Isle of Man Government - Sea Defence Options

Design Input Statement

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Contract

This report describes work undertaken by JBA Consulting, on behalf of Isle of Man, Department of Infrastructure, by contract documentation issued 11 July 2014. Department of Infrastructure's representative for the contract is Jeffrey Robinson. Alexander Dane and Graham Kenn of JBA Consulting completed this work element.

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Purpose

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JBA Consulting has no liability regarding the use of this report except to the Department of Infrastructure.

Acknowledgements

This Design Input Statement has been developed based on an initial site investigation and subsequent project meetings between the study team, consisting of JBA Consulting and the Department of Infrastructure.

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Abbreviations and definitions

1D	One-dimensional
2D	Two-dimensional
3D	Three-dimensional
CDM	Construction Design and Management Regulations (2007)
Defra	Department for Environment, Food and Rural Affairs
DoI	Department of Infrastructure
Douglas02	Datum for Isle of Man
DIS	Design Input Statement
EIA	Environmental Impact Assessment
EurOtop	European Wave Overtopping Manual
GIS	Geographic Information System
HAT	Highest Astronomical Tide
Hm0	Significant Wave Height
Hs	Significant Wave Height
IoM	Isle of Man
JBA	Jeremy Benn Associated Consulting
LAT	Lowest Astronomical Tide
l/s/m	Litres per second per metre (the average rate of wave overtopping)
MCA	Multi-Criteria Analysis
MHWN	Mean High Water Neaps
MHWS	Mean High Water Springs
MLWN	Mean Low Water Neaps
MLWS	Mean Low Water Springs
MSL	Mean Still Water Level
PDF	Portable Document Format
Sd	Standard Rock Armour Damage Parameter
SWL	Still Water Level
Tm	Wave Period
Tp	Peak Wave Period
UKCP09	UK Climate Projections 09

1 Introduction

Jeremy Benn Associates Ltd (JBA Consulting) is tasked with developing a number of technically viable concept solutions to address still water level flooding in harbour environments and wave overtopping in open coast environments, at seven harbours and coastal sites across the Isle of Man, on behalf of the Department of Infrastructure (DoI). The seven sites are listed below and visually represented in Figure 1-1.

- Castletown
- Douglas
- Laxey
- Ramsey
- Peel
- Port St Mary
- Gansey

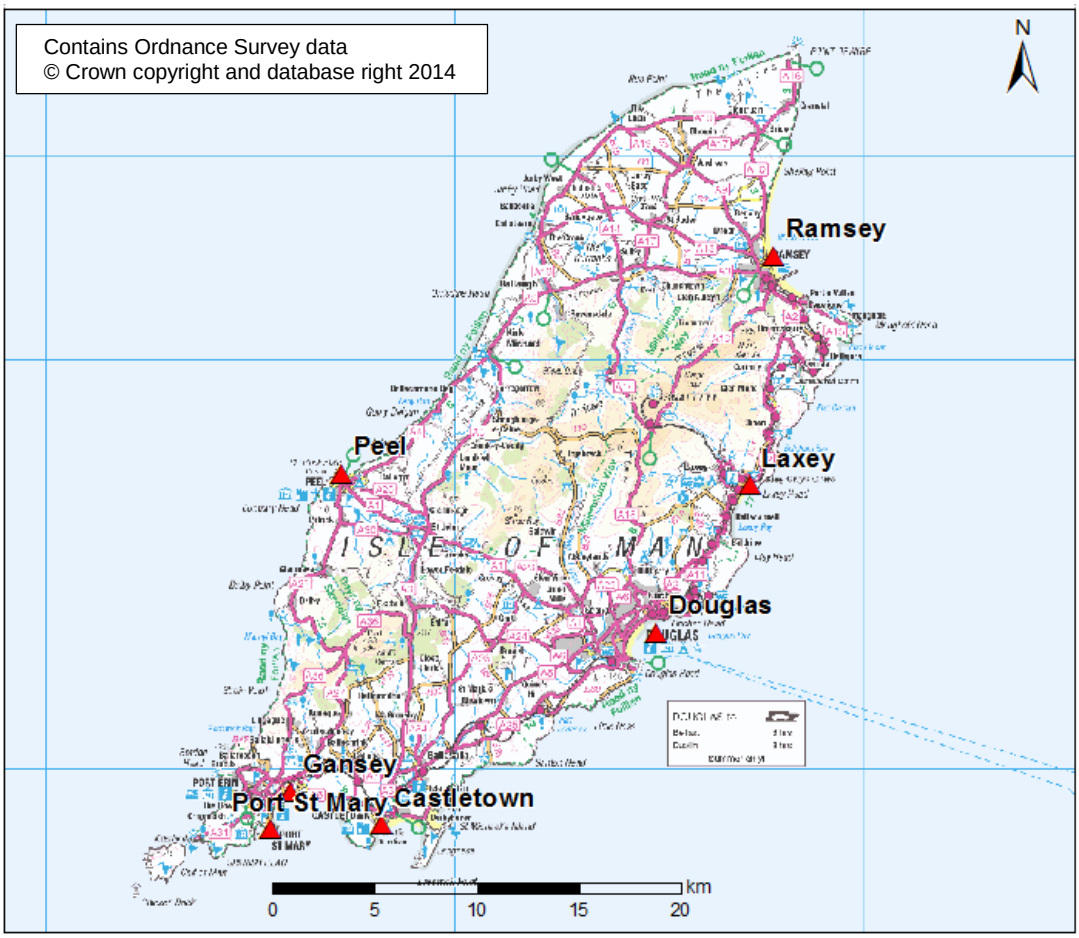


Figure 1-1: Location of study sites

This Design Input Statement (DIS) provides details of the key assumptions and methodology that will be used for the concept design development for the new coastal and harbour defences.

The study will be supported by individual technical notes prepared for each proposed design option. These notes will list all the assumptions for each concept design and record the design methodology and decision making process in detail. These will be issued as part of the final deliverables package.

1.1 Study aim

The primary aim of the study is to undertake an investigation to develop a number of concept solutions to reduce the risk posed by coastal processes to the hinterland, at seven sites across the Isle of Man. Within each of the seven sites, the risk mechanism can be split into two primary

risks, the still water level flood risk and the wave overtopping risk. These two risk mechanisms are broadly defined as:

Still Water Level (SWL) flooding occurs where the water level exceeds the defence crest level (commonly the top of the quay / harbour walls) and water inundates the hinterland. The water level at any given time is a function of the astronomic and atmospheric components. The astronomic component of the still water level is predominately driven by the tidal cycles, while the atmospheric conditions include the effects of low pressure and local wind driven set-up contributing to increased water levels.

Wave Overtopping occurs where waves run up the face of the coastal defence. Where the wave run-up exceeds the defence crest level, water will pass over the crest and inundate the hinterland.

The seven sites and their coastal risk mechanisms are provided in Table 1-1.

Table 1-1: Study sites and coastal risk mechanisms

Site	Risk
Castletown	SWL and Wave Overtopping
Douglas	SWL and Wave Overtopping
Laxey	SWL and Wave Overtopping
Ramsey	SWL and Wave Overtopping
Peel	SWL and Wave Overtopping
Port St Mary	Wave Overtopping
Gansey	Wave Overtopping

At each site a number of technically viable solutions to reduce the risk posed by coastal processes will be considered. The number and type of options proposed will vary on a site by site basis, decided based on the technical feasibility, engineering judgement, environmental impact, cost and consideration of the long term vision and key criteria determined by the project stakeholders. A maximum total of 42 options will be developed covering all the study sites.

1.2 Outline of overall project methodology and key objectives

The project will follow several stages of assessment, development, design, modelling and refinement as described below. Each of these stages is discussed in detail within the methodology description in Section 3.

It is proposed that the project is structured as follows:

1. **Design Input Statement,** (this report) which describes the assumptions and methodology of the project.
2. **Data collection,** which includes the collection of existing hydrodynamic, topographic and environmental data.
3. **Numerical modelling,** where wave transformation and wave overtopping modelling will be undertaken.
4. **Concept engineering design,** where the options to reduce coastal risk will be designed and refined based on wave overtopping calculations and predicted extreme water levels.
5. **Cost assessment,** which will assess the construction costs for each of the options proposed.
6. **Options appraisal and selection,** which will review the four overtopping options, considering technical viability, cost, environmental impacts and stakeholder interests using a Multi Criteria Analysis process

1.3 Structure of this report

In addition to this introductory chapter the Design Input Statement includes the following chapters:

- **Chapter 2 (Design input criteria)** describes the assumptions for the design life, ultimate limit state, climate change, overtopping limits, tidal water levels, extreme water levels, currents, waves and joint probability assessments.
- **Chapter 3 (Methodology)** describes the proposed methodology for numerical wave, hydrodynamic and overtopping modelling, engineering design, environmental assessment, cost assessments, options appraisals and final reporting.

2 Design input criteria

This section describes the input conditions for the design of all coastal defence options to ensure clarity and transparency in the methods of the design.

2.1 Datum

All elevation/depth measurements used throughout the project will be quoted to the GPS datum known as 'Douglas02'.

The conversion from Chart Datum to Douglas02 for the seven ports, provided by the DoI, are shown in Table 2-1.

Table 2-1: Tidal conversions from chart datum to Douglas02

Site	Chart datum to Douglas 02 conversion
Castletown[1]	-3.87m
Douglas	-3.77m
Laxey[1]	-3.94m
Ramsey	-3.94m
Peel	-3.30m
Port St Mary	-3.32m
Gansey[2]	-3.32m

2.2 Design life and level of protection

The European Wave Overtopping Manual (EurOtop)[3] acknowledges the interrelationship between the design life and level of protection, providing the following guidance for selecting these design standards:

Table 2-2: Recommended design life and standard of protections

Hazard type and reason	Design life (years)	Level of protection (1 in X)
Temporary or short term measures	1-20	5-50
Majority of coast protection	30-70	50-100
Flood defences protecting large areas at risk	50-100	100-10,000
Special structure, high capital cost	200	Up to 10,000
Nuclear power stations	-	10,000

In practice, these return periods and design lives are considered too short. UK national guidelines now suggest that a level of protection of between 1 in 200 and 1 in 1000-year protection should be adopted for all new defences. This level of protection is often referred to as the design storm event, which is adopted throughout this document.

The selected design standards adopted for all conceptual design options will be as follows:

- Target design life for all elements will be 100 years
- Design storm event will be the 1 in 200-year event.

2.3 Climate change

By selecting a design life of 100 years, it is important to factor in the predicted effects of climate change. It is proposed that the latest UK Climate Projections (UKCP09) are used to determine climate change allowance for:

- Still water levels;
- Wind driven waves; and
- Swell waves.

[1] Admiralty Chart Datum to Douglas 02 Datum is approximate, calculated proportionately between two nearest ports

[2] The Port St Mary conversion will be applied for Gansey as it does not have a unique conversion factor

[3] Pullen, T., Allsop, W., Bruce, T., Kortenhaus, A., Schuttrumpf, H & van der Meer, J (2007) 'Wave overtopping of sea defences and related structure: Assessment manual'. Accessed from www.overtopping-manual.com

Within UKCP09 estimates for sea level rise are provided under low, medium and high emissions scenarios. Within the three scenarios the estimate is further refined by 5th, 50th and 95th percentile confidence ratings. In simple terms this should be interpreted as the relative likelihood of the projected change being at, or less than, the given change. For this study it is proposed that the medium emissions scenario is considered and that the 95th percentile confidence rating is used. This gives a projected sea level rise of 650mm by the year 2115 for Castletown, Douglas, Laxey, Port St Mary and Gansey. Whereas Ramsey and Peel have a 2115 projected sea level rise of 640mm.

UKCP09 acknowledges the difficulty in predicting changes in wind speeds over the next 100 years and concludes that there will be a negligible increase in wind speed. Therefore, the wind driven wave component of the numerical modelling will have no direct increase in wave intensity due to climate change. However, as a result of the increased still water levels from relative sea level rise, there will be an indirect increase in wind driven wave height. As a result of the larger depth of water at the coastal defence toe, larger waves will be able to travel inshore before breaking creating a higher intensity wave climate in the year 2115.

For changes in swell waves, UKCP09 gives a prediction of the change in annual maximum wave height for the year 2115 of up to **1.0m** for the UK. It should be noted that wave height increases could be limited by the water depth at the study location and therefore the full 1.0m increase is not applicable for all scenarios. It is proposed that the 1.0m allowance is applied to offshore swell wave conditions, which will be subject to wave transformation modelling to determine the change in wave height at each individual site.

2.4 Metocean data

The metocean data is used to form the input conditions within the numerical wave transformation model. The three boundary conditions required to consider the hydrodynamic conditions for an analysis of the coastal flood and overtopping risk are as follows:

- Extreme water levels
- Extreme wind speeds
- Extreme swell waves.

The source of the data and methodology for their incoporation into the numerical model is explored below.

2.4.1 Tidal data

The only A-class tide gauge is at Port Erin. The transformed astronomic tide levels for Douglas, Ramsey, Peel and Port St Mary have been extracted from the United Kingdom Admiralty Office Total Tide[4] software, which contains worldwide tidal information for over 7,000 ports and 3,000 tidal streams. The astronomic tide levels are shown in **Error! Not a valid bookmark self-reference.**.

Table 2-3: Tide levels for secondary ports in the Isle of Man

Location	Douglas (mD02)	Ramsey (mD02)	Peel (mD02)	Port St Mary (mD02)
Chart Datum Correction to D02	-3.77	-3.94	-3.03	-3.32
Highest Astronomical Tide (HAT)	4.03	4.26	2.67	3.47
Mean High Water Springs (MHWS)	3.13	3.46	2.17	2.87
Mean High Water Neaps (MHWN)	1.63	1.96	1.27	1.77
Mean Still Water Level (MSL)	0.02	0.22	-0.12	0.22
Mean Low Water Neaps (MLWN)	-1.37	-1.64	-1.53	-1.43
Mean Low Water Springs (MLWS)	-2.97	-3.04	-2.63	-2.53
Lowest Astronomical Tide (LAT)	-4.07	-3.74	-3.23	-3.13

4 The United Kingdom Hydrographic Office Admiralty Total Tide software

2.4.2 Extreme water levels

The extreme water levels around the Isle of Man have been adopted based on the Environment Agency *Coastal flood boundary conditions for UK mainland and islands* project[5], which developed a consistent set of design sea levels for Scotland, England and Wales. The project analysed tide-level data for Class A water level gauges around the UK and undertook a statistical analysis to produce estimates of extreme water levels.

The point used for this project is located at Port Erin. Other ports located around the Isle of Man have used the JBA Coastal flood boundary data model, to interpolate the values around the Isle of Man, based on Port Erin extreme water levels. This dataset uses 50 years of tidal gauge data. Table 2-4 provides the estimate for high water extremes at each site, including sea level rise for the year 2115[6].

Table 2-4: Extreme water levels for Isle of Man

Return Period (year)	mD02	Castletown	Peel	Laxey	Ramsey	Port Erin	Port St Mary	Douglas
1	2014	3.48	3.17	4.22	4.16	3.14	3.35	3.98
2		3.57	3.26	4.30	4.25	3.23	3.44	4.07
5		3.68	3.38	4.39	4.36	3.34	3.55	4.18
10		3.76	3.46	4.51	4.45	3.42	3.63	4.27
20		3.84	3.54	4.60	4.53	3.49	3.71	4.35
25		3.87	3.56	4.68	4.56	3.51	3.73	4.37
50		3.95	3.64	4.71	4.64	3.59	3.81	4.45
75		3.99	3.68	4.79	4.68	3.63	3.85	4.50
100		4.02	3.71	4.81	4.71	3.65	3.88	4.53
150		4.06	3.75	4.87	4.75	3.69	3.92	4.57
200		4.09	3.78	4.89	4.78	3.72	3.94	4.60
250		4.11	3.80	4.92	4.81	3.74	3.97	4.63
300		4.13	3.81	4.94	4.82	3.75	3.98	4.64
500		4.18	3.86	5.00	4.87	3.80	4.03	4.70
1,000		4.25	3.92	5.04	4.94	3.85	4.09	4.76
10,000		4.44	4.09	5.29	5.13	4.01	4.26	4.97
1	2115	4.12	3.81	4.86	4.80	3.79	4.00	4.62
2		4.21	3.90	4.95	4.90	3.87	4.09	4.71
5		4.33	4.02	5.04	5.01	3.98	4.20	4.83
10		4.41	4.10	5.16	5.10	4.06	4.28	4.91
20		4.49	4.18	5.24	5.18	4.14	4.36	5.00
25		4.52	4.21	5.33	5.21	4.16	4.38	5.02
50		4.60	4.28	5.35	5.28	4.23	4.46	5.10
75		4.64	4.32	5.43	5.33	4.27	4.50	5.15
100		4.67	4.35	5.46	5.36	4.30	4.53	5.18
150		4.71	4.39	5.51	5.40	4.34	4.57	5.22
200		4.74	4.42	5.53	5.43	4.37	4.59	5.25
250		4.76	4.44	5.56	5.45	4.38	4.61	5.27
300		4.78	4.46	5.58	5.47	4.40	4.63	5.29
500		4.83	4.50	5.64	5.52	4.44	4.68	5.34
1,000		4.90	4.56	5.69	5.59	4.50	4.74	5.41
10,000		5.09	4.74	5.94	5.78	4.66	4.91	5.62

2.4.3 Extreme winds

Extreme design wind conditions will be calculated using the British Standard BS6399[7] which provides estimates of hourly wind speeds during the course of a ten hour storm event with a standard 50-year return period. Using published information several factors will be applied to the 50-year hourly wind speed to account for altitude, direction and seasonality, and a number of return period factors applied to calculate the extreme design wind conditions for each location. The extreme design wind speed formula is:

$$U_D = U_b S_a S_d S_p S_f S_w$$

[5] Coastal flood boundary conditions for UK mainland and islands, Project: SC060064/TR2: Design sea-levels. Environment Agency, Feb 2011.

[6] Coastal Flood Boundary Conditions for UK Mainland and Islands, 2011

[7] British Standard, 1997, BS 6399-2 Loading for buildings – Part 2: Code of practice for wind loads

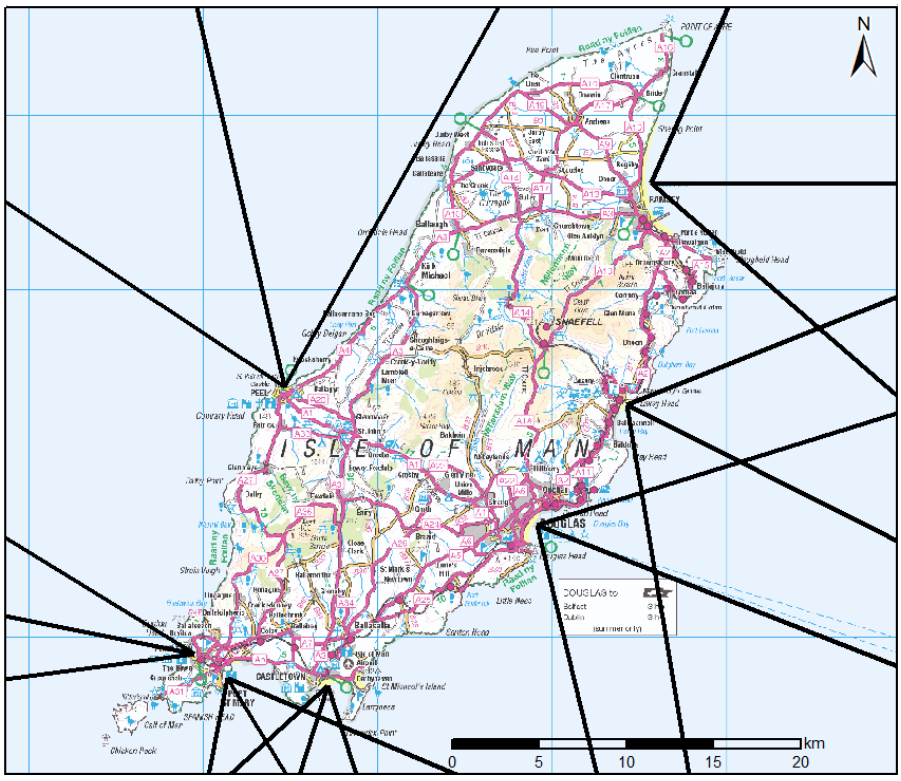
Where U_D is the design wind speed (m/s), U_b is the 50-year basic hourly wind speed (m/s), S_a is an altitude factor, S_d is a factor to account for the wind direction (e.g. south-westerly winds tend to be stronger than north-easterlies over the England and Wales), S_p is a factor to adjust for different return periods, S_f is a factor to convert hourly wind speed to a more appropriate duration for the water body under study and S_w is an over-water speed-up factor to account for the effect of reduced friction as wind travels over water.

Each of the factors listed above have been assessed for the Isle of Man coastline and are summarised in Table 2-5.

Table 2-5: Variables for the design wind speed formula and there method of calculation

Variable	Method of calculation
U_b – 50-year basic hourly wind speed (m/s)	Use BS6399 estimates.
S_a – altitude factor	This remains constant. A value of 1 x 1.001 was used.
S_d – directional factor	Three directional sectors have been used, including, West, North West, North, North East and Easterly conditions. A table in BS6399 defines the values for England and Wales[8].
S_p – probability factor	A table in BS6399 defines the probability factor for each return period.
S_f – duration factor	A duration factor of 1 has been applied, which is associated with hourly wind durations. This is the standard wind duration used for longer fetch length generated waves.
S_w – over water speed-up factor	Over water speed-up values have been based on the It will be assumed that over a generalised area, all locations will have an average fetch above 10km therefore a constant value of 1.31 will be used at all locations for this factor. Due to the reduction in friction of wind on water compared to land the wind speed is increased by this factor.

The fetch length is dependent on the exposure of each geographic area to the open sea and the length over which wind can blow towards the shoreline. Fetch lengths were manually determined using a Geographic Information System (GIS) for the three longest fetch lengths at each location, as shown in Figure 2-1.



[8] McConnell K (1998) Revetment systems against wave attack – A design manual.

Figure 2-1: Wind directions simulated within assessment. Contains Ordnance Survey data © Crown copyright and database right 2014.

2.4.4 Extreme swell waves

In addition to extreme winds and water levels, extreme swell waves have been applied to the northern and southern boundaries during key simulations. The extreme wave conditions were adopted based on the Environment Agency's *Coastal flood boundary conditions for UK mainland and islands* project[9] which developed a consistent set of design swell wave conditions around Scotland, England and Wales. Extreme waves were analysed from the north and south of the Irish Sea.

The EA's coastal *flood boundary conditions for UK mainland and islands* dataset also contains information on wave period, which is categorised by the relative frequency for each wave height. For each wave height the most common wave period has been assigned to each simulation.

Table 2-6: Extreme wave estimates, waves originating from the southwest and northwest.

Return Period	Extreme swell waves from the southwest		Extreme swell waves from the northwest	
	Wave height (m)	Wave period (s)	Wave height (m)	Wave period (s)
1	3.3	10	3.01	10
2	3.62	10	3.11	10
5	4.03	10	3.22	10
10	4.34	10	3.28	10
20	4.64	10	3.34	10
50	5.02	10	3.4	10
100	5.31	10	3.44	10
200	5.58	10	3.48	10

2.4.5 Joint probability analysis

In order to determine the combination of water level and wave height that constitutes the worst case scenario for a given recurrence period, a joint probability analysis must be undertaken. The joint probability analysis is used to determine a range of possible combinations of sea level and wind speed for each return period. The wind and water values obtained in the analysis will be used in the wind driven wave model (SWAN). The wave data will be obtained from the SWAN model. For example, for a 100-year joint return period and for a high level of dependence, the combinations might include a 1-year wind speed with a 100-year sea level, a 10-year wind speed with a 10-year sea level, and a 100-year wind speed with a 1-year sea level.

In order to establish suitable sea level and wind speed values a joint probability assessment will be undertaken using established Defra methodology[10]. The Defra methodology specifies levels of dependence for many locations throughout the UK, which has been conservatively taken as chi=0.3 for this project (refer to Figure 2-2). A range of combinations will be modelled for return periods of 1, 5, 10, 20, 50, 100, and 200-year to determine the 'worst case' scenarios for any proposed structures.

[9] Coastal flood boundary conditions for UK mainland and islands, Project: SC060064/TR3: Design swell-waves. Environment Agency, Feb 2011.

[10] 'Defra (2003) 'Joint Probability: Dependence Mapping and Best Practice', Report: FD2308/TR1, Defra/Environment Agency, July 2003.

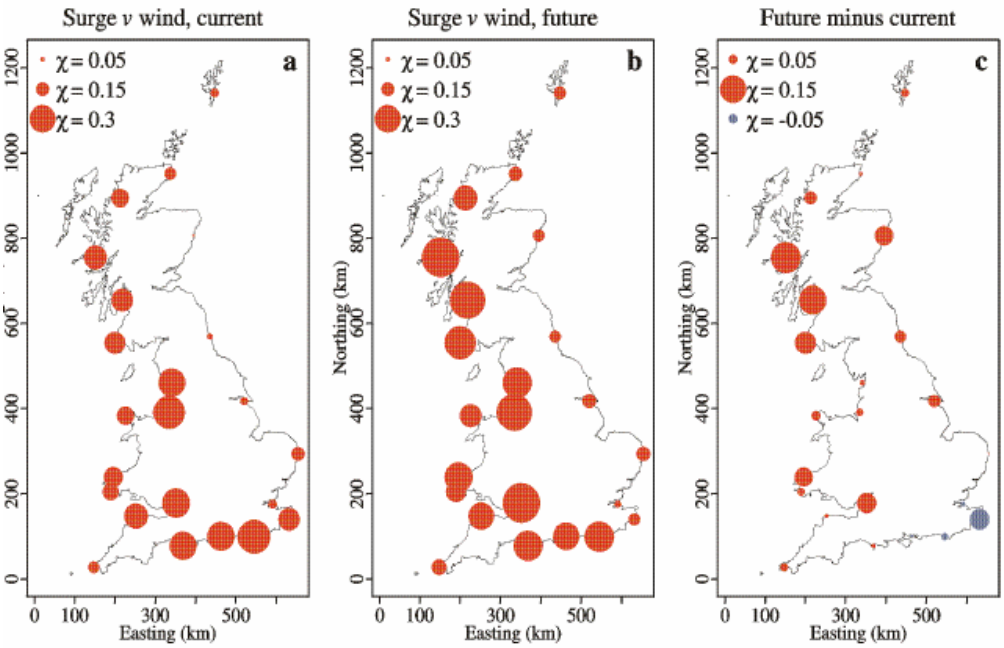


Figure 2-2: Dependence information for wind speed and sea level (Source: Defra 2003)

2.5 Level of design detail

This study will constitute concept design commensurate with RIBA Plan of Work 2013 Stage 2[11]. Therefore the following apply:

- No detailed structural analysis and design will be undertaken;
- No geotechnical analysis will be undertaken;
- No material analysis will be undertaken;
- Assumptions will be used, and stated, where necessary;
- Typical sections and alignments will be indicative; and

Final designs may differ, based on variables that are outside the scope of this work.

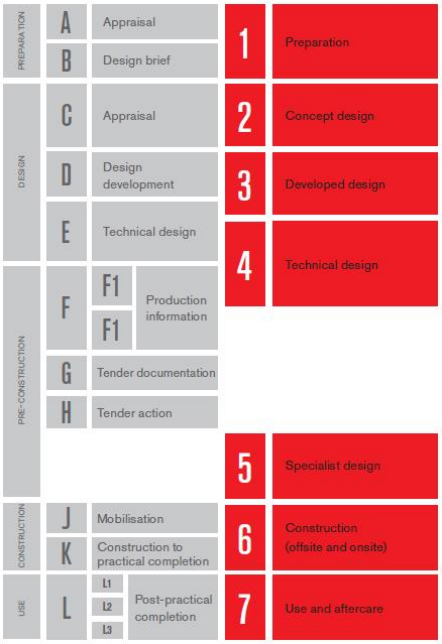


Figure 2-3: RIBA Plan of Work 2013

[11] RIBA Plan of Work 2013 http://www.ribaplanofwork.com/About/Concept.aspx

2.6 Design standards, guidance and references

The following material will be used as the point of reference for all design assumptions unless specifically advised otherwise:

- BS 6349-1 1:2000 Maritime Structures – Part 1: Code of Practice for General Criteria
- BS EN 206-1:2000 Concrete – Part 1: Specification, performance, production and conformity
- BS EN 12620:2002 Aggregates for concrete
- BS EN 13383-1:2002 Armourstone – Part 1: Specification
- BS EN 13383-2:2002 Armourstone – Part 2: Test methods
- CIRIA (2007), The Rock Manual: The Use of Rock In Hydraulic Engineering (second edition)
- CIRIA (2010), The Beach Management Manual (second edition)
- CIRIA (2010), The use of concrete in maritime engineering – a guide to good practise
- DEFRA (2009) UK Climate Projections 09
- Delft University of Technology (2006) 'SWAN User Manual'
- Delta Marine Consultants (2011), Xbloc - Guidelines for Xbloc Concept Designs
- HR Wallingford (2007), EurOtop, Wave Overtopping of Sea Defences and Related Structures: Assessment Manual
- McConnell, K (1998), Revetment Systems Against Wave Attack – A design manual
- US Army Corp of Engineers (2002), Coastal Engineering Manual

2.7 Ultimate limit state standard

The ultimate limit state refers to the design limit for the proposed structural components of any option(s) developed. The ultimate limit state takes the maximum wave height and maximum SWL in isolation from the design storm event (1 in 200-year storm), to ensure structural stability during the worst case scenario.

This limit state is used to ensure that defence designs will withstand the maximum wave conditions in combination with the maximum extreme sea-levels, including the effects of climate change to the year 2115 for the design storm event. The overall likelihood of an event of this magnitude occurring will have a return period far greater than 1 in 200-year storm, incorporating a preliminary level of safety into the critical design elements.

The target structure damage level at this return period will be a damage level equivalent to 'no damage' that will jeopardise the integrity of the structure. For structures utilising armour units the industry standard damage level will be adopted[12], this allows 5% damage during the design event.

The wave and sea level data will be sourced from the JBA wave transformation modelling and extreme sea level guidance. The 1 in 200-year joint probability event will include an allowance for climate change, which is discussed in more in Section 2.3.

2.8 Performance standards

The performance standard can be split into two areas, still water level performance and wave overtopping performance for harbour and open coast environments respectively.

2.8.1 Still water level performance

For harbour environments, sheltered from wave action, the performance standard is dictated by the still water level. This performance factor, for all coastal and harbour environments, assumes that the still water level will not exceed the defence crest level during the design storm event (1 in 200-year storm). This still water level is taken in isolation (not in joint probability with wave height), to represent the maximum still water level possible from a storm of the given return period.

[12] Section 5.2.2.2, page 565, CIRIA Rock Manual 2007

2.8.1.1 Harbour structure crest height design

The crest height of all proposed concept options will be established to prevent the maximum design storm still water level exceeding the defence crest level.

2.8.1.2 Harbour structure freeboard

By convention a minimum freeboard allowance of 150mm for hard defences and 300mm for soft defences is used in many situations[13]. In the case of flood defence walls the defence height will be assumed as the top level of the core of the structure. The coping of any walls will not be included within the freeboard allowance, due to the uncertainties of structural fixings, and would therefore provide an additional nominal level of protection.

No additional allowance for flood defence settlement has been included.

2.8.2 Wave overtopping performance

It is proposed that two thresholds are used to limit the volume of overtopping that is deemed acceptable for the concept design options:

1. The first lower threshold will be established for a common coastal storm event, considered to have a 1 in 1-year return period, based on a joint probability assessment (refer to Section 2.4.5).
2. The second higher threshold will be established for the design storm event, considered to have a 1 in 200-year return period, based on a joint probability assessment. During this event it is considered that general public use of the pavement and road immediately behind the structure will be discouraged and only trained personnel will be operating within the vicinity of the structure.

Table 2-8 below summarises the guidance for vehicles and pedestrians provided within the European Wave Overtopping Manual (EurOtop).

Table 2-7: Limits for overtopping for vehicles (source: EurOtop[14])

Hazard type and reason	Mean discharge	Max volume
	q (l/s/m)	V_{max} (l/m)
Driving at low speed, overtopping by pulsating flows at low flow depths, no falling jets, vehicle not immersed.	10 - 50[15]	100 – 1,000
Driving at moderate or high speed, impulsive overtopping giving falling or high velocity jets.	0.01 – 0.05[16]	5 – 50 at high level or velocity
Trained staff, well shod and protected, expecting to get wet, overtopping flows at lower levels only, no falling jet, low danger of fall from walkway	1-10	500 at low level
Aware pedestrian, clear view of the sea, not easily upset of frightened, able to tolerate getting wet, wider walkway	0.1	20-50 at high level or velocity

The following twofold tolerable discharge thresholds have been proposed for all concept options on open coast environments:

- 1 in 1-year event – <0.1l/s/m
- 1 in 200-year event – <10l/s/m.

These tolerable discharges are such that all structures will be considered safe for pedestrian access during the more regular storm event, while vehicular and emergency staff will be safe to inspect defences during the less frequent, higher magnitude storm.

[13] N.B. New guidance relating to freeboard allowances will be issued autumn 2014 through Defra Science Project SCI20014 - The role of freeboard in flood risk management.

[14] Pullen, T., Allsop, W., Bruce, T., Kortenhaus, A., Schuttrumpf, H & van der Meer, J (2007) 'Wave overtopping of sea defences and related structure: Assessment manual'. Accessed from www.overtopping-manual.com

[15] Note: These limits relate to overtopping defined at highways.

[16] Note: These limits relate to overtopping defined at the defence, assumes the highway is immediately behind

By adopting a twofold approach to acceptable overtopping levels, the new defence options considered for the sites will have a dual purpose of preventing the frequent overtopping caused by common storms while providing structural and overtopping protection during rare events. By incorporating dual overtopping targets the crest height of all structures can be minimised, reducing both construction cost and visual impact.

2.8.2.1 Open coast structure crest height design

The crest height of all proposed concept options will be established to meet the overtopping limits proposed in Section 2.8.2 (i.e. below 0.1l/s/m for a 1 in 1-year event and below 10l/s/m for a 1 in 200-year event). The required crest height will be calculated using the EurOtop Neural Network tool. The Neural Network is a wave overtopping calculation tool that is particularly useful for complex structures, as will be encountered on the Isle of Man. The Neural Network will be used to calculate the wave overtopping for each of the proposed concept options, with the results used in an iterative manner to refine the concept options to meet the proposed design criteria. Please refer to Section 3.2.2 for further information on the methodology.

2.8.2.2 Open coast structure freeboard

As conservative approaches are being adopted for the input parameters, it is suggest that no further freeboard allowances are included within the options proposed to reduce wave overtopping at open coast environments.

The use of setback walls has been identified as a possible solution in some circumstances to contain any overtopped water. The use of setback walls will specify an additional freeboard allowance to contain any local increases in water level. These will be in line with industry standards, applying 150mm for hard defences and 300mm for soft defences.

2.8.3 Fluvial flood risk reduction performance

The provision of defence options to reduce fluvial flood risk has not been included as part of this study as it was considered outside the scope of works. No allowance for the joint probability analysis of a large fluvial event occurring in combination with a high still water level event has been made. The still water level is therefore only considered as a function of the astronomic and atmospheric components and not a combined fluvial, astronomic and atmospheric still water level flood risk.

However, at a number of locations, the use of tidal gates may provide a viable option to reduce still water level flood risk in inner harbour environments. Where this is the case, a high level, conceptual analysis of the feasibility of the gates will be undertaken, which will consider the available storage capacity and likely maximum fluvial discharge during a design storm event. For more information on the proposed methodology, refer to Section 3.3.3.2.

2.9 Ground conditions

Limited geotechnical and ground condition information was made available as part of this study and this commission does not include geotechnical analysis of design elements. Therefore, all structure designs will be progressed assuming poor ground conditions, e.g. low bearing capacity. This should provide a conservative approach to the development of concept designs. No allowance for settlement will be included within the concept design development.

It should be noted however, that all designs could be subject to significant change based on geotechnical investigation results and analysis. It is suggested that a geotechnical investigation is undertaken prior to the development of outline designs and their submission for planning approval.

2.10 Structural design

Structural design of concept options was not included within this commission. As stated above a full structural analysis could not be completed without relevant ground condition information. All concept designs will be reviewed by a structural engineer to assess the general design principles. It should be noted that the details of the concept structures are liable to change during outline and detailed design stages when more ground condition information is available.

2.11 Existing defences

A number of options may look to modify or adapt the existing defence structures. Where the existing defence is adapted, the overall design life of the sea defence will be dictated by the current condition of the asset and the estimated residual life, rather than that of the newly designed defence. In these circumstances, the design will not conform to the target design life of 100 years.

For the purpose of progressing concept design options, it is assumed that any defence concept that seeks to make use of the existing defences will need to be mindful of the estimated residual life. Provision of individual existing defence improvement options at each site will be commented on at each location to provide adequate protection against future deterioration.

2.12 Services information

No detailed services information was provided as part of this study and a services search is not included within the scope of works. However, the location of more critical services has been identified by DoI. These critical services will be considered in the development of the concept design options and highlighted on concept drawings and in hazard inventories. If the project progresses to outline and detailed design it will be essential that a full service plan is developed.

2.13 Contaminated land

No information regarding the location of areas of contaminated land has been provided as part of this commission. Therefore all design options will be developed with the assumption that none of the areas are subject to contaminated land constraints. An invasive contaminated land survey should be undertaken at all locations prior to detailed design to enable detailed assessment of suitable construction techniques and options for removal or re-use of excavated material.

To progress concept design options as part of this study the following have been assumed:

- No investigation of contamination issues at individual development sites; and
- Development flood defence options may require some contaminated land treatment depending on the result of the investigations.

2.14 Tie-in details

Tie-in details between old and new defences will be considered at a conceptual level. The key consideration should be to develop an option that does not create an area of outflanking or weak point, where flood water can bypass the defences and flood the hinterland.

2.15 Health and safety

In accordance with the requirements of the Construction Design and Management Regulations (CDM) (2007) a designer's risk assessment will be completed for each of the proposed concept designs. The purpose of the designer's risk assessment will be to initially eliminate any potential hazards associated with the construction, management and decommissioning of any designed elements. If a risk cannot be eliminated then measures will be considered to minimise that risk as far as is practicably possible. The JBA design risk assessment process is referred to as Hazard Inventory development.

2.16 Environment

This commission does not include the preparation of any formal Environmental Impact Assessment (EIA) or carrying out any environmental site surveys. All information to be used in the environmental appraisal will be obtained from readily-available online data sources, a literature review and through information requests to a range of relevant organisations. However, all concept designs will be reviewed to consider their environmental and visual constraints and opportunities and this will be fed into the Multi-Criteria Analysis (MCA) assessment. During the design process environmental impacts will be considered and eliminated and/or minimised where ever possible.

2.17 Construction cost assessment and buildability analysis

As part of the MCA process all proposed concept designs will be reviewed by a marine construction contractor, and outline construction costs and construction programme will be provided. The

contractor will also be involved in providing advice on the general buildability of all proposed concepts.

2.18 Sustainable development

Design adaptability is a key consideration due to the current uncertainties regarding the future impacts of climate change. Therefore, wherever possible the designs developed will aim to include an element of adaptability. The intention will be to allow the proposed designs to be modified in the future to best suit the climatic conditions.

2.19 Summary of design input criteria

The design input criteria has been summarised in Table 2-8 below for ease of use.

Table 2-8: Summary of design input criteria

Design Criteria	Input
Datum	Douglas02
Design life	100 years
Design storm	1 in 200-year event
Allowances for climate change	Equivalent to the medium emissions scenario for the 95th percentile confidence rating for the year 2115.
Relative Sea Level Rise for 2115	650mm for Port St Mary, Gansey, Castletown, Douglas and Laxey, 640mm for Ramsey and Peel
Increase in wave height for 2115	1.0m at offshore boundary
Level of design detail	Concept (Stage 2 RIBA Plan of Work)
Ultimate limit state standard	1 in 200-year still water level in combination (not in joint probability) with 1 in 200-year wave height (including climate change)
Performance standard 1 - Still water level	Defence crest > 1 in 200-year still water level in isolation (including climate change)
Performance standard 1 - Freeboard	150mm for hard defences 300mm for soft defences
Performance standard 2 - Wave overtopping	Twofold threshold against wave overtopping 1) reduce overtopping to <0.1l/s/m for 1 in 1-year event (in joint probability) 2) reduce overtopping to <10l/s/m for 1 in 200-year event (in joint probability)
Performance standard 2 - Freeboard	No additional allowance for freeboard except for in setback wall options (as in Performance standard 1)
Performance standard 3 - Fluvial	No analysis of fluvial flood risk except where tidal gates are proposed
Ground conditions	No geotechnical analysis undertaken, designs progressed assuming poor ground conditions
Structural design	No structural design undertaken, concept designs reviewed (high level) by a structural engineer
Existing defences	Assumed all existing defences will be maintained during 100 year design life of new structures
Services information	No detailed services information available, high level consideration during options development
Contaminated land	Assumed all sites are not subject to contaminated land constraints.
Tie-in details	Tie-in details will be considered at a conceptual level.

3 Methodology

The following sections describe the proposed methodology for the project. It is proposed that the project is structured as follows:

1. **Design Input Statement,** (this report) which describes the assumptions and methodology of the project.
2. **Data collection,** which includes the collection of hydrodynamic, topographic and environmental data.
3. **Numerical modelling,** where wave transformation and hydrodynamic modelling will be undertaken.
4. **Engineering design,** where the options to reduce coastal risk will be designed and refined based on wave overtopping calculations and predicted extreme water levels.
5. **Cost assessment,** which will assess the construction costs for each of the options proposed.
6. **Impact assessment,** which will review the potential impact the proposed options will have on the environment, landscape and heritage.
7. **Options appraisal and selection,** which will review the four overtopping options, considering technical viability, cost, environmental impacts and stakeholder interests.
8. **Final report,** which will summarise the results of this work.

These contiguous steps will be explained in more detail in the following sections.

3.1 Data collection

Site specific data on wave, water levels and existing defence geometry are required to be used within numerical models and the engineering design.

3.1.1 Metocean data

The extreme water levels around the Isle of Man will be extracted from the Environment Agency *Coastal flood boundary conditions for UK mainland and islands* project, which developed a consistent set of design sea levels for Scotland, England and Wales.

The use of the SWAN wave model will allow calculation of steady state wave conditions for specific inputs applied to the boundary conditions. Boundary conditions will include:

- Extreme sea levels
- Extreme wind speeds
- Extreme swell wave conditions.

The source of these inputs are been described in Section 2.4.

3.1.2 Topographic data

The DoI will complete a topographic survey of the seven ports and promenade areas to provide cross sections for the development of concept options. Cross section locations will be decided based on low point and known areas that first break bank.

3.2 Numerical modelling

In order to investigate wave overtopping and still water level flooding, several coastal processes must be assessed in detail. Unfortunately, no one numerical model can calculate these processes simultaneously. The proposed modelling approach will combine individual wave transformation and wave overtopping models, to apply a holistic modