Annex G

Floating Docks Surveying and Replacement Design

2024

Reference Documents

Background Information


THE GEOLOGICAL MAP OF BERMUDA
THE MINISTRY OF WORKS AND ENGINEERING, THE BERMUDA GOVERNMENT
Mapping and compilation by H. L. Vacher, M. P. Rowe and P. Garrett
1989
Physiographic and tectonic setting of the Bermuda volcanic seamount
NORTH AMERICA
BERMUDA
ATLANTIC OCEAN
CARIBBEAN SEA
Continental crust
Ocean floor basalt – Jurassic Period, Cretaceous Period and Cenozoic Era.
Isochrons corresponding to the Cenozoic/Cretaceous and Cretaceous/Jurassic boundaries
Major fracture zone
Contours of water depth - 2000m intervals
EXPLANATION
QUATERNARY
HOLOCENE
PLEISTOCENE
Beach sediments Includes shoreline dunes at Warwick Long Bay, Horseshoe, Elbow, and Mid-Ocean Beaches.
Marsh deposits Up to 25m thick at Devonshire and Pembroke Marsh
Qs
SOUTHAMPTON FORMATION Loosely consolidated aeolianite with many snail-rich protosols. Includes shelly marine deposits (Qsm), notably along west coast of Sandy's Parish. Building sand.
Poorly developed palaeosol
Qr
ROCKY BAY FORMATION Lightly cemented aeolianite with localised underlying, shelly marine deposits (Devonshire member, Qdm). Includes gently dipping (beach?) along north shore near Blackwatch Pass (Qbw). Snail-rich protosol separates the Devonshire marine and overlying aeolianite and also occurs between aeolianites in central parishes. Principal fresh water aquifer. Building stone locally.
Shore Hills Geosol (terra-rossa palaeosol)
Qb
BELMONT FORMATION Mostly aeolianite. Grades seaward to, or is underlain by, beach deposits (Qbm) found along the south shore of the central parishes, notably at Spittal Pond. Locally includes protosol between marine and overlying aeolian facies. Building stone.
Ord Road Geosol (terra-rossa palaeosol)
Qtu
TOWN HILL FORMATION Aeolianite with isolated marine deposits (Qtm).
Upper Member Large aeolianites. Includes, one or more extensive protosols. At North Street in Hamilton a protosol separates marine and overlying aeolian facies. Building stone and roofing slate.
Harbour Road Geosol (terra-rossa palaeosol)
Qtl
Lower Member Indurated and locally cavernous aeolianite. Includes terra-rossa palaeosol at Naval Air Station, St. Davids. Building stone and roofing slate.
Castle Harbour Geosol (terra-rossa palaeosol)
Qw
WALSINGHAM FORMATION Tightly cemented to recrystallised aeolianite. Cavernous. Includes terra-rossa palaeosol at Castle Harbour Hotel and marine deposits (Qwm) in St Georges West. Road aggregate.
The formations consist of cross-bedded, bioclastic limestones deposited during interglacial epochs when the Bermuda Platform was submerged. The limestones accumulated in coastal-dune, beach and rocky shore environments as aeolianites, marine calcarenites and conglomerates. Induration of the rock increases generally down-section, from the friable Southampton to the tightly cemented Walsingham.
Formation contact (generally palaeosol) exposed.
Formation contact concealed; dotted where uncertain.
Protosol exposed.
Protosol concealed; dotted where uncertain.
Dune foreset strike and dip (local average). Range of dips is 32° to 38°.
Sc School
Ch Church
H Hotel
PO Post Office
GC Golf Club
Prominent building or site
Urban zone
Road
Cliff or Quarry face
Filled land surrounding former island (now levelled)
Parish boundary
ST. GEORGE'S ISLAND
ST GEORGE'S TOWN
PAGET ISLAND
ST GEORGE'S HARBOUR
SMITH'S ISLAND
FERRY REACH
U.S. NAVAL AIR STATION
ST. DAVID'S ISLAND
CONEY ISLAND
COOPER'S ISLAND
CASTLE HARBOUR
NONSUCH ISLAND
CASTLE ISLAND
HAMILTON
TRUNK ISLAND
HARRINGTON SOUND
THE NORTH LAGOON
IRELAND ISLAND NORTH
IRELAND ISLAND SOUTH
BOAZ ISLAND
WATFORD ISLAND
SANDYS
SOMERSET ISLAND
SMITHS
PEMBROKE
DEVONSHIRE
CITY OF HAMILTON
HAMILTON HARBOUR
PAGET
WARWICK
SOUTHAMPTON
GREAT SOUND
LITTLE SOUND
ELY'S HARBOUR
U.S. NAVAL ANNEX
GRACE ISLAND
BURT ISLAND
DARRELL ISLAND
HAWKIN'S ISLAND
LONG ISLAND
PORT ISLAND
MARSHALL ISLAND
HINSON ISLAND
GRANAWAY DEEP
TWO ROCK PASSAGE
SPANISH POINT
THE ATLANTIC OCEAN
Grid North
Magnetic North
True North
Annual change 02' West
Scale 1:25000
Contour interval 10 metres
Numbered lines indicate 5 kilometre Universal Mercator Grid
Source of base map information 6811 (Bda 311), British Government Directorate of Overseas Surveys
THE BERMUDA PLATFORM
NORTH ROCK
THE NORTH LAGOON
Average depth to volcanics 75m
Holocene
coralgal and algal-vermetid reefs
carbonate lagoonal sediments
Pleistocene
predominantly aeolian calcarenites
THE ATLANTIC OCEAN
SECTIONS
St. George's Parish
Smith's Parish
Pembroke and Paget Parishes
Southampton Parish
Warwick-Paget Parish boundary (Cobbs Hill Road)
Horizontal scale for sections 1:12500
* projected onto line of section
Geological mapping and compilation by authors 1972–1980 commissioned by the Public Works Department, the Bermuda Government, J. Smith O.B.E., Director. Re-compilation at 1:25000 scale and co-ordination of map production by M.P. Rowe 1988. Final draught and printing 1989 by Oxford Cartographers, Oasis Park, Eynsham, Oxford OX8 1TP. U.K. Copies of this map can be obtained from the Ministry of Works and Engineering, P.O. Box HM 525, Hamilton HM CX, Bermuda.

Bermuda's Climate Change Predictions

An important part of assessing Bermuda's coastal vulnerability is the most recent projections of climate change, based on the latest understanding and research on the expected scenarios of the earth's environment. The table[1] below summarises the parameters considered and changes observed, as well as the projections, based on historical data and climate change models respectively.

