Gulhifalhu Dredging, Reclamation and Shore Protection Project

Climate Change Impact Considerationss

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1. CLIMATE CHANGE RISK CONSIDERATIONS

1.1 Introduction

This chapter summarises the consideration of climate change risks involved in the project design phase and relevant mitigation measures proposed in the project design by CDE and the environmental impact assessment (EIA) report for the Project (CDE, 2020). Information provided by Boskalis and publicly available information are also used to consolidate the chapter, and further recommendations are propounded for the future developments of the overall Gulhifalhu reclamation.

1.2 Project Design

This section describes the starting points of the design of the reclamation and the revetments.

1.2.1 Design Life and Design Return Period

The design life of the Project is 25 years and a return period of 1/50 years is adopted for the design. The adoption of such design return period is a standard practice for coastal structures of 25 years design life in Maldives (CDE).

1.2.2 Socio-economic Conditions

Since the Project's proponent is Ministry of National Planning, Housing and Infrastructure (MNPHI), the elevation of land platform to be reclaimed is suggested to 2 m in accordance with the default design elevation used by government reclamation projects. This design elevation has been previously used as the highest design elevation for Hulhumale's development project located adjacent to the Project. It is understood that the average elevation of islands in the central region of Maldives is between +1 to +1.2 m Mean Sea Level (MSL). The other considerations taken for the decision of 2 m of land elevation are an elevation higher than 2 m will affect the accessibility to groundwater, as wells are usually constructed shallowly in Maldives, and higher elevation will also affect the accessibility to other coastal infrastructure (e.g., harbours) that are designed based on a specific boat size normally used in Maldives, which is usually +1.4 m MSL. It is further noted that the design levels go beyond the currently constructed structures such as those in neighbouring Villigili Island and Hulhumale' Island.

1.2.3 Physical conditions

An overview of design water levels and design waves is presented in **Table 1.1** and **Table 1.2** below.

- Water level and design high water level are derived from a joint probability analysis of storm surge with tidal elevations conducted for Bolidhuffaru lagoon reclamation project located approximately 13 km southwest from the Project. The final results of water level and design high water are calculated based on a projection of 50 years return period.
- The return period of tsunami wave at 2 m tsunami wave is an event of 1 in 50 years based on the estimation of tsunami modelling undertaken in *Developing a Disaster Risk Profile for Maldives* (UNDP, 2006) (please refer to ***section 1.3.1.1 Tsunami Hazard***).
- A swell at a height of 1.10 m is estimated to be an event of 1 in 50 years according to various adjacent project experiences[1,2,3].

[1] Artelia and CDE Consulting (2016). Offshore Metocean and Wave Transformation Modelling Report, Bolidhuffaru lagoon, South Male, Maldives.
[2] LHI and CDE Consulting (2016). Offshore Metocean and Wave Transformation Modelling Report, Rahffalhu Huraa lagoon, North Male, Maldives.
[3] Hydronamic (November, 2010) , Design wave conditions, Gulhi Falhu, Maldives, 06008-09-R-01-0a-FJOL

- A storm tide of a height of 1.15 m is predicted to be an event of 1 in 50 years (***please refer to section 1.3.1.2 Cyclone***)
- The sea level is projected to rise 0.13 m by the end of 2040s (***please refer to section 1.3.2.1 Sea level rise***).

Table 1.1 Design Water Level

Event	
Water Level (Return period of 50 years)	0.70 (m +MSL)
Wave Setup (Return period of 50 years)	0.35 m
Sea Level Rise (by the end of 2040s under IPCC 5, RCP 8.5)	0.15 m
Design High Water Level (1/50 years)	**1.20 (m +MSL)**
Elevation level of land reclamation	**2.00 m +MSL**
Highest Elevation level of revetment	**3.00 m +MSL**

Table 1.2 Design Waves Considered in Design

Event	Wave height
Storm Surge Tide (1/50 years)	1.15 m
Swell (1/50 years)	1.10 m
Wind Waves (1/100 years)	1.00 m
Tsunami Wave Height - 2006 (1/50 years)	2.00 m

1.3 Physical Risks

The Task Force on Climate-related Financial Disclosures (TCFD) defines physical risk as aggravated meteorological threats that emanate from acute climate-driven events such as increased severity of extreme weather events (e.g., cyclones, droughts, floods, and fires). These risks can also relate to longer-term shifts (chronic) in precipitation, temperature, and increased variability in weather patterns, and sea level rise. As located in Maldives, the Project is susceptible to climate risks including tsunami, cyclones, and sea level rise according to the UN publication, *Developing a Disaster Risk Profile for Maldives* (UNDP 2006).

The sections below provide the baseline data of acute and chronic physical risks and describe the measures already included in the project design to manage risks related to tsunamis, cyclones and sea level rise.

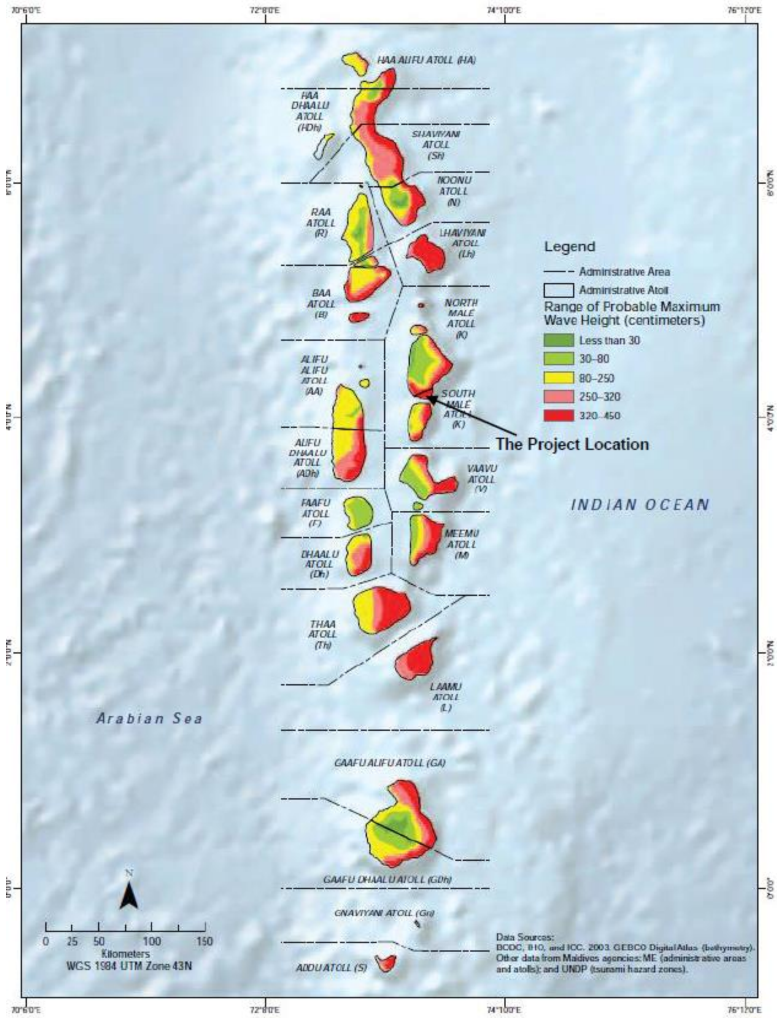
1.3.1 Acute Physical Risks

1.3.1.1 Tsunami Hazard

Tsunamis are destructive sea waves generated by the disturbances on the sea floor, such as an earthquake, a volcanic eruption or an underwater landslide, etc. Given the geographical location and topographical features of Maldives, the source zones where tsunamis are generated that may affect Maldives include Sumatra Subduction Zone, the Carlsberg Transform Fault Zone and Makran Coast Zone. The Sumatra Subduction Zone is located in the east part of Indian Ocean and extends 5,500 kilometres from Myanmar towards the southeast Sumatra and Java, and then east towards Australia. The Carlsberg Transform Fault Zone is a mid-ocean ridge located in the Arabian Sea between India and northern Africa that marks the boundary between Indian and African plates. Makran Coastal Zone is located in a mountain range of the Makran region in south-western section of Balochistan Province, south-western Pakistan. Tsunami threats to the Maldives are largely from the east and are relatively low from the north and south, which means that islands along the eastern fringe are more likely exposed to the hazard. According to the Multihazard risk analysis, Maldives (UNDP, 2020), the

