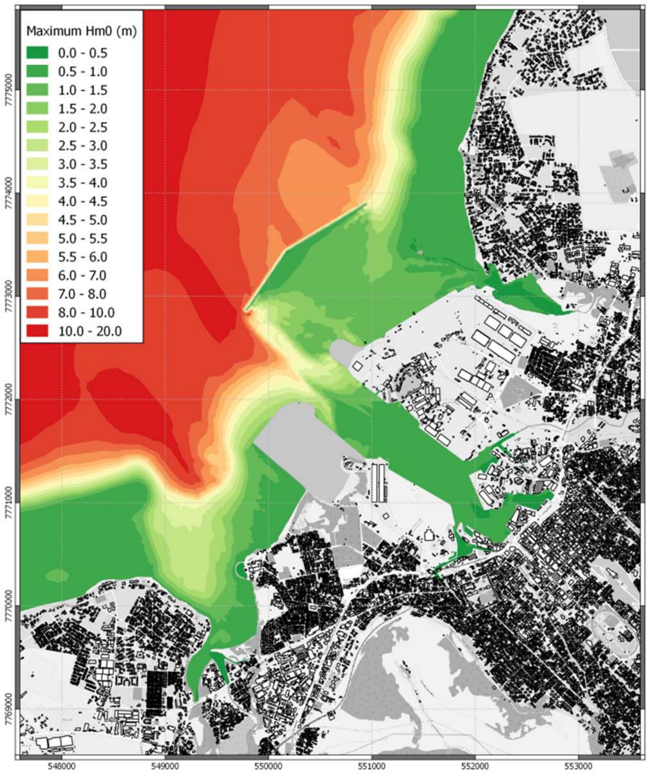


Figure 10. Maximum swell significant height – T100 actual – Short breakwater

For this calculation, the maximum significant wave height at the foot of the MCT is about 1.2 m. The waves in the basin between the MCT and the breakwater are as expected higher than with the long breakwater, though still well shielded. Like in the previous configuration, the most impacted areas are the reclaimed area west of the port (which is not protected by the breakwater) and the Indian Oil Terminal.

Figure 11 shows the maximum water level reached in the port of Port-Louis during the simulation and the maximum water height calculated on the quays.

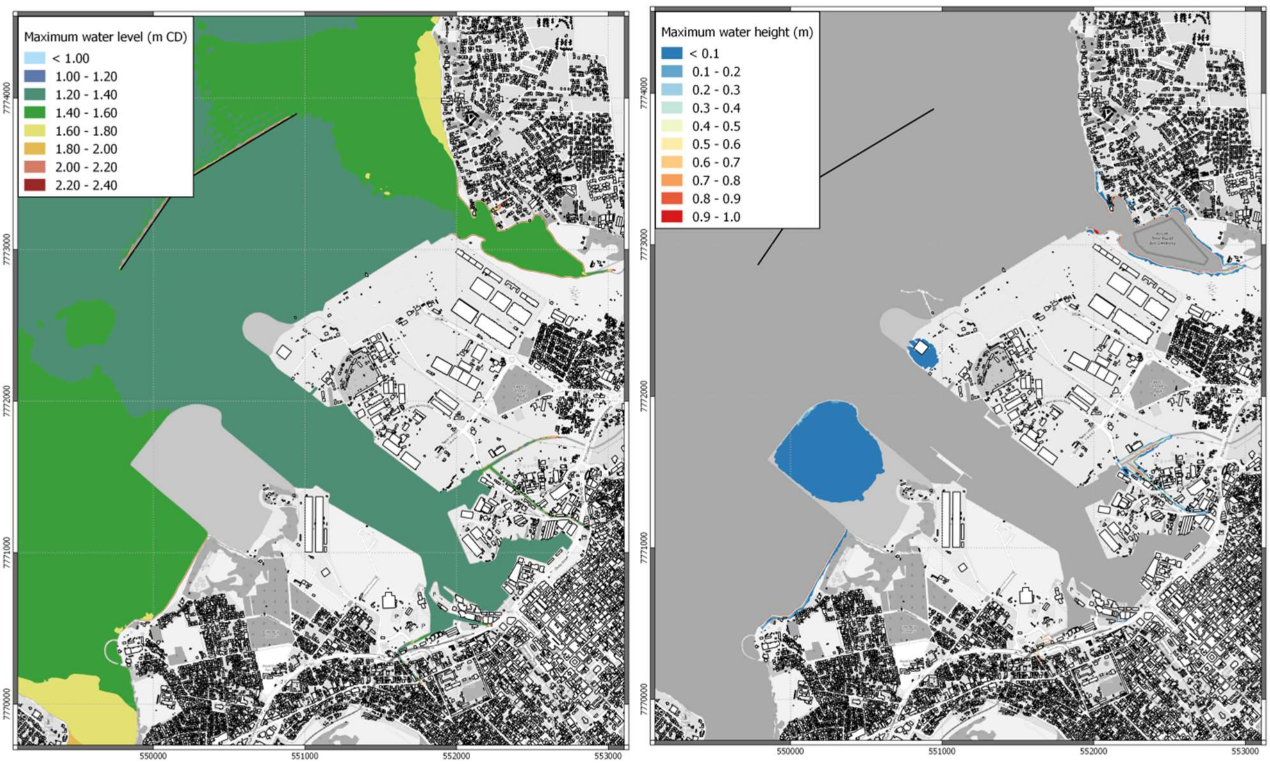


Figure 11. Maximum water level (left) and maximum water height (right) – T100 actual - Short breakwater

The maximum water level is about 1.40 m CD. Like in the previous configuration, the reclaimed area west of the port and the Oil Indian terminal are flooded. The maximum water height on these areas is less than 10 cm and the surface flooded is a little smaller than with the long breakwater. This is due to the mathematical accuracy of the model. However, the difference in water heights between the two configurations is not significant.