Parameter	Historical Trend	Projection
Temperature	Air temperature varies through the year with highest temperatures from July - September and lowest in January - March. Mean monthly temperature has been increasing between 0.22°C and 0.6°C per decade. Hot days & nights have also been increasing at a rate of 4% & 3% per decade, respectively.	Temperature is expected to keep increasing with global warming. In the medium term (2040-2060) the projected annual increase is between 0.6 & 1.7°C. In the long term (2070-2090) the projected annual increase is between 0.6 & 3.2°C. Hot days & nights are increasing & will account for nearly 100% of days by end of the century (under RCP 8.5). Heatwave durations are increasing & will reach near 60 days by the end of the century (under RCP 8.5). The World Meteorological Organization (WMO) defines a heat wave as a period during which the daily maximum temperature exceeds for more than five consecutive days the maximum normal temperature by 5°C, the normal period being defined as 1961–1990.
Rainfall	The island's climatology exhibits a bimodal rainfall pattern with peaks in January and September, and with the September peak receiving more rainfall.	The RCPs suggest no real varying trend toward the end of the century. In the medium term (2040-2060) mean annual rainfall projected change is 4 - 11%. In the long term (2070-2090) mean annual rainfall projected change is 3 - 48%. Extreme events will be characterised by significant interannual variability. However, rainfall indices reflect no real overall trends with, for example, projected change in consecutive dry days (CDD) of between 0.1 & 0.2 days/decade & changes in consecutive wet days (CWD) of 0.0 & 0.2 days/decade.
Sea Surface Temperature (SST)	SSTs are highest between August - September & coolest from December - April. SSTs are increasing at a rate of 0.26 °C per decade.	SSTs are projected to increase at a rate of 0.43 °C per decade (under RCP 8.5). In the medium term (2040-2060) monthly projected increase ranges from 1.0 – 2.3 °C (for RCP 8.5). In the long term (2070-2090) monthly projected increase ranges from 2.5 – 4.0 °C (for RCP 8.5).
Sea Level Rise	Bermuda lies in an area that has experienced sea level rise of more than 3.84 mm/year.	For Bermuda, there is good consensus across the two mapping tools examined about SLR. By 2100, mean SLR is projected to be approximately 0.69-0.82m for SSP5-8.5 (more than the global SLR estimate of 0.77m). However, this estimate does not include revised Antarctic ice-sheet contributions, incorporation of which may result in a worst-case SLR of up to 1.46m for Bermuda ("low confidence" SSP5-8.5 scenario). For this study, the median SSP5-8.5 scenario was applied, with a SLR rate of 10.5 mm/year.
Hurricanes	Over the last 4 decades there were 21 storms passing within 50km of Bermuda. 5-8 storms passed per decade except for 1991 to 2000 when no storms were recorded passing within 50km.	The future will likely be characterized by more intense hurricanes (Categories 3, 4 and 5) with corresponding high winds and greater rainfall. A likely increase in rainfall rate of between 20% and 33% is projected, particularly near the hurricane's core, by the end of the century.

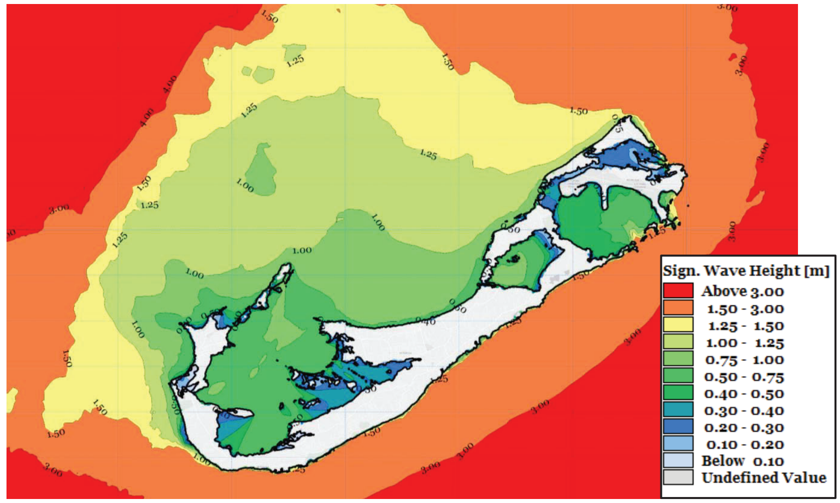
[1] Clarke, L., Taylor, M. & Maitland, D. 2022. "Climate Profile and Projections for the Island of Bermuda", Climate Studies Group Mona, University of the West Indies, Mona, Jamaica.

due to substantially fewer outer reef formations. Within enclosed embayments (e.g. Harrison Sound), wave heights are further reduced to less than 0.3m.

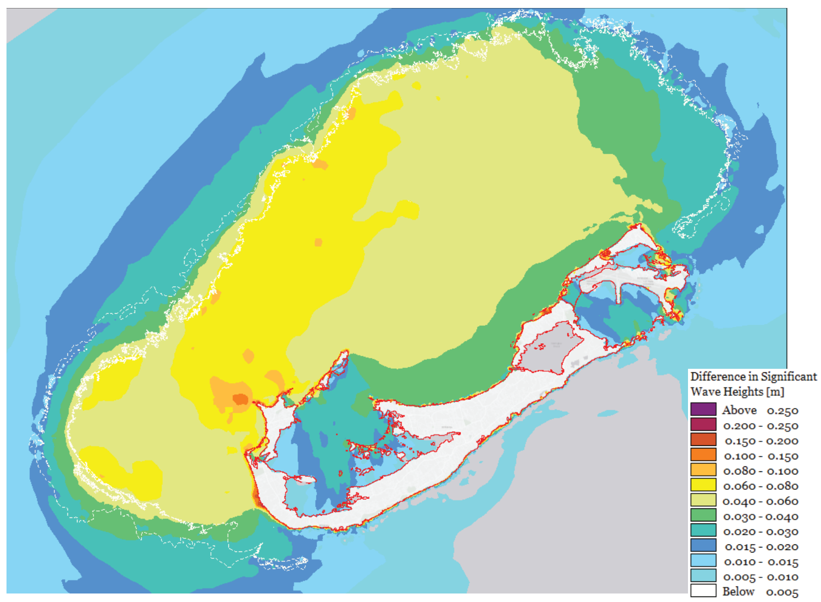
Under future climate scenarios, the lagoon in the lee of the reef will see the most impact. This is expected as the effectiveness of the reef to reduce wave heights will be significantly reduced as sea levels rise. For the 100-year horizon, significant wave heights within the lagoon could increase by 0.08m to 0.15m for the RCP 4.5 and RCP 8.5 scenarios, respectively. These values are significant and equate to a 15-20% increase in the significant wave height.

The south coast has less increase in wave energy, likely because the south coast is not as dependent on protection from the reef as is the north coast.

From this assessment we can conclude:



99th percentile significant wave heights (present day conditions)



Increases in 99th percentile significant wave height between present day and SSC 8.5 100 year wave event

- The western coast (near Dockyards) is at risk of greater wave energy. This has implications for the maritime activities in this area, i.e., more disturbance to cruise ships, shipping, ferries and general navigation in the area.
- Likewise, the north coast areas outside the protection of the sounds will see larger increases in wave energy. Industries such as the power plant could be affected.
- Within the Sounds, wave heights could increase by up to 250%, however, this only reflects a change in wave height of approximately 5mm.
- Under statistically significant events, significant wave heights will increase by more than 0.3m and will have implications on sediment movement.