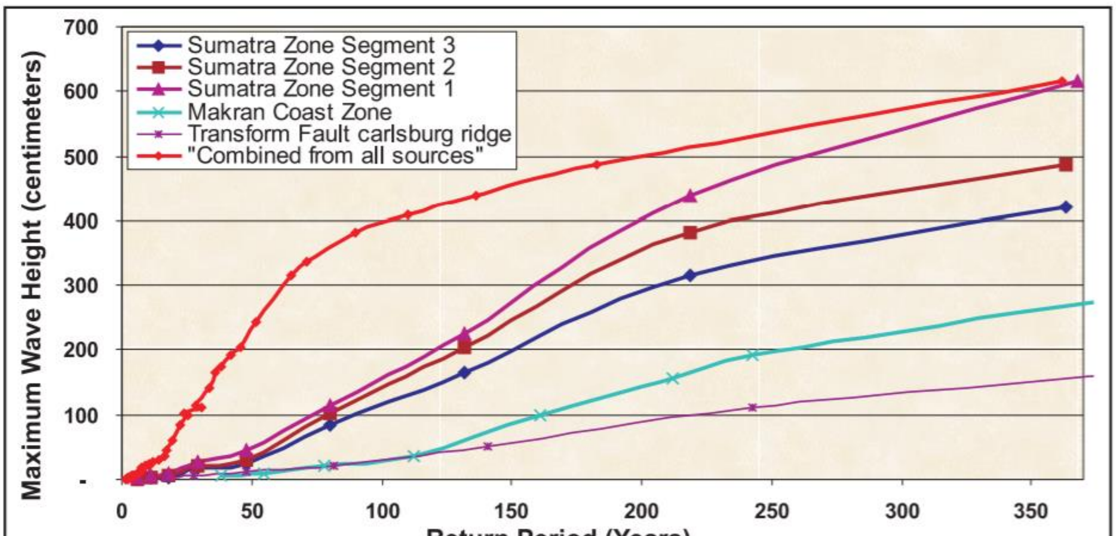
Project is located in Zone 5 (i.e. the highest risk from Tsunami hazard), where the probable maximum wave height ranges from 3.2 m **-** 4.5 m as indicated in **Figure 1.1**. The calculated return periods of tsunami wave heights from various sources by *Developing a Disaster Risk Profile for Maldives* (UNDP, 2006) are presented in **Figure 1.2**. The return period of a tsunami wave at a height of 1 m is 25 years, while that of 2 m tsunami wave is 50 years.

Figure 1.1 Tsunami Hazard Zones in the Maldives



Source: Multihazard risk analysis, Maldives (UNDP, 2020)

Figure 1.2 Return Periods of Maximum Tsunami Wave Heights from various Source Zones



Source: Developing a Disaster Risk Profile for Maldives (UNDP 2006)

1.3.1.2 Cyclone

Cyclones are usually accompanied with wind bursts, rainfall and storm surges, which could further result in flooding to low-lying islands. According to *Developing a Disaster Risk Profile for Maldives* (UNDP, 2006), the Maldives have a low likelihood to be affected by tropical cyclones. Only 21 tropical cyclones have been recorded since 1877, the most recent cyclone that impacted Maldives was a tropical storm went through Dhidhdhoo, the northernmost end of Maldives during 12-19 January 2006. Most of the cyclones crossed Maldives north of 6.0° N and none of them crossed south of 2.7° N during the recording period as presented in **Figure 1.3**[4] (for referenced Saffir-Simpson Hurricane Wind Scale is showed in **Table 1.3**). No cyclone has been recorded in the area adjacent to the Project (i.e. 50 km from the Project) since 1991. However, the country experiences severe thunder storms, known locally as "Freak Storms". Between 1958 and 1988, these events have affected 92 islands throughout the course of a year with peak seasons from May to July. Male was struck by seven such storms. As shown in **Figure 1.5**, the Project is located in an area of moderate to high level of Cyclonic Wind Hazard. *Developing a Disaster Risk Profile for Maldives* (UNDP, 2006) calculated the probabilities and return periods of wind speeds according to the method described by Chu and Wang (1998)[5], by which the return period of a cyclonic storm with a wind speed of 34 knots is 23 years (please refer to **Figure 1.4**). The Project falls into Zone 2 (i.e. low risk zone) of the Surge Hazard Zoning map as presented in **Figure 1.6**, which implies that the area is less exposed to the hazard of storm surge. The results of an analysis[6] conducted to estimate the maximum height of storm surge for various return periods based on the Hulhule[7] data are presented in

Table 1.4 below. A storm tide of a height of 1.15 m is predicted to be an event of 1 in 50 years.

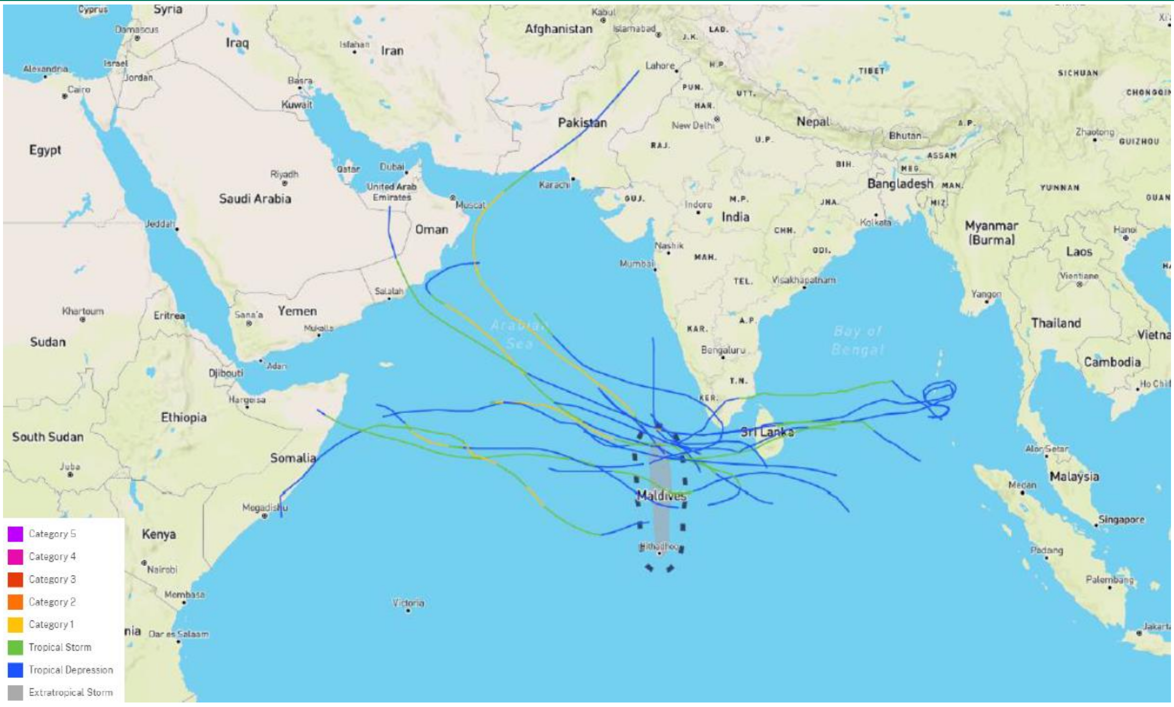
[4] The categorisation of the cyclones follows Saffir-Simpson Hurricane Wind Scale, by which category 1 cyclone is accompanied with very dangerous winds and will produce some damage, and category 3 and above cyclones are considered to cause devastating damage.

[5] Chu, P.S., and J. Wang, 1998, "Modeling Return Periods of Tropical Cyclone Intensities in the Vicinity of Hawaii", J. Appl. Meteor., 37, pp.951-960.

[6] Assessments undertaken for Bolidhuffaru Island Resort located about 12 km from the site. Report states that "Water level measurements at Male' for the period between 26th August 1989 and 4th February 2015 were used to calculate the tidal residuals. An extreme value analysis (EVA) study was undertaken on these residuals to estimate storm surge for various return periods."

[7] Hulhule is one of the meteorological stations providing daily precipitation data for central territories of Maldives

Figure 1.3 Tracks of Cyclones affecting Maldives, 1877-2020

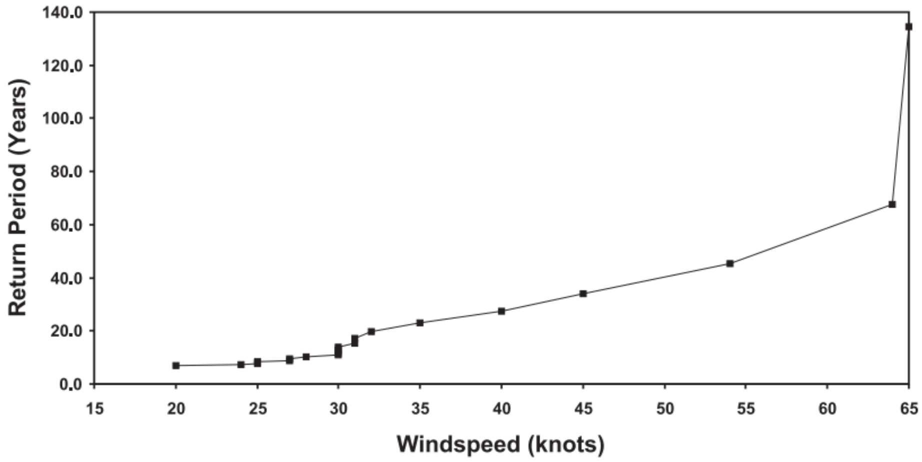


Source: https://coast.noaa.gov/digitalcoast/tools/hurricanes.html

Table 1.3 The Saffir-Simpson Hurricane Wind Scale

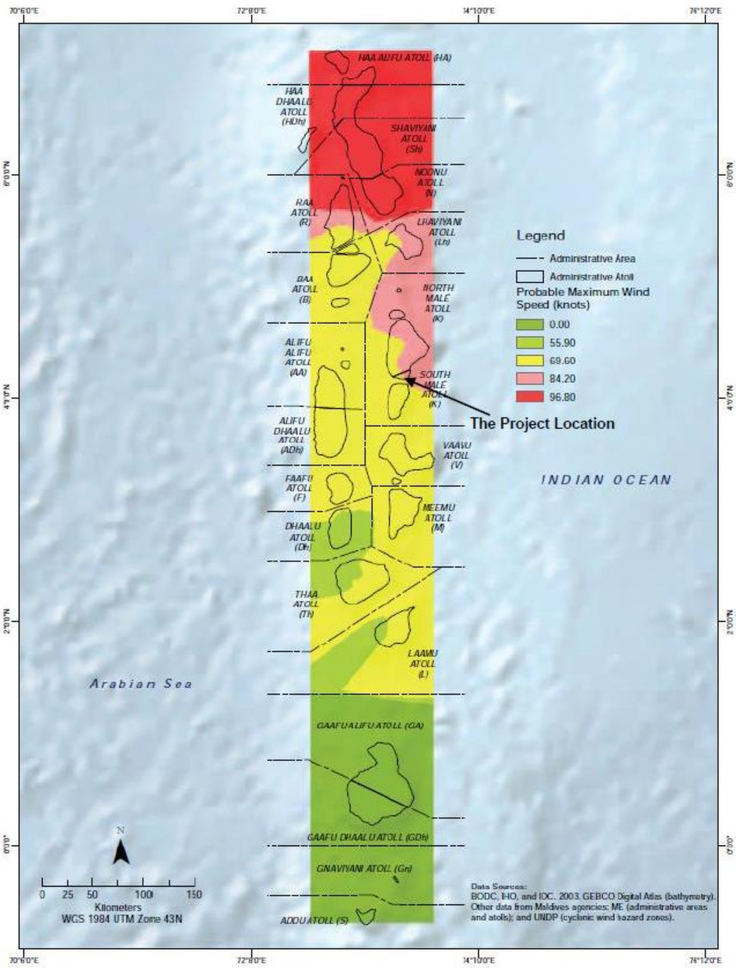
Category	Sustained Winds
1	64-82 kt (119-153 km/h)
2	83-95 kt (154-177 km/h)
3 (major)	96-112 kt (178-208 km/h)
4 (major)	113-136 kt (209-251 km/h)
5 (major)	137 kt or higher (252 km/h or higher)

Figure 1.4 Return Period of Wind Speeds associated with Cyclones in Maldives



Source: Disaster Risk Profile (UNDP 2006)

Figure 1.5 Maldives Cyclone Wind Hazard Zone



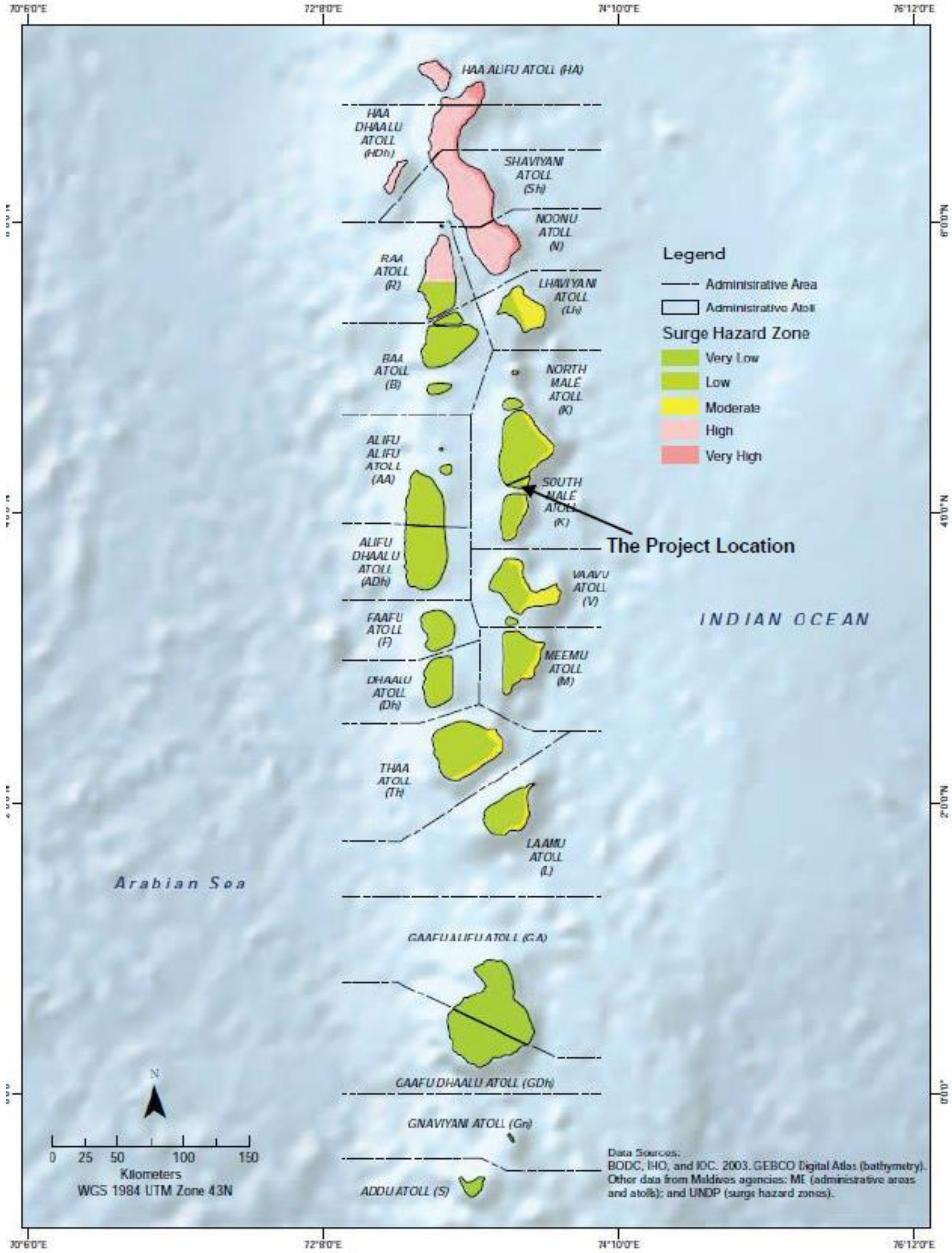
Source: Multihazard risk analysis, Maldives (UNDP, 2020)

Table 1.4 Probable Maximum Storm Tide

Return Periods	Storm Surge Height (m)	Average Tide Level* (m)	Storm Tide Level (m)
1	0.16	0.93	1.09
50	0.22	0.93	1.15
100	0.24	0.93	1.22

**Data obtained from Disaster Risk Profile for Maldives (UNDP, 2006)*

Figure 1.6 Maldives Cyclone Surge Hazard Zone



Source: Multihazard risk analysis, Maldives (UNDP, 2020)

1.3.2 Chronic Physical Risks

Chronic physical risks refer to longer-term shifts in climate patterns such as sustained higher temperatures and precipitation and associated sea level rise. For Phase I of the project (reclaim land on Gulhifalhu and protect the shoreline) only sea level rise is deemed to constitute a climate change induced chronic physical risk. For future phases, especially operation of the port, it is recommended that other factors such as impact of increasing temperatures or more intense rainfall on the workforce and port safety are also considered.

1.3.2.1 Sea level rise

Sea Level Rise is generally determined based on IPCC (Intergovernmental Panel on Climate Change) assessments. The Project has mainly adopted the result for future sea level rise from a climate change projection undertaken for a nearby project. The projection is based on the IPCC's Fifth Assessment Report (IPCC 5) and followed the Representative Concentration Pathways 8.5 (RCP 8.5[8]), for consideration of the worst scenario. In terms of the model database, the projection applied Coupled Model Intercomparison Project Phase 5 (CMIP 5). The model timescale is the same as the design life of the Project, which is 25 years. The results of the projection suggest the sea level is anticipated to rise 0.13 m by the end of 2040s, based on which the Project further adopts 0.15 m as the design basis.

1.3.3 Planned Measures in Response to Physical Risks during Project Construction

The shore protection is designed to be at three different heights of +2.2 MSL, +2.5 m MSL and +3.0 MSL considering different locations and wave conditions, respectively. The design high water level is estimated at +1.2 MSL, which is based on a 25 years design lifetime and 1/50 per year storm event. The safety of the design is determined by this design water level in combination with governing wave conditions. Wave height are ranging 1-2 m and with different wave periods. Three scenarios can be taken into consideration:

1. A scenario with no wave overtopping. This is 'normal' situation without storm conditions. The current design can withstand these conditions.
2. A scenario with wave overtopping during storms, while the overtopping water does not cause structural damage, the overtopping water can be drained, and the waves do not cause severe damage to the structure. The current design can withstand these conditions, given that the recommendation in ***section 1.3.4*** are taken into consideration.
3. A very extreme scenario where the overtopping water will cause significant flooding behind the revetment and safety issues can be expected. This is in the event of a high tsunami and extreme storm.

For the third scenario, considering that the Maldives is a state prone to tsunamis and cyclones, the country has deployed an earthquake and tsunami awareness alert system that is classified as Alert 1, Alert 2 and Alert 3 from low to high risk level. Boskalis is recommended to follow the specific guidance under each of alert level during Phase I. Additional measures are proposed as followings:

Before the Storm and Tsunami

- Staff should pause working in advance of storm arrival;
- Staff should be trained to understand where emergency medical assistance can be obtained and where disaster stations will be established before storm arrives;
- Staff should stay away from oceans;
- Set up an office routine of checking reports on progress of storms; and
- Secure all outdoor objects that might be blown away or uprooted by anchoring them or moving them indoors.
- Labour facilities should be protected against damage and labour should have an appropriate shelter during the storm, also for sub-contractors.
- Have a satellite phone at main locations, charged and functional.
- Bring ships in sheltered areas.

During the Storm and Tsunami

[8] RCP 8.5 represents a high greenhouse gas emission scenario with no mitigation efforts.

- Beware the eye of the storm. A lull in the wind can occur lasting from minutes to over an hour when the calm storm centre passes.
- Keep communication lines open among the different shelters and with the emergency services.

After the Storm and Tsunami

- Stay out of disaster areas;
- When electric power is disrupted, turn off appliances and light switches so that electric circuits will not be overloaded when electricity is restored;
- Eat food stored in refrigerators and freezers within first few hours only, otherwise eat canned food; and
- Check on colleagues and assist anyone in need of medical attention.
- Check and repair damage on facilities, equipment and ships.

1.3.4 Recommended Measures in Response to Physical Risks during Port Construction and Operations

This section includes recommendations for the Project Proponent MNPHI to minimize physical risks during port construction and operations due to climate change hazards.

1.3.4.1 Revetment design:

1. Since ports can be considered critical infrastructure with high capital investment, it is recommended to increase the safety level. Increasing the design return period (to 1/100 per year) and design lifetime (to 50 years) is hereby advised, which is in line with similar coastal protection projects in the area. A design lifetime of 50 years is in line with the national building code of The Maldives for buildings (Ministry of Construction and Public Infrastructure, 2008);
2. It is recommended that other factors such as impact of increasing temperatures or more intense rainfall on the workforce and port safety are also considered; and
3. It is advised to assess the hydraulic boundary conditions (including governing wave conditions and the effects of cyclones) into more detail.

1.3.4.2 Constructed sections of the revetment:

It is noted that some revetment sections have already been built in Stage 1 of the project. In order to avoid having to re-construct these sections, it is recommended to make these sections more climate-resilient in the first 25 years by:

1. Adopting an extensive operation and maintenance program that ensures structural stability during the design lifetime. For example: budget and equipment shall be allocated for immediate repairs at all time. This way, more damage can be allowed (temporarily) whilst the structure stability and design life is not put at risk;
2. Strengthening the current revetment (e.g. widening and/or strengthening the crest and rear side of the crest to prevent scour by either widening the crest or by building an asphalt layer / high quality grass cover).

1.3.4.3 Design / Layout of the Port Area

The alignments and layout of the future port area on the reclamation has not been assessed at this stage, the following recommendations are, therefore, made:

1. An integrated design of the revetment in relation with the area directly behind the crest is advised to be considered in relation to the overtopping criterion;
2. It is advised to include a recommendation for minimum floor levels or levels for critical elements of facilities (e.g. electrical equipment and mechanical installations) within the national building code. A minimum level of at least 3m+CD is recommended; and
3. It is recommended that other factors such as impact of increasing temperatures or more intense rainfall on the workforce and port safety are also considered.

1.4 Transition Risks

During construction period, greenhouse gases (GHGs) will be emitted by the operation of vessels and vehicles powered by fossil fuels. Combustion of fossil fuels generates GHGs such as CO_2, CH_4, and N_2O. **Table 1.5** below presents the detailed emission sources during the construction phase. The quantity of emission directly depends on the types of fuel as carbon content and energy density of different fuels varies. Emissions are estimated using the fuel consumption and emission factors provided by USEPA, and the results are shown in **Table 1.6**. The overall emission during the construction phase (lasting approximately 15 months) is anticipated to be approximately 81,414.28 tonnes of CO_2 equivalent. As per EP 4, a project will be subject to an assessment of transition risks when its combined scope 1 and scope 2 emissions are expected to be more than 100,000 tpa (tonnes per annum) of CO_2e. Therefore, the transition risks of the Project will not be further discussed in the report.

Table 1.5 Anticipated Fuel Consumption Level

	Stage 1			Stage 2		
Equipment	**Units**	**Fuel Type**	**Total Fuel Consumption/L**	**Units**	**Fuel Type**	**Total Fuel Consumption/L**
Wheel loader	1	Diesel	64,000	1	Diesel	154,249
Bulldozers	3	Diesel	27,500	3	Diesel	275,445
Excavator	8	Diesel	71,200	6	Diesel	771,246
Telehandler	1	Diesel	2,268	1	Diesel	4,000
Dump trucks	5	Diesel	210,000	2	Diesel	210,000
Service truck	1	Diesel	7,000	1	Diesel	8,000
Speed boat	5	Petrol	28,800	5	Petrol	37,900
TSHD Fairway	1	Marine Gas Oil (MGO)	5,667,440			
TSHD Gateway				1	MGO	20,736,128
BHD	1	MGO	231,500	1	MGO	156,742
Multicat	1	MGO	101,170	1	MGO	1,195,186
Tugs	1	MGO	24,100	1	MGO	31,380
Landing craft	1	MGO	19,300	1	MGO	38,091

Table 1.6 Anticipated Emission Levels (Tonnes)

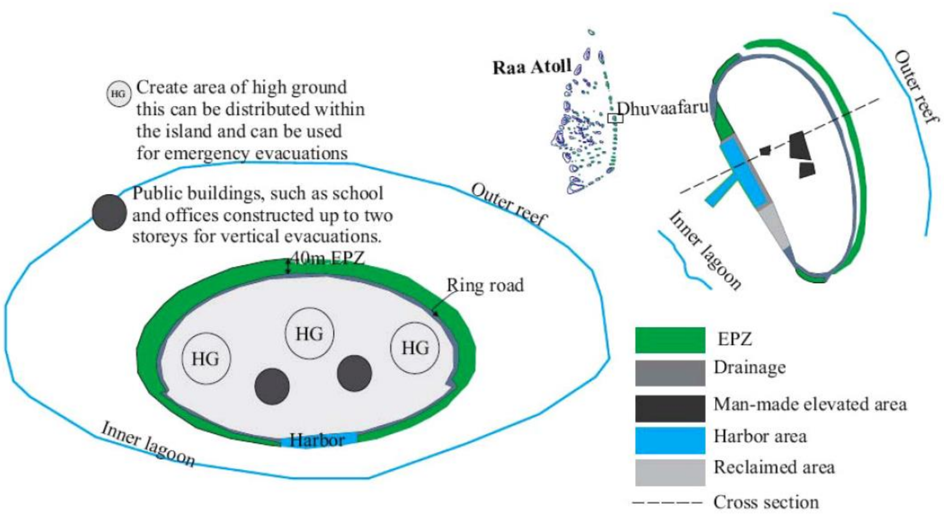
Fuel Type	CO_2	CH_4	N_2O	CO_2e
Petrol and Diesel	5,022.90	0.26	0.23	5,096.58
MGO	76,063.73	3.05	0.60	76,317.70

In total	81,086.63	3.31	0.83	81,414.28

1.5 Compatibility with Host Country Climate Change Commitments

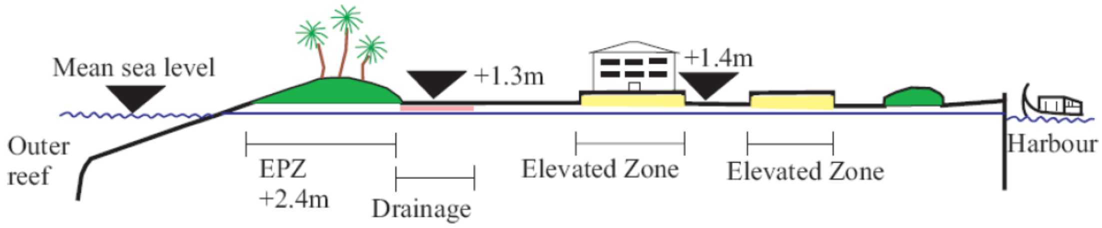
Maldives is a signatory to the Paris Climate Accord, and the Maldives Government has released various policies and regulations to fulfil its commitment to climate change mitigation and adaptation, and to develop communities resilient to natural hazards. Climate Emergency Act (10/2021) and Disaster Management Act (28/2015) are the two overarching laws directly related to climate change. Climate emergency act ensures the adaption of measures and actions to defend climate change shall be included in national development plans, programmes and projects, whereas Disaster Management Act not only stipulates the actions required during disaster events, but also sets forth objectives that projects shall include disaster mitigation measures. Policies including Strategic Action Plan 2019-2023 and National Spatial Plan and set out the objectives to enhance Climate Resilience and Disaster Preparedness through integrated infrastructure and sectoral planning in a streamlined manner to ensure short, medium and long-term sustainability, and to build climate resilient infrastructure and communities to address current and future vulnerabilities. After the Indian Ocean Tsunami of 2004, the Ministry of Planning and National Development of Maldives developed National Recovery and Reconstruction Plan, by which the Government has developed a strategy namely Safe Island Concept (please refer to **Figure 1.7** and **Figure 1.8**) to increase the safety of island communities, by redesigning the physical development features of islands and incorporating measures such as wider environmental protection zones, creating elevated areas for vertical evacuation in the event of floods, and providing easy access in emergencies. Safe Island Concept has further been developed as the default method for adaptation in newly reclaimed islands since 2006.

Figure 1.7 Schematic of the Safe Island Concept



Source: National Recovery and Reconstruction Plan, Programmes and Projects (2005) developed by Ministry of Planning and National Development (MPND)

Figure 1.8 Cross section of the Safe Island Concept



Source: National Recovery and Reconstruction Plan, Programmes and Projects (2005) developed by Ministry of Planning and National Development (MPND)

As mentioned above, the Project will raise the island elevation to +2.0 m and install shore protection at +2.5 m MSL to further prevent coastal flooding impacts. Besides, the vertical design of the whole port development project also adopts Safe Island Concept through installing shore protection all around the exposed shorelines to prevent erosion, introducing buffer area between ocean side revetment and nearest structure, locating critical infrastructure away from the coast and creating green vegetation belt between shoreline and developments.