The short breakwater has hence an equivalent level of protection as the long breakwater for this meteorological scenario.

4.2.3.2. T100 mean future

Figure 12 shows the maximum significant wave height reached during the simulation.

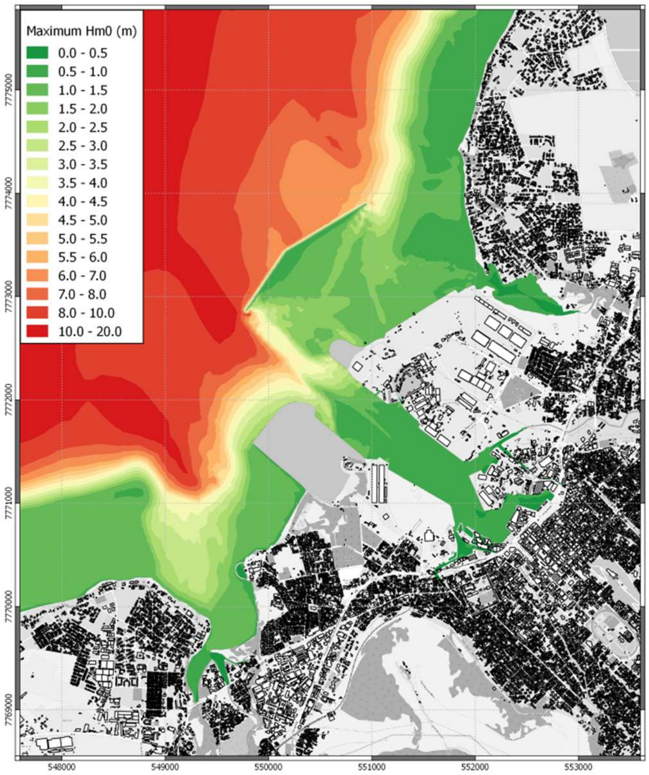


Figure 12. Maximum swell significant height – T100 mean future – Short breakwater

The maximum significant wave height at the foot of the MCT is about 1.3 m. In the basin between the MCT and the breakwater, the significant wave height can reach 2 m. The reclaimed area west of the port and the Indian Oil Terminal are still the areas most impacted by waves.

Figure 13 shows the maximum water level reached in the port of Port-Louis during the simulation and the maximum water height calculated on the quays.

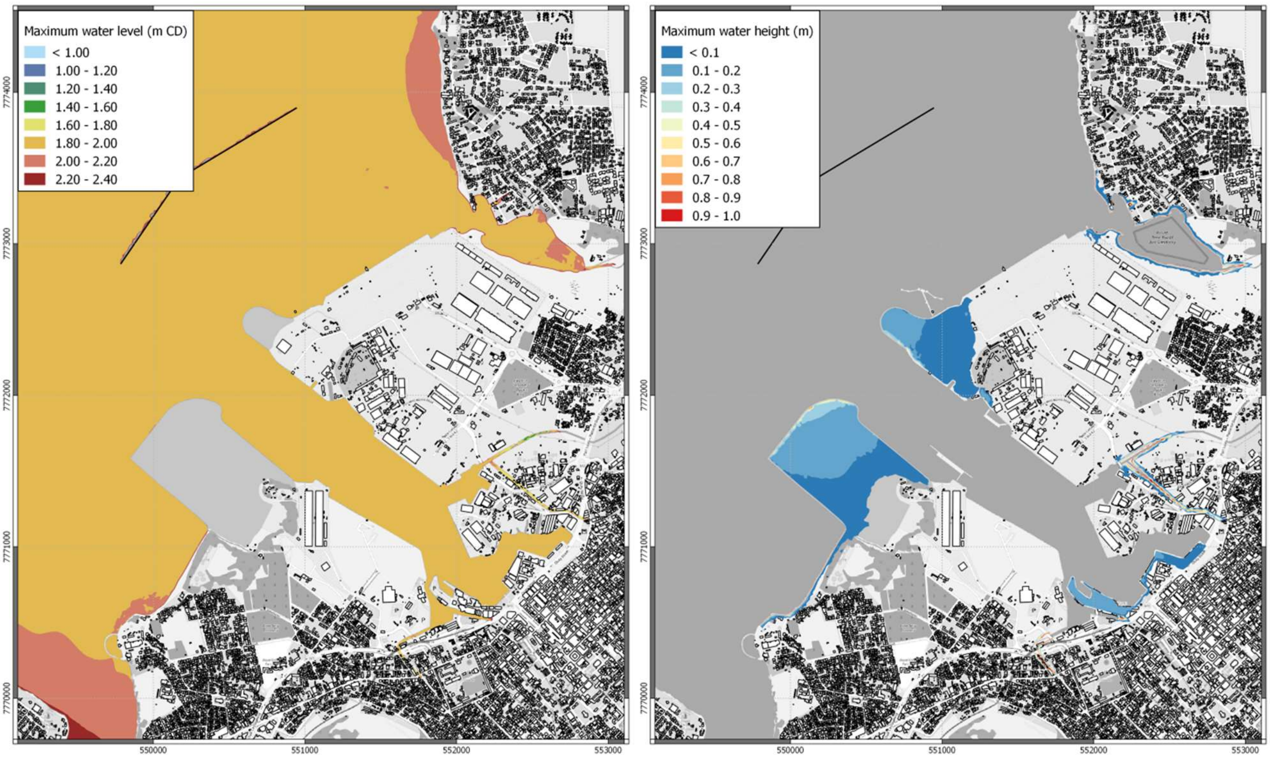


Figure 13. Maximum water level (left) and maximum water height (right) – T100 mean future - Short breakwater

Like in the configuration with the long breakwater, the maximum water level is about 1.9 m CD. The reclaimed area west of the port, the Oil Indian terminal, the Caudan waterfront and the fishing port are still flooded.

The maximum water heights calculated on the docks are similar to those calculated with the long breakwater.

The short breakwater has hence an equivalent level of protection as the long breakwater for this meteorological scenario.

4.3. CONCLUSION

The results of the simulations are similar for the two breakwater configurations:

- the significant wave height at the toe of the MCT during a storm is considerably reduced ;
- the MCT quay is therefore no longer flooded ;
- maximum wave heights are observed at the reclaimed area west of the port and at the Indian Oil terminal ;
- only these two terminals are expected to be flooded during the passage of the reference cyclone and the water heights are reduced compared to the current situation ;
- the western part of the breakwater prevents swells from entering the harbor directly. However, it should be noted that the model set up does not take into account wave agitation inside the port. The wave height calculated at the end of the basin is therefore probably underestimated ;
- the Caudan waterfront and the fishing port are still flooded for calculations with a sea level rise of 47 cm, but this is due to the low altimetry of these quays (+2 m CD). A breakwater will not help, local flood walls may be needed.

The main difference between the two breakwater configurations is the significant wave height in the basin between the MCT and the breakwater, which is smaller (less than 1.5 m) for the long breakwater.

5. PRE-FEASIBILITY STUDY OF SELECTED ADAPTATION MEASURES

5.1. LONG BREAKWATER

Measure 1 is a long breakwater to protect the port and the MCT, as shown on Figure 4 (§ 4.1).

The pre-dimensioning of the protection structures was carried out on the basis of expert judgement and the Rock Manual (see reference). The main characteristics are proposed below, including:

- the size of the rocks in the external armour layer ;
- the size of the rocks in the internal armour layer ;
- the composition of the core and any underlayer.

5.1.1. Technical feasibility

5.1.1.1. External layer

Two methods are used for the pre-sizing of armour layer blocks, based on the Hudson and Van der Meer formulas. The first was validated on regular wave physical models. Hudson's formula is robust and has proven its effectiveness over time. However, it is a simple formula that does not take into account some parameters.

The second method of Van der Meer, validated on more recent tests carried out in irregular swell, takes into account a greater number of parameters, including the wave-to-level ratio, the damage parameter, etc.

1. Hudson's formula

The size of the stable blocks can be deduced from the Hudson formula which reads:

$$P = \frac{H^3\,\rho_s}{H_D\left(\frac{\rho_s}{\rho_e}-1\right)^3 cotg\alpha}$$

with :

P (tonne)	average weight of a block
ρ_s	density of the material (2.65 t/m³)
ρ_e	density of seawater (1,028 t/m³)
Hs (m)	significant height of design wave
α	slope angle with the horizontal
K_D	stability coefficient. This dimensionless coefficient takes into account the nature and arrangement of the blocks

2. The Van der Meer's formula

The Van der Meer formulas are presented below:

- In deep water (i.e. the water depth at the toe of the structure is at least three times the significant wave height):
  - Plunging waves:

$\xi_m < \xi_{cr}$

$$\frac{H_s}{\Delta \times D_{n50}} = 6{,}2 \times P^{0{,}18} \times \left(\frac{S_d}{\sqrt{N}}\right)^{0{,}2} \times \xi_m^{-0{,}5}$$

- Surging waves:

$\xi_m \geq \xi_{cr}$

$$\frac{H_s}{\Delta \times D_{n50}} = 1{,}0 \times P^{-0{,}13} \times \left(\frac{S_d}{\sqrt{N}}\right)^{0{,}2} \times \xi_m^{p}$$

- In shallow water (.e. the water depth at the toe of the structure is less than three times the significant wave height):
  - Plunging waves:

$\xi_m < \xi_{cr}$

$$\frac{H_s}{\Delta \times D_{n50}} = 8{,}4 \times P^{0{,}18} \times \left(\frac{S_d}{\sqrt{N}}\right)^{0{,}2} \times \left(\frac{H_S}{H_{2\%}}\right)$$

  - Surging waves:

$\xi_m \geq \xi_{cr}$

$$\frac{H_s}{\Delta \times D_{n50}} = 1{,}3 \times P^{0{,}18} \times \left(\frac{S_d}{\sqrt{N}}\right)^{0{,}2} \times \left(\frac{H_S}{H_{2\%}}\right)$$

with:

ξ_m	surge parameter calculated from mean wave period (Tm) in accordance with time domain analysis: $\xi_m = \frac{tan\ \alpha}{\sqrt{(2\pi H_S / g T_m^2)}}$
ξ_{cr}	critical value of the surge parameter: $\xi_{cr} = (6{,}2 \times P^{0.31} \times \sqrt{tan\,\alpha})^{\frac{1}{P+0.5}}$
Hs (m)	significant height of incident swell at the toe ($H_{1/3}$)
N	number of incident waves, depending on the duration of the sea state
Δ	relative density deflated: $\Delta = \frac{\rho_s}{\rho_w} - 1$
P	nominal permeability parameter of the structure
D_{n50} (m)	median nominal diameter of rocks: $D_{n50} = \sqrt[3]{\left(\frac{M_{50}}{\rho_s}\right)}$
ρ_r (kg/m³)	density of rocks: ρ_r = 3,0 t/m³
ρ_w (kg/m³)	seawater density: ρ_w = 1,028 t/m³
α (rad)	slope of the structure
S_D	level of damage, depending on the slope of the structure

5.1.1.2. Inner, sub-layer and core

According to standard design rules, these layers will be defined as follow:

- Core from all sources of limestone (possibility to use the rocks from the rock-breaking if the quality is satisfactory)
- a size of riprap in accordance with the following ratio (CERC, 1984):

$$\frac{Mass\ of\ the\ rock\ of\ the\ inner\ layer\ M_{50u}}{Mass\ of\ the\ rock\ of\ the\ external\ layer\ M_{50a}} = \frac{1}{15}\ to\ \frac{1}{10}$$

5.1.2. Design criteria

The Rock Manual (see reference) defined a set of functional requirements for the structure that can be agreed upon and used as design criteria. Acceptable damage levels should be properly defined before the design process. The criteria should relate to the design methods being used.

The balance of economics and operational safety relating to performance and level of risk over time should also be calculated. It should be expressed in terms of risk of non-performance or exceedance of specified conditions. For example, a structure built to last for 100 years (i.e. it has a 100-year design life) has an 87% risk of being exposed to a one in 50-year wave condition, and a 39% risk of being exposed to a 1 in 200-year wave condition. Designing to resist damage for the latter condition might be more expensive, but it will mean there is a much lower likelihood that the structure will have to be repaired during its operational lifetime.

The following criteria must be met:

- Design for a 100-years return period with some acceptable damage to the external layer ;
- Design for a 50-years return period with limited damage to the external layer ;
- Climate change taken into account ;
- With the objective to protect the MCT, the Indian Oil Terminal and the Caudan basin.

5.1.3. Application to Port-Louis in Mauritius

Calculations have been done for three points along the breakwater:

- Point A at the eastern roundhead ;
- Point B at the elbow ;
- Point C at the western roundhead.

These three points are illustrated in the figure below.

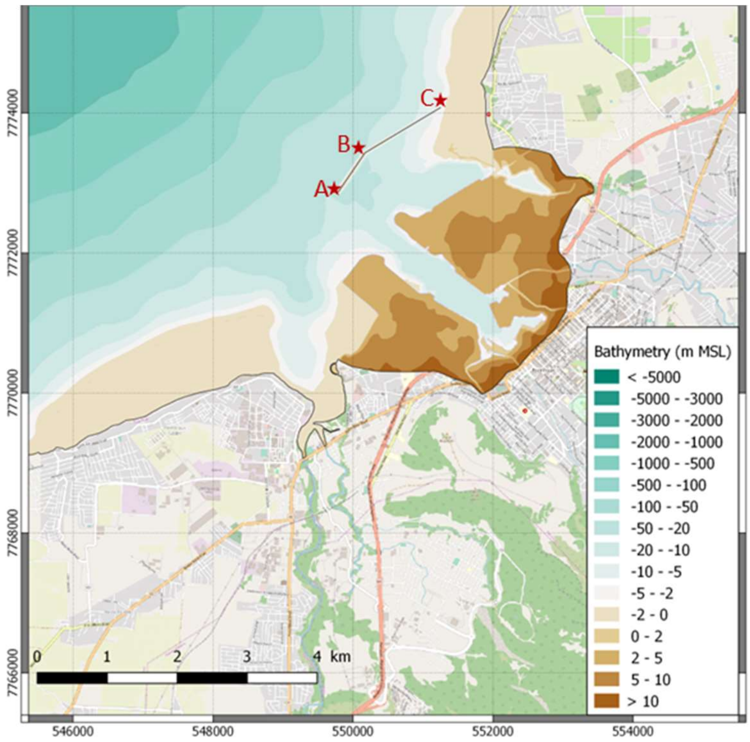


Figure 14. Long breakwater: location of characteristic points

Table 5 : Waves characteristics at Points A, B and C: significant wave height / peak wave period

Return Period	Point C (depth -4.0m MSL)	Point B (depth -22.5m MSL)	Point A (depth -26.8m MSL)
T50	3.0m / 16s	8.4m / 16s	8.3m / 16s
T100	3.0m / 15s	11.3m / 15s	11.4m / 15s

Preliminary calculations have been based on the following parameters:

- Sea state = 24h (cyclonic duration), corresponding to a number of waves N between 5,200 and 7,000
- S_D = 4 : intermediate damage
- P = 0.4 for the external layer
- KD = 16 for ACCROPODE™ or 7 for BCR (cubic blocs). For large wave heights, carapace stabilization will be achieved by using very large armour blocks to withstand large swells.

Other types of blocks exist but have not been investigated here.

Remarks:

- The ACCROPODE™ unit has been the benchmark single-layer armour unit since 1981. It is simple, robust, reliable and easy to fabricate using basic techniques. It can be adapted seamlessly to all types of structure. It has a high stability coefficient derived from its shape as well as from the associated placing techniques. It can be used on structures of all types from coastal defenses in shallow water to large breakwaters designed to protect ports or nuclear power plants. This is a technology with minimal maintenance costs since these structures are normally intended to withstand the design wave without sustaining damage.

- The BCR is a simple cubic block with a semi-circular groove on the four non-parallel faces. The grooves allow a better circulation of water inside the carapace and a reduction of overpressures. In addition, they facilitate the bonding of the blocks between them which improves their hold and gives them a group behavior. It is arranged in two layers on slopes of slopes generally between 4/3 and 2/1. The lower layer acts as a separator with the blocks of the upper layer.

Results are summarized in the following table:

Table 6 : Rock size at Points A, B and C

Return Period	Point C (depth -4.0m MSL)	Point B (depth -22.5m MSL)	Point A (depth -26.8m MSL)
T50	D_{n50} = 1.0m / M_{50} = 2.9t	D_{n50} = 3.4m / M_{50} = 100t	D_{n50} = 3.1m / M_{50} = 80t
T100	D_{n50} = 1.1m / M_{50} = 3.1t	D_{n50} = 3.8m / M_{50} = 150t	D_{n50} = 4.0m / M_{50} = 165t

Table 7 : Bloc size for ACCROPODE™ at Points A, B and C

Return Period	Point C (depth -4.0m MSL)	Point B (depth -22.5m MSL)	Point A (depth -26.8m MSL)
T50	V = 0.5m^3 / M = 1t	V = 13m^3 / M = 31t	V = 12m^3 / M = 30t
T100	V = 0.6m^3 / M = 1t	V = 28m^3 / M = 65t	V = 29m^3 / M = 68t

Table 8 : Bloc size for BCR at Points A, B and C

Return Period	Point C (depth -4.0m MSL)	Point B (depth -22.5m MSL)	Point A (depth -26.8m MSL)
T50	V = 1.2m^3 / M = 3t	V = 26m^3 / M = 61t	V = 25m^3 / M = 58t
T100	V = 1.2m^3 / M = 3t	V = 64m^3 / M = 150t	V = 66m^3 / M = 155t

Values in red are not realistically achievable due to their excessive weights and size. Values in orange require specific lifting equipment.

Given the results, caissons could also be considered, particularly for the breakwater section with depths greater than 20m MSL.

5.1.3.1. Cost estimate

At this prefeasibility stage, costs are of the following order of magnitude:

Table 9 : Cost for an offshore breakwater – Values 2020

Depth (m MSL)	5 – 10	10 – 15	15 – 20	20 – 25	25 – 30	30 – 35
Average price USD / ml	$40 000	$80 000	$120 000	$170 000	$250 000	$370 000

The cost for the long breakwater will be around 300 million of US dollars detailed as follow:

Table 10 : Cost estimate of the long breakwater – Values 2020

Depth (m MSL)	5 – 10	10 – 15	15 – 20	20 – 25	25 – 30	30 – 35
Distance (m)	580	370	300	150	300	300
Cost	23.2m$	30.0m$	36.3m$	26.0m$	75.9m$	111.9m$

Note that the cost could probably be substantially optimised by modifying the layout to avoid larger depths, as the linear cost of a breakwater is quadratic with the water depth.

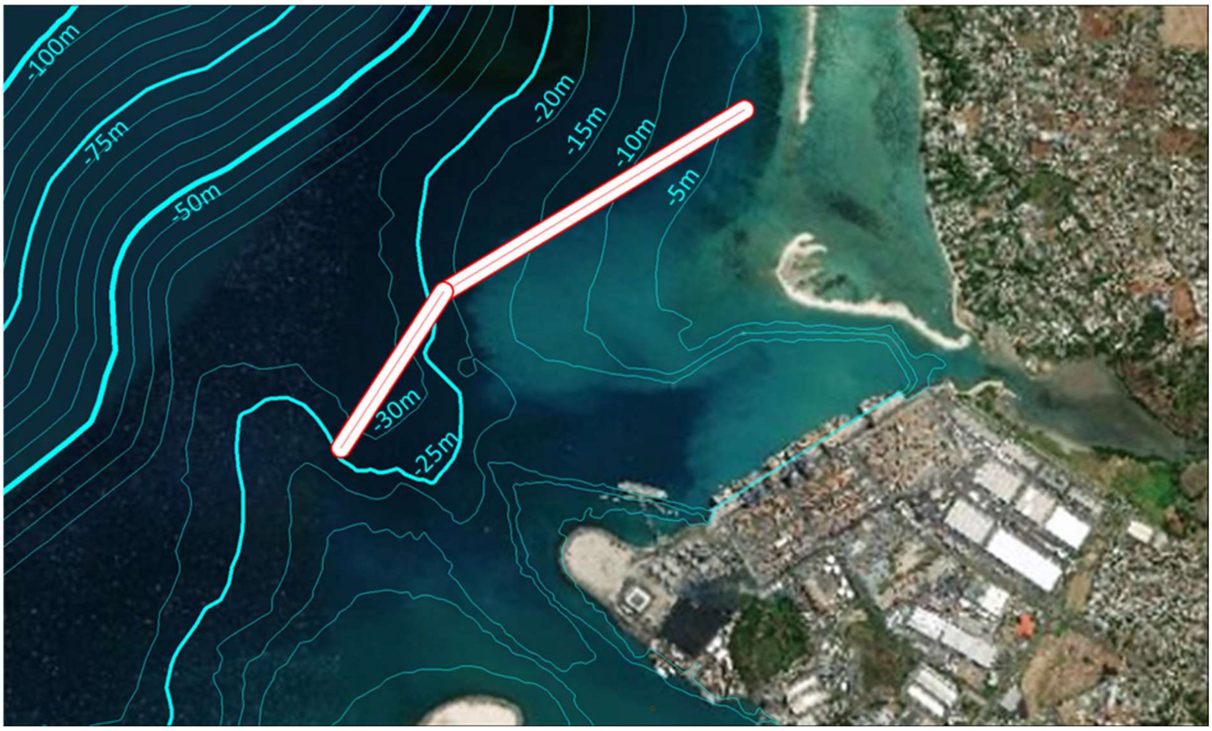
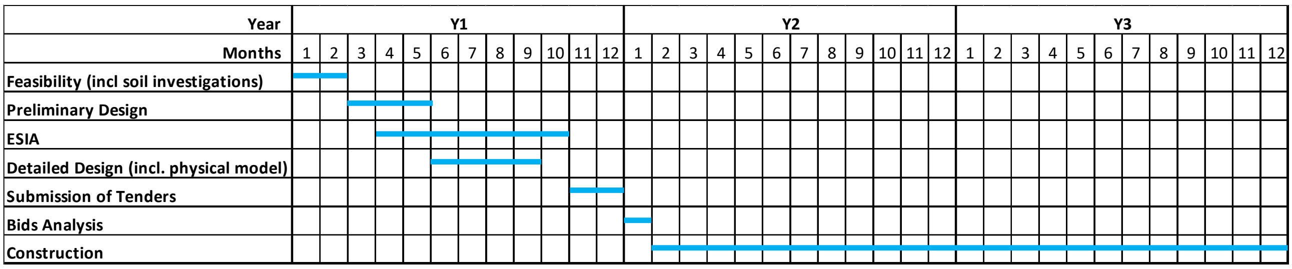


Figure 15. Long breakwater: detailed bathymetry

5.1.3.2. Timeline

The timeline for this type of offshore structure could be as follow:



5.1.3.3. Stakeholders

The main stakeholders are expected to be:

- Government services or authorities to issue calls for proposals, to validate the results of the studies, to obtain funding, to hire contractor, … ;
- Engineering or design offices to carry out the different studies (feasibility, preliminary and detailed design, soil investigations, ESIA, …) ;
- The contractor to build the offshore structure ;
- Funders if needed.

5.1.3.4. Resources

The source of the raw materials (especially rocks) will have to be identified, to know whether rocks are present in quantity and quality on site in Mauritius or have to be imported from abroad (South Africa, Madagascar). Artificial blocks are a viable solution when rocks of sufficient quality or quantity cannot easily be sourced.

Given the size and nature of the structure, it is likely that international companies with specialized equipment will need to be mobilized.

5.2. SHORT BREAKWATER

Measure 2 is a short breakwater to protect the port and the MCT, as shown on Figure 5 (§ 4.1).

The pre-dimensioning of the protection structures was carried out on the basis of expert judgement and the Rock Manual (see reference). The main characteristics are proposed below, including:

- the size of the rocks in the external armour layer ;
- the size of the rocks in the internal armour layer ;
- the composition of the core and any underlayer.

5.2.1. Technical feasibility

The technical feasibility is the same than for the long breakwater (see § 5.1.1.

5.2.2. Application to Port-Louis in Mauritius

Calculations have been done for three points along the breakwater:

- Point A at the eastern roundhead ;
- Point B at the elbow ;
- Point C at the western roundhead.

These three points are illustrated in the figure below.

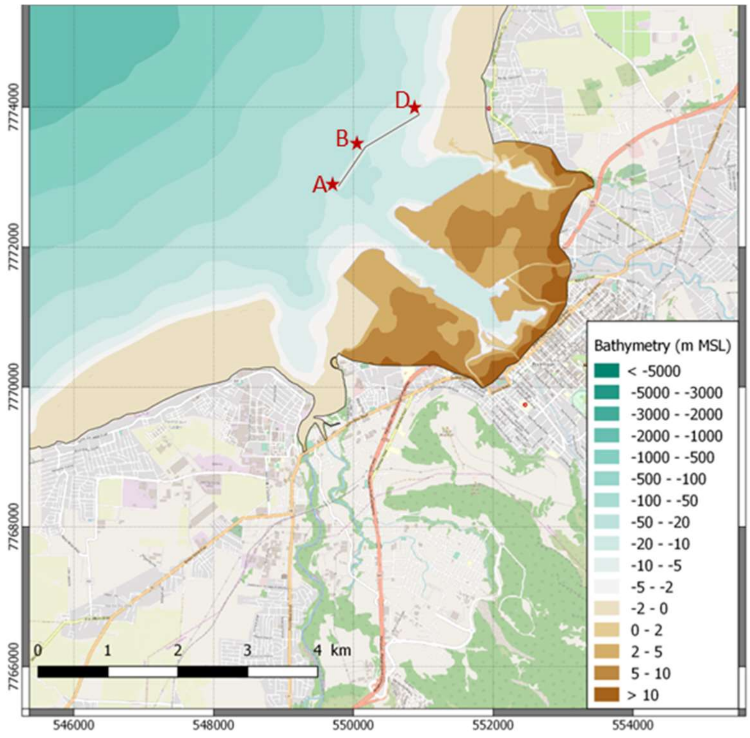


Figure 16. Short breakwater: location of characteristic points

Table 11 : Waves characteristics at Points A, B and D: significant wave height / peak wave period

Return Period	Point D (depth -9.7m MSL)	Point B (depth -22.5m MSL)	Point A (depth -26.8m MSL)
T50	5.9m / 16s	8.4m / 16s	8.3m / 16s
T100	6.8m / 15s	11.3m / 15s	11.4m / 15s

Preliminary calculations have been based on the following parameters:

- Sea state = 24h (cyclonic duration), corresponding to a number of waves N between 5,200 and 7,000
- S_D = 4 : intermediate damage
- P = 0.4 for the external layer
- KD = 16 for ACCROPODE™ or 7 for BCR (cubic blocs). For large wave heights, carapace stabilization will be achieved by using very large armour blocks to withstand large swells.

Results are summarized in the following table:

Table 12 : Rock size at Points A, B and D

Return Period	Point D (depth -9.7m MSL)	Point B (depth -22.5m MSL)	Point A (depth -26.8m MSL)
T50	D_{n50} = 2.3m / M_{50} = 32t	D_{n50} = 3.4m / M_{50} = 100t	D_{n50} = 3.1m / M_{50} = 80t
T100	D_{n50} = 2.4m / M_{50} = 38t	D_{n50} = 3.8m / M_{50} = 150t	D_{n50} = 4.0m / M_{50} = 165t

Table 13 : Bloc size for ACCROPODE™ at Points A, B and D

Return Period	Point D (depth -9.7m MSL)	Point B (depth -22.5m MSL)	Point A (depth -26.8m MSL)
T50	V = 4.5m^3 / M = 12t	V = 13m^3 / M = 31t	V = 12m^3 / M = 30t
T100	V = 6.0m^3 / M = 14t	V = 28m^3 / M = 65t	V = 29m^3 / M = 68t

Table 14 : Bloc size for BCR at Points A, B and D

Return Period	Point D (depth -9.7m MSL)	Point B (depth -22.5m MSL)	Point A (depth -26.8m MSL)
T50	V = 9.0m^3 / M = 21t	V = 26m^3 / M = 61t	V = 25m^3 / M = 58t
T100	V = 14m^3 / M = 33t	V = 64m^3 / M = 150t	V = 66m^3 / M = 155t

Values in red are not realistically achievable due to their excessive weights and size. Values in orange require specific lifting equipment.

Given the results, caissons could also be considered, particularly for the breakwater section with depths greater than 20m MSL.

5.2.2.1. Cost estimate

Using the cost estimates presented in the previous section 5.1.3.1. , the cost for the short breakwater is estimated to be around 285 million of US dollars detailed as follow:

Table 15 : Cost estimate of the short breakwater – Values 2020

Depth (m MSL)	5 – 10	10 – 15	15 – 20	20 – 25	25 – 30	30 – 35
Distance (m)	180	370	300	150	300	300
Cost (US dollar)	7.2m$	30m$	36.3m$	26.0m$	75.9m$	111.9m$

Note that the cost could probably be substantially optimised by modifying the layout to avoid larger depths, as the linear cost of a breakwater is quadratic with the water depth.

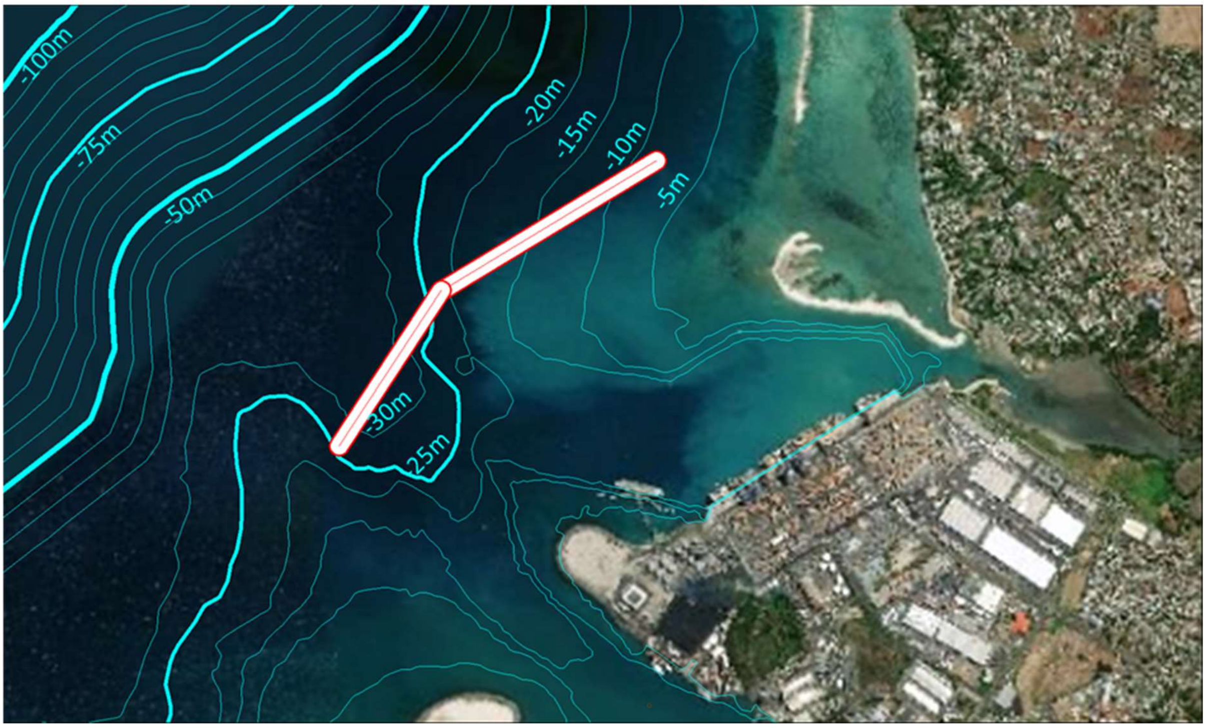


Figure 17. Short breakwater: detailed bathymetry

5.2.2.2. Timeline

The timeline for this type of offshore structure could be as follow:

Year	Y1												Y2												Y3								
Months	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9
Feasibility (incl soil investigations)	x	x																															
Preliminary Design			x	x	x																												
ESIA				x	x	x	x	x	x	x																							
Detailed Design (incl. physical model)						x	x	x	x																								
Submission of Tenders											x	x																					
Bids Analysis													x																				
Construction														x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x

5.2.2.3. Stakeholders

The main stakeholders are expected to be:

- Government services or authorities to issue calls for proposals, to validate the results of the studies, to obtain funding, to hire contractor, … ;
- Engineering or design offices to carry out the different studies (feasibility, preliminary and detailed design, soil investigations, ESIA, …) ;
- The contractor to build the offshore structure ;
- Funders if needed.

5.2.2.4. Resources

The source of the raw materials (especially rocks) will have to be identified, to know whether rocks are present in quantity and quality on site in Mauritius or have to be imported from abroad (South Africa, Madagascar). Artificial blocks are a viable solution when rocks of sufficient quality or quantity cannot easily be sourced.

Given the size and nature of the structure, it is likely that international companies with specialized equipment will need to be mobilized.

5.3. PRE-EVALUATION FOR THE ENVIRONMENTAL AND SOCIAL IMPACT ASSESSMENT

The primary role of the breakwater would be to protect the entrance channel, quays and wharfs from overtopping in times of swells and cyclonic weather, whose frequency and strength are expected to increase over time, as a direct result of climate change. The breakwater will also allow MPA to reclaim areas for the increase of its container storage and handling capabilities, enable larger capacity ships to serve Port Louis and attain its objective of making the port a favorite place for transshipment in this part of the Indian Ocean.

The Mauritius Environment Protection Act (EPA) of 2002 requires the proponent (MPA) for the "construction of breakwaters, groins, jetties, revetments and seawalls" and "modification of existing coastline such as beach reprofiling, coastal protection works and removal of basaltic and beach rock' to submit an Environmental Impact Assessment (EIA) for approval by the concerned Authorities. The breakwater proposed for construction as part of the overall protection of the port against the negative effects of climate change is a major development that will impact the surrounding environment. As per statutory provisions, an EIA for the development is therefore obligatory. At this stage, no preliminary environment and socio-economic impact study has been initiated, nor does it form part of the current TOR for climate change vulnerability and adaptation study for the port, but we recommend that the EIA to be carried out should generally include the following activities:

(i) baseline survey to identify the existing environment ;
(ii) assessment of expected impacts to the existing environment by the construction of the breakwater ;
(iii) identification of mitigating measures and corresponding actions.

Coastal and shoreline engineering works may have considerable effects on the environment, such as:

- Ecosystem
- Geomorphology, existing physical structures
- Individual sensual aspect (optical disturbance, noise, odour)
- Historical and cultural aspects
- Air, water and soil quality (pollution or contamination)
- Social/socio-economic aspects.

The above have to be addressed in the EIA as the proposed breakwater will have an impact on the marine environment and ecosystem in and around the zone of construction.

Experience shows that dredging has a harmful influence on the sea ecosystem in the area where such works are undertaken. It may significantly and irreversibly degrade coral reef and the ocean floor. Possible leaks of petroleum products from equipment to be utilized for the construction of the breakwater will also contribute to pollute the ecosystem.

Construction of the breakwater and the new container terminal will require some dredging works. Dredging will impact on water quality and its effect may span further than the immediate environment of the works. Fine materials will go in suspension during dredging and cause turbidity. Thus, sunlight penetration in the surrounding sea will be reduced and may affect light-dependent organisms. Fine materials may also diminish some filter-feeding organisms' food.

Pollutants such as heavy metals presently trapped in seabed sediments, which traces will be in the surrounding sea water, may be released from sediments.

Residences and hotels in the nearby Northern area (Roche Bois, Baie du Tombeau and Balaclava) of the construction zone, will witness the open sea view on the port they are presently enjoying, partly blocked by the breakwater structure. The value of properties in the area, including hotels, restaurants, seafront bungalows, run the risk of going down. Residents and the tourism sector will also suffer from noise, odor and dust during construction, and even subsequently, though to a lesser extent, due to an increase in port activities. In fact, pollution will be created during construction by heavy equipment and machinery and transportation of rocks and concrete blocks across highly residential, commercial and industrial areas. During operation, there will be an increase in heavy vehicle and of cargo handling, including containers.

There are some important historical and cultural sites such as the Aapravasi Ghat, a UN classified monument for celebrating the arrival of indentured laborers to Mauritius, and Terre Rouge bird sanctuary, which is a wetland of international importance and hence classified as a Ramsar site. The EIA will have to thoroughly cover the present state of the environment and project the risks linked to the new development in the port, proposing all mitigation measures required to avoid any degradation. Existing stormwater drainage by River Terre Rouge, silting, including that transported by River Terre Rouge and sediment movement, needs to be dealt with.

The Wastewater Management Authority, a body corporate, is responsible for the wastewater sector in Mauritius and has, among others, to monitor, supervise, maintain, manage and control wastewater works. It operates a wastewater treatment plant in Baie du Tombeau. Sewage collected from part of Port Louis and Baie du Tombeau area undergoes some very basic treatment before being discharged into the open sea through a 1.5 km long sea outfall. Dispersion of the sewage is facilitated by South West currents in the sea. By constructing a breakwater South of the nearby outfall, there is a risk of interference on the sewage dispersion and increased pollution.

One crucial element of the EIA will be public consultation with a view to obtaining their tacit agreement to the breakwater project. While it is expected that local residents would be less reticent to the proposal, given its potential to generate jobs and economic activities, fishermen and operators in the tourism sector could be more skeptical. It is a fact that there will be an impact on fishermen who presently berth their boats close by and are used to crossing the part of the ocean where the breakwater will be erected, for their daily activities, will have to be made aware beforehand that the port being a restricted area, they are indulging in an illegal activity which has been tolerated so far inasmuch as it is not causing any problem to present port operations. However, when construction of the breakwater will commence, they will have to review their navigation routes. As for the operators in the tourism industry, there will also be benefits to be derived from additional movement and increased handling in the port.

The EIA must list out all mitigating measures for abating possible nuisance to the environment and locals by the implementation of the breakwater project. It is also very important that public consultation be held with all those likely to be affected by the construction so as to thwart the potential risk of public outcry and delays/shelving of the project, which is considered to be essential for:

- Protecting existing structures and installations at the port against the impacts of climate change
- Creating additional economic opportunities for Mauritius through an increase in port activities, including higher transshipment activities.

6. CONCLUSION

This report scans adaptation measures for Port Louis and details some key aspects of some less usual measures through technology fact sheets. Based on a multicriteria analysis with the participation of the main stakeholders, the feasibility of an offshore breakwater has been further worked out at pre-feasibility level.

Numerical modelling shows that a shorter breakwater may be sufficient to achieve the desired level of protection from wave overtopping at the MCT. A breakwater will probably not be able to fully protect the Indian Oil Terminal due to geographical constraints generated by the presence of navigation channels.

The cost of a breakwater is mostly driven by the very large water depth at its western tip, such that an optimisation of the layout may result in substantially lower construction costs. In any case, such a measure would require proper design studies, value engineering as well as a full-fledged ESIA.

In the Caudan basin the relative freeboard, i.e. the difference between the quay level and the extreme water level, is expected to be close to zero in 2100. A breakwater will have no effect on overtopping there, flood walls on the quay will eventually be necessary.

Finally the issue of gender inclusion in adaptation planning has been studied. The workforce in the port sector is mostly male-dominated. Mauritius has already embarked on several initiatives to address gender parity. Some additional, specific recommendations have been made in the report.

The next deliverable formulates an overall adaptation plan based on the selected adaptation measures.

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ANNEXES

ANNEX 1 – FACT SHEETS