- Under statistically significant events, significant wave heights will increase by more than 0.3m and will have implications on sediment movement.

Impacts of Climate Change on the Hurricane Climate

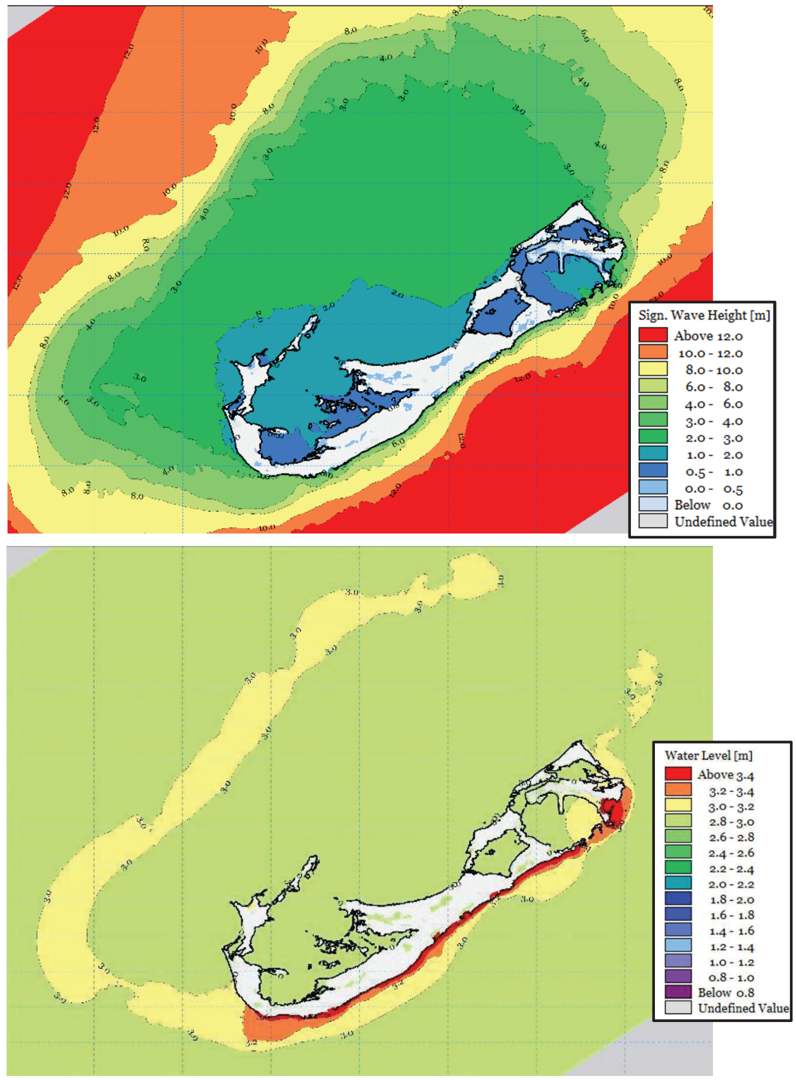
Presently, the reef effectively protects the north shore from hurricane waves. The rim reef at the north reduced wave heights from 10m (offshore) to approximately 2m at the shoreline.

Despite this reduction, waves 1-2m high affect the shoreline of the north coast under the 25-year return period event. Under the 150-year event, wave heights on the north shore are 2-3m with accompanying inundation.

Unlike the north shore, the south shore has significantly less protection from reefs. As a result, wave heights immediately offshore can be 8-10m during a hurricane.

Storm surge is expected to be greater than 1.2m on the north shore while along the south shore, storm surge levels will exceed 1.6m. At these levels, large coastal areas will be under water.

Under future climate change projections, the north shore is more severely impacted as the reef's protection from waves becomes less effective with increased sea levels. Increased storm wave conditions impact the north shore and propagate into the Great Sound area. For example, under the 150-year return period in an RCP 8.5 scenario in the next 100 years, areas previously effectively protected by the reef (the north, north-west and Great Sound) will see increases in wave heights of 10.8% to 20.3%. A similar trend exists for storm surge.



100 year conditions for 150-year storm event under RCP 8.5 scenario

5 Nearshore Hurricane Waves and Water Levels

The MIKE 21 software, using both its SW (Surface Wave) and HD (Hydrodynamic) modules, conducted simulations of nearshore hurricane wave and water level conditions along Bermuda's coast through a coupled mode, allowing for the simulation of the interplay between waves and currents. This coupling between hydrodynamics and wave action is crucial for accurate storm surge predictions, especially in areas where wave setup significantly contributes to the overall storm surge. As substantial waves break in shallow waters or against a reef, they elevate the water level and generate localized currents. These currents, along with the altered water levels, enable waves to reach further inland.

For the analysis of Bermuda's coastline, eight directional sector scenarios were examined: east, northeast, north, northwest, west, southeast, south, and southwest. These scenarios were integrated with conditions derived from deep-water wave models for return periods of 25, 50, 100, and 150 years. The outcomes from the wave transformation modeling under various hurricane conditions are detailed in the following sections.

5.1 Present Day Conditions

In the present-day conditions, the influence of sea level rise was not considered. The results are shown in Figure 5.1 and Figure 5.2 following. Without the effects of climate change, the following was observed:

- The reef effectively protected the north shore from hurricane waves. The rim reef at the north reduced wave heights from 10m to approximately 2m at the north shore.
- Despite this reduction, significant wave heights between 1-2m affect the shoreline on the north coast under the 25-year return period event. Under the 150-year event, the wave heights on the north shore are 2-3m. These wave conditions will have significant wave run-up potential.
- Unlike the north shore, the south shore does not have protection from the reefs. As a result, the wave heights immediately offshore are 8-10m in height during a hurricane.
- The storm surge levels are less than 1.2m on the north shore, while along the south shore, the surge levels are greater than 1.6m.

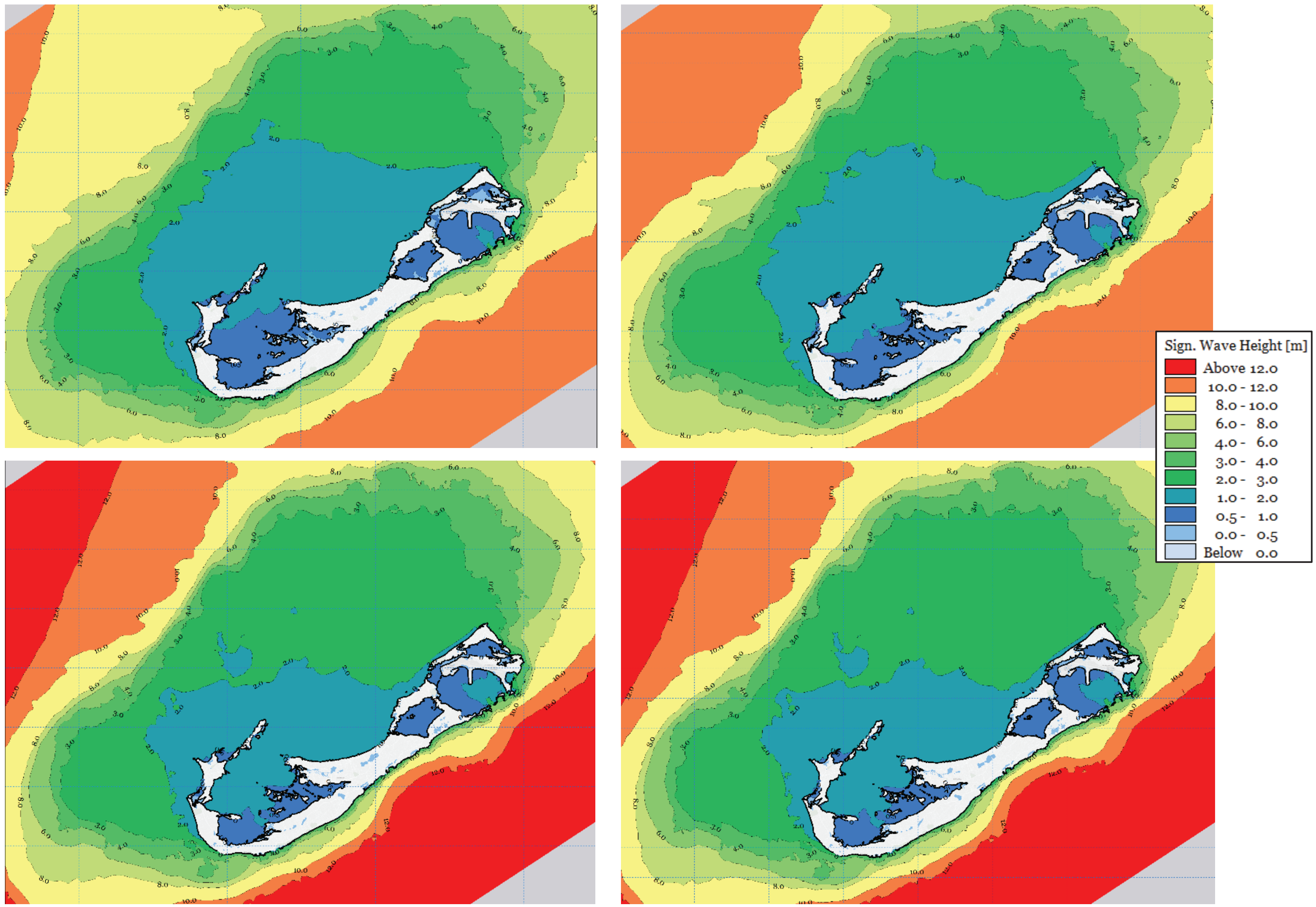


Figure 5.1 Hurricane wave heights computed for the 25-yr, 50-yr, 100-yr and 150-yr return period without the effect of SLR

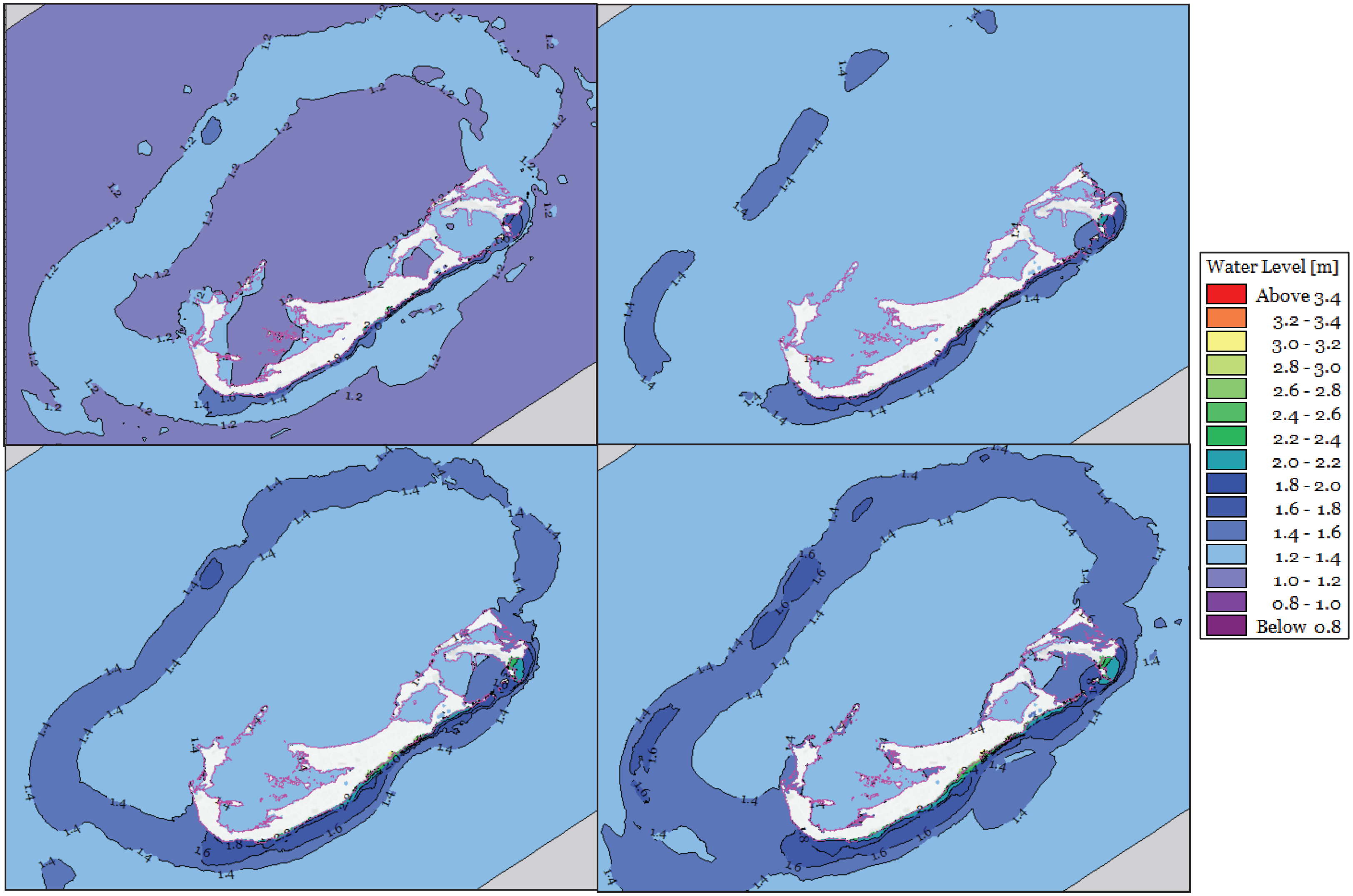


Figure 5.2 Storm surge computed for the 25-yr, 50-yr, 100-yr and 150-yr return period without the effect of SLR

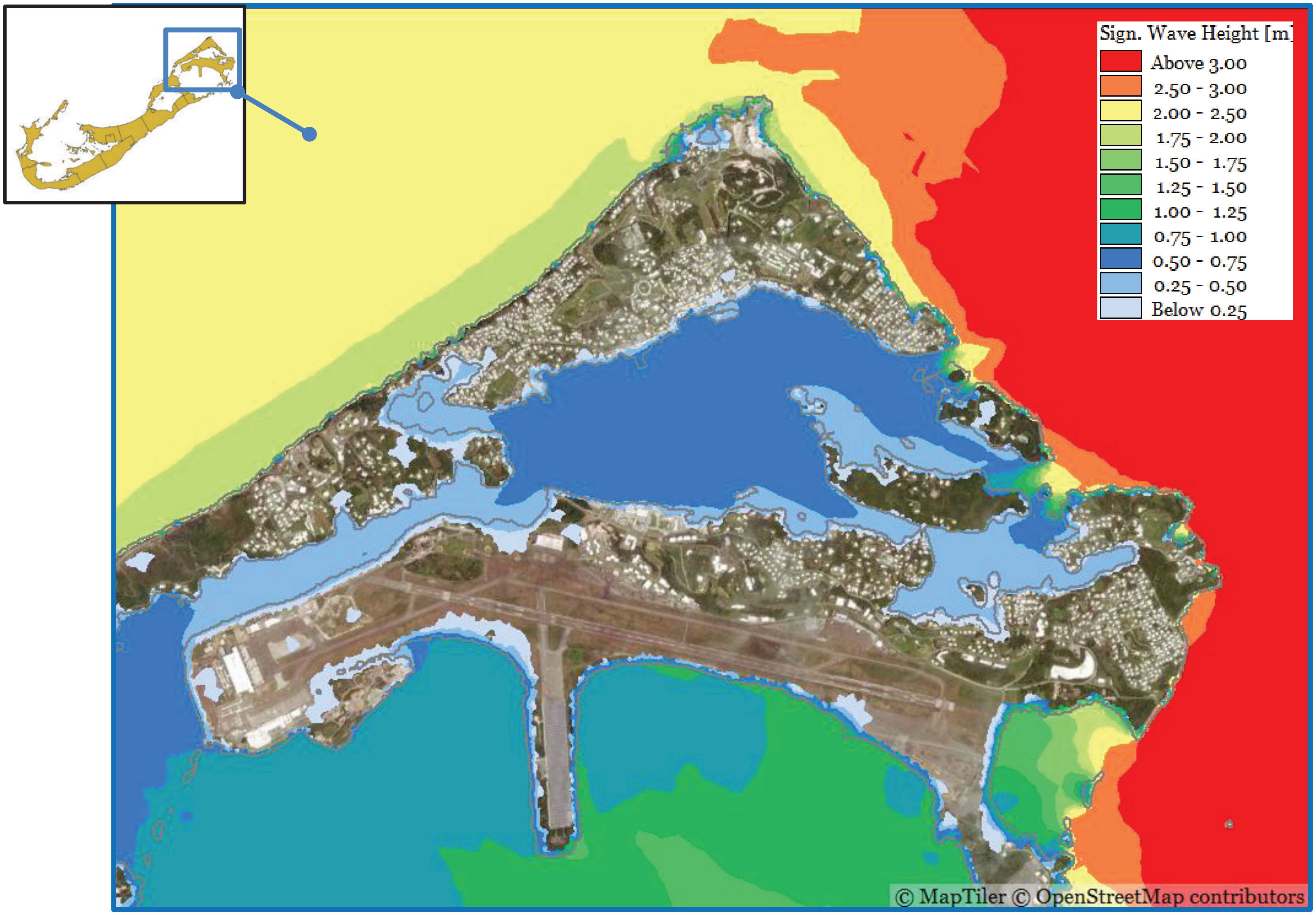


Figure 5.3 Computed hurricane wave height for Castle Harbour and the Town of St George's for the 150-Year Return Period

5.2 Hurricane Conditions under the RCP 4.5 and RCP 8.5 Scenarios

Based on the historical storm analysis, hurricane conditions (combination of a significant wave height, wave period, wind speed, and the inverse barometer rise) were computed for return periods (RP) of 1 in 25, 50, 100, and 150 years. The effects of sea level rise due to climate change on these conditions were examined using the mild (RCP 4.5) and extreme (RCP 8.5) scenarios in three-time horizons: 20 years (~2042), 50 years (~2072) and 100 years (~2122). This resulted in a total of 24 scenarios summarized in Table 5-1.

Figure 5.4 to Figure 5.7 present the 100-year time horizon conditions for the RCP 4.5 and 8.5 scenarios for the return periods 25-year, 50-year, 100-year and 150-year. Appendix E contains the other simulation results.

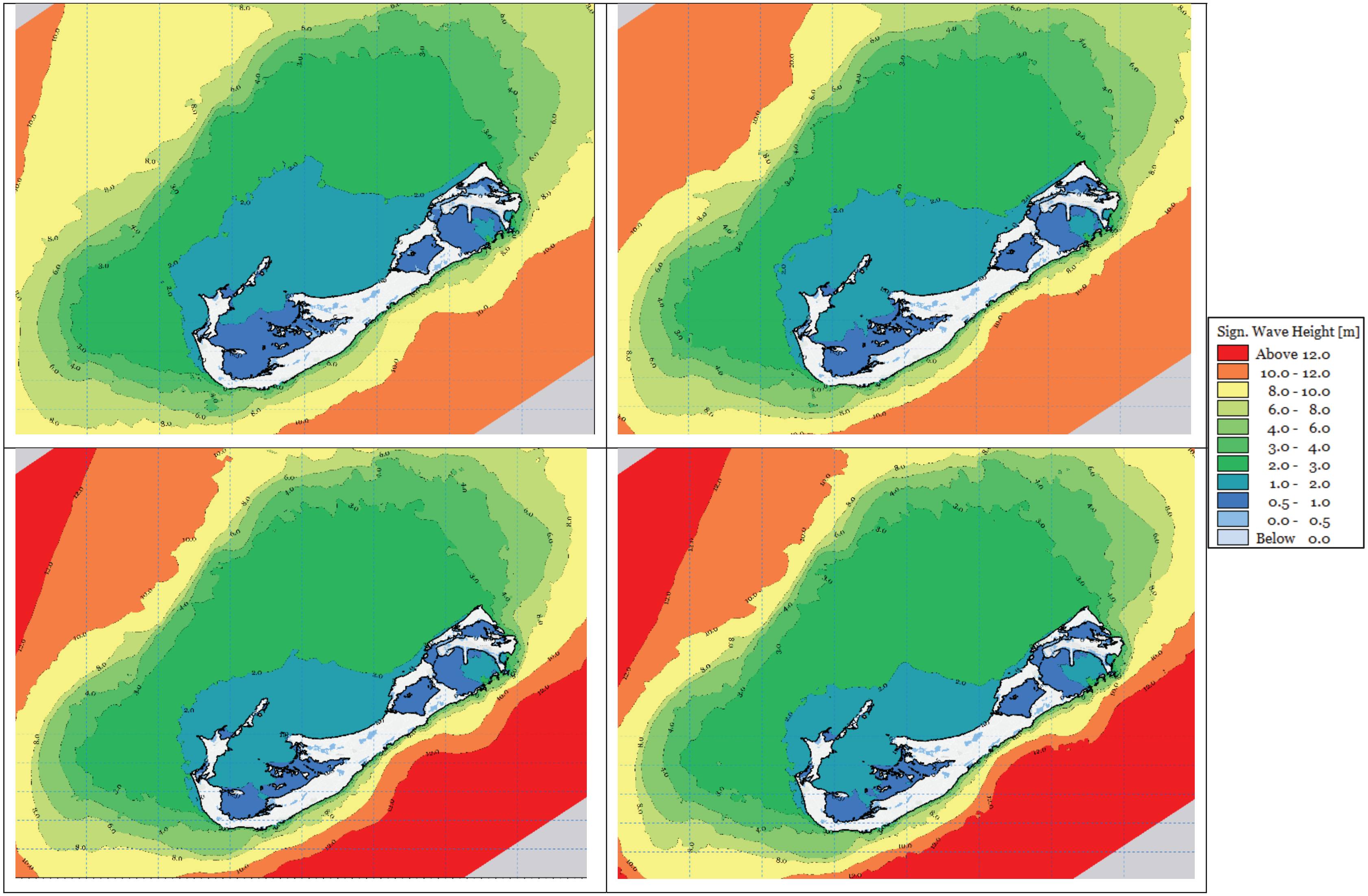


Figure 5.4 RCP 4.5 100-year horizon hurricane wave heights computed for the 25-yr, 50-yr, 100-yr and 150-yr return period with the effect of SLR

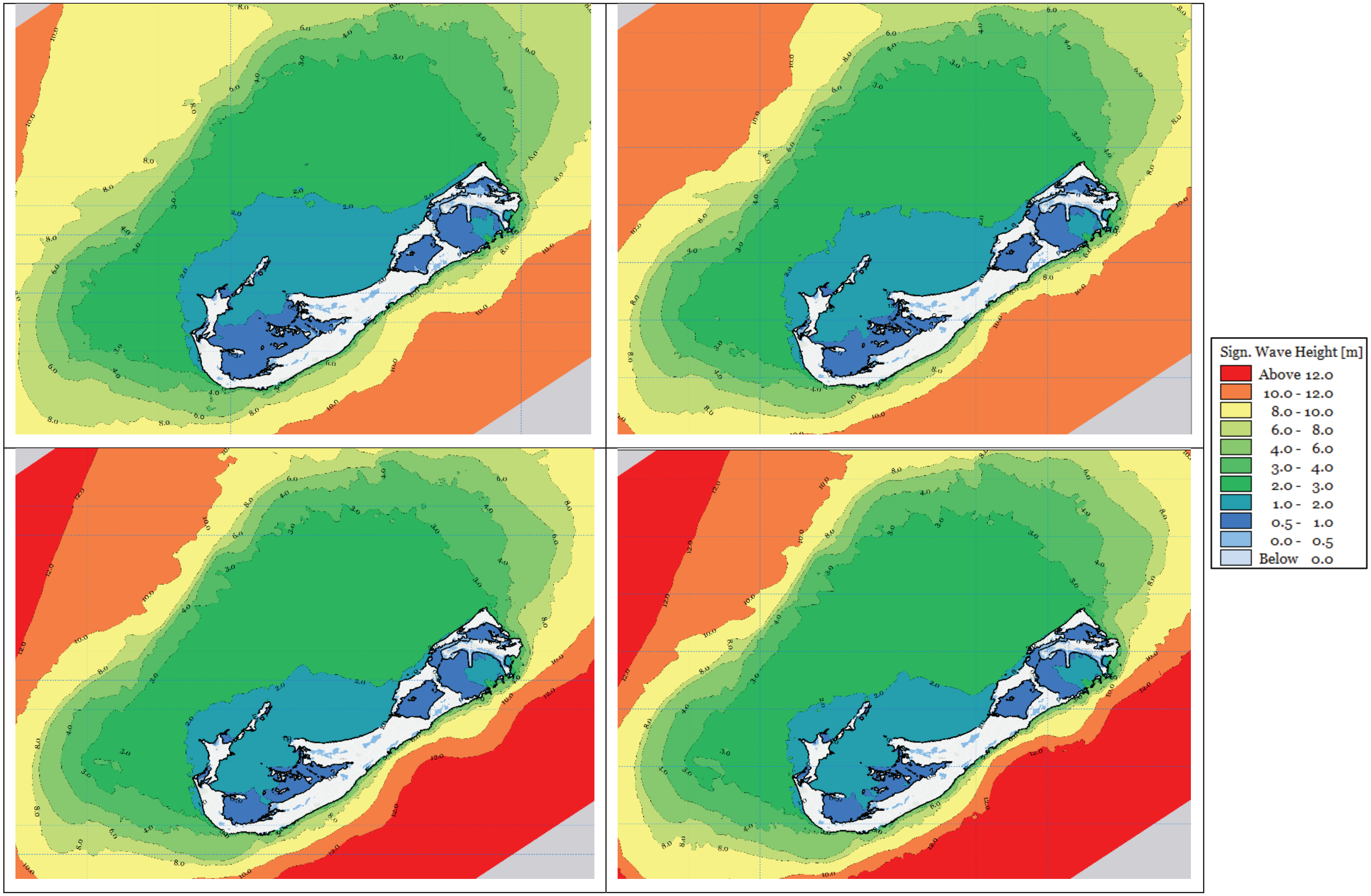


Figure 5.5 RCP 8.5 100-year horizon hurricane wave heights computed for the 25-yr, 50-yr, 100-yr and 150-yr return period with the effect of SLR

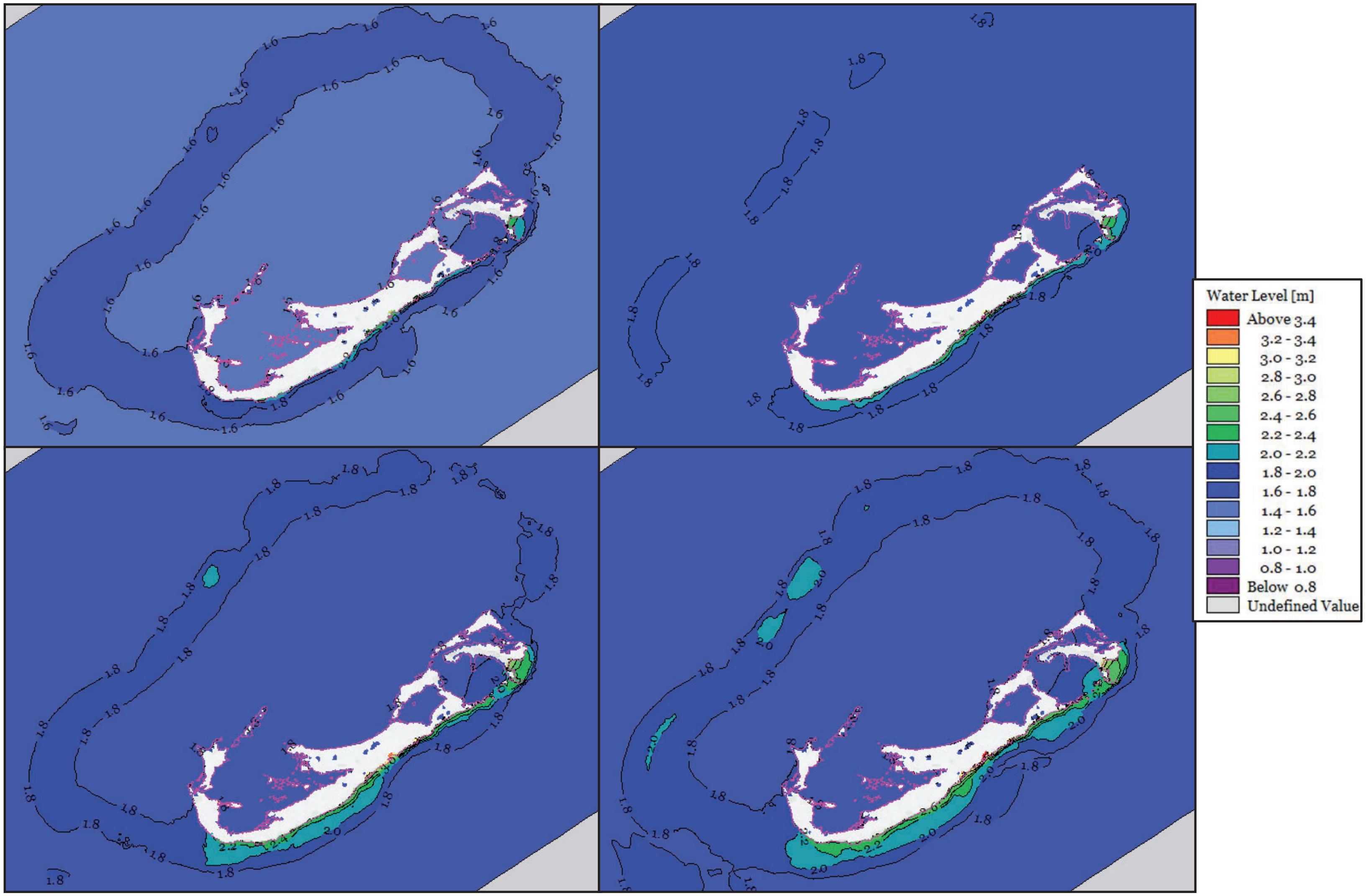


Figure 5.6 RCP 4.5 100-year horizon storm surge computed for the 25-yr, 50-yr, 100-yr and 150-yr return period with the effect of SLR

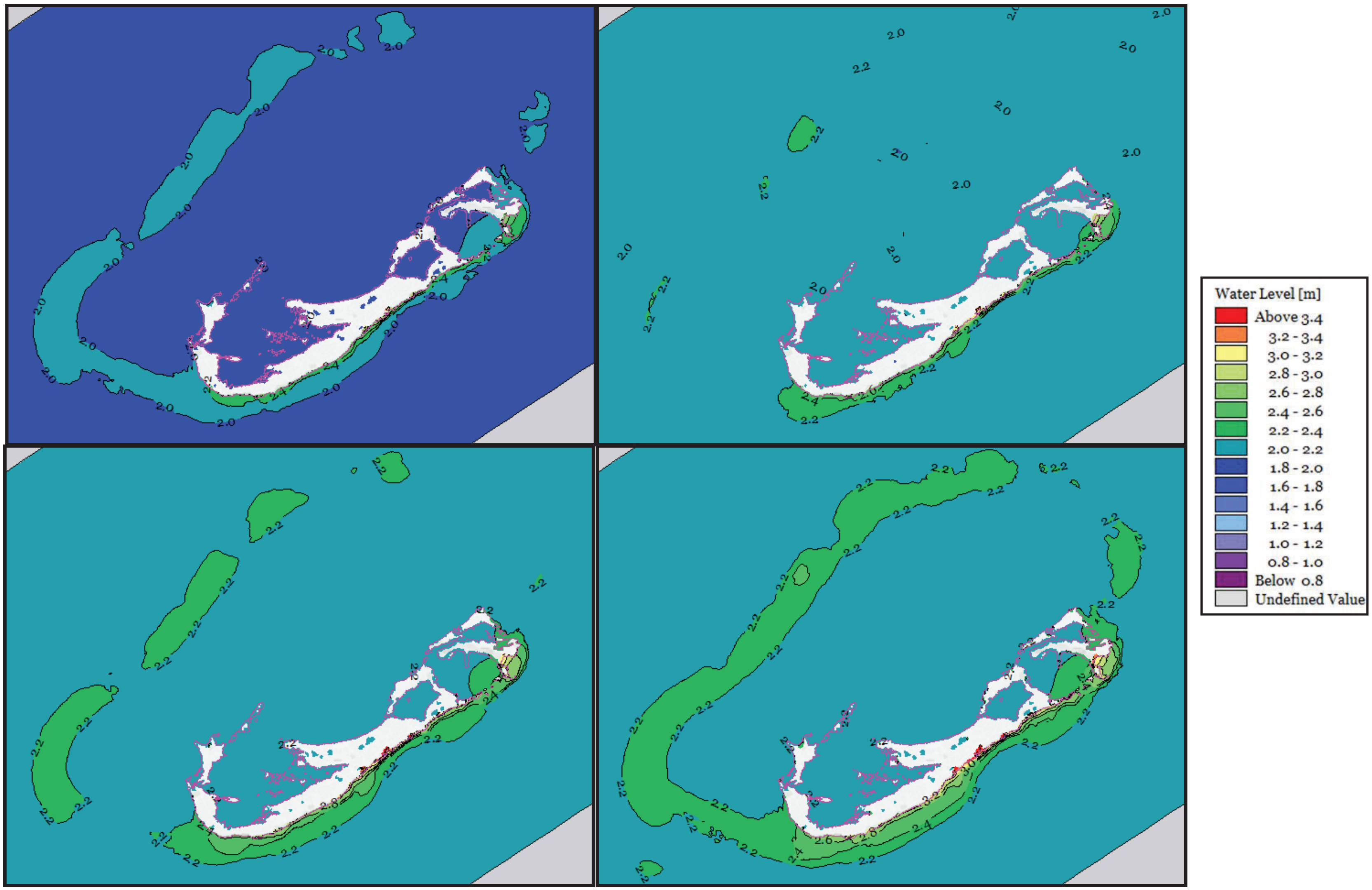
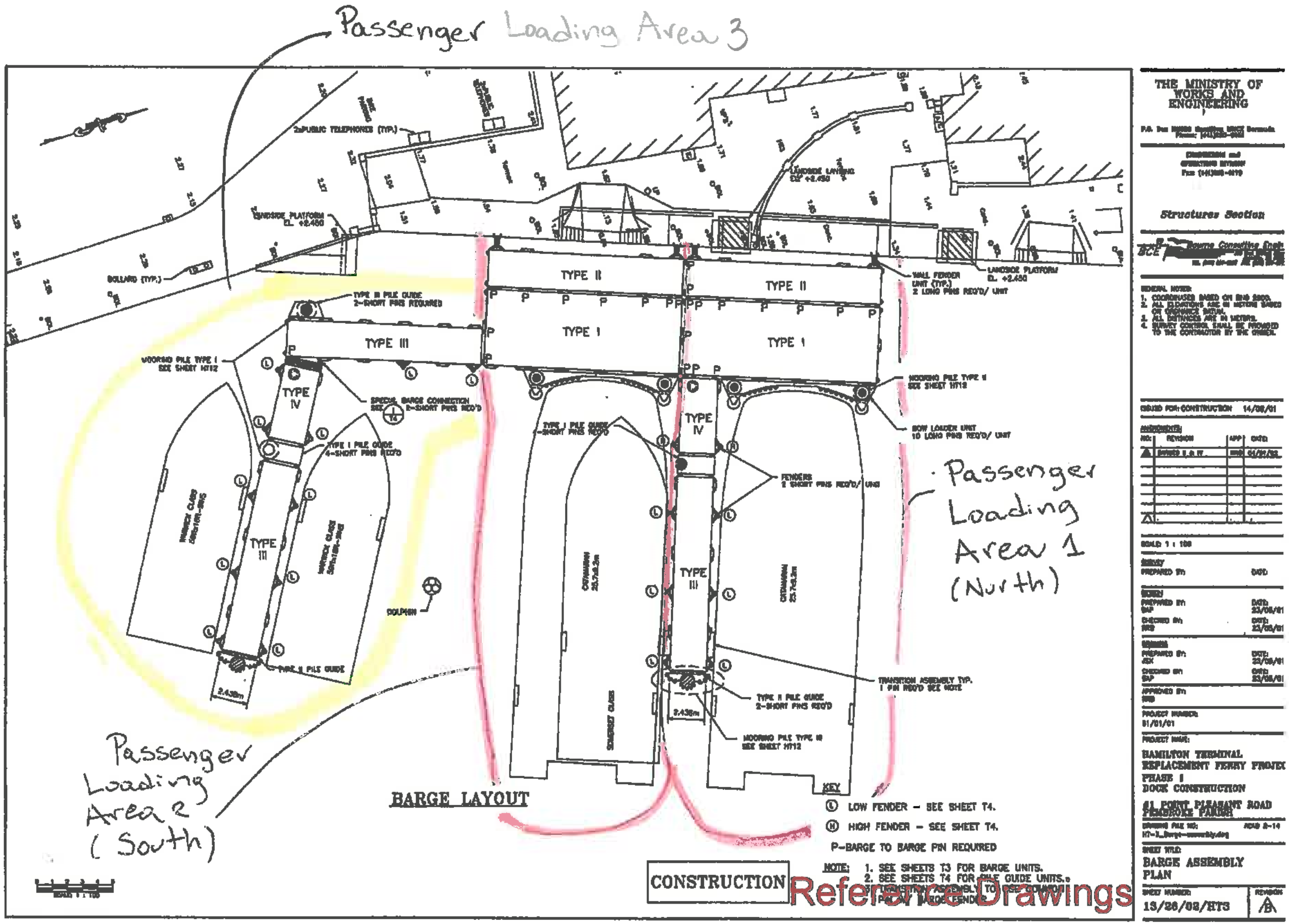


Figure 5.7 RCP 8.5 100-year horizon storm surge computed for the 25-yr, 50-yr, 100-yr and 150-yr return period with the effect of SLR


Passenger Loading Area 3
Passenger Loading Area 1 (North)
Passenger Loading Area 2 (South)
TYPE II
TYPE I
TYPE III
TYPE IV
BARGE LAYOUT
LOW FENDER - SEE SHEET T4.
HIGH FENDER - SEE SHEET T4.
P-BARGE TO BARGE PIN REQUIRED
NOTE: 1. SEE SHEETS T3 FOR BARGE UNITS.
2. SEE SHEETS T4 FOR PILE GUIDE UNITS.
CONSTRUCTION
Reference Drawings
THE MINISTRY OF WORKS AND ENGINEERING
Structures Section
HAMILTON TERMINAL REPLACEMENT FERRY PROJECT
PHASE 1
DOCK CONSTRUCTION
BARGE ASSEMBLY PLAN
13/26/02/HTS

VESSEL DESIGN STANDARDS

Vessel Description			Somerset	Warwick	Gladding Hearn Catamaran	Teknicraft Catamaran	Derektor Shipyards Catamaran	Design Vessel
LOA			23.2 M (76’)	18.0 M (59’)	25 M (82’)	23.7 M (78’)	**37.8 M (124')**	**37.8 M**
Beam			6.4 M (21’)	6.1 M (20’)	8.5 M (28’)	8.1 M (26.4’)	**9.0 M (29.5')**	**9.0 M**
Displacement	Lightship		60 MT	55 MT	45 MT	50 MT		**60 MT**
(metric ton)	Loaded		90 MT	70 MT	72 MT	63 MT	**128MT**	**90 MT**
Capacity	*Passengers*		250	150	250	180	**350**	**350**
	Scooters		15	0	8	6	**10**	**15**
Draft			1676 mm (5.5’)	1676 mm (5.5’)	1850 mm (6’)	915mm (3’)	**1210mm (4')**	**1850 mm**
Berthing Speed	Normal							
		Side	3.7 KPH	4.5 KPH	3.7 KPH	3.7KPH		**3.7 KPH**
		Bow	N/A	N/A	2.8 KPH	2.8KPH	**1.65 KPH**	**1.65 KPH**
	Extreme							
		Side	8.0 KPH	10.0 KPH	7.0 KPH	7.0KPH		**7.0 KPH**
		Bow	N/A	N/A	5.0 KPH	5.0KPH	**2.00 KPH**	**2.0 KPH**
Angle of Approach			15°	15°	90°	15°	**15º**	**15º**
Loading Freeboard								
	Side		1020 mm (3.3’)	1020 mm (3.3’)	1800 mm (6’)	1430mm (4.7’)	**2060mm (6.75')**	**1800 mm**
	Bow		N/A	N/A	2300 mm(7.5’)	2300mm (7.5’)	**2650mm (8.7')**	**2500 mm**
Loading Location from Bow			14.2 M (46.5’)	7.3 M (24’)	20 M (65.6’)	19.45 M (63.8’)	**28.85 M (94.7')**	
Turning Area	*Normal*		50 M (164’)	40 M (131’)	50 M (164’)	25 M	**40 M**	**50 M**
Required	*High Winds*		75 M (246’)	60 M (197’)	75 M (246’)	50 M	**80 M**	**75 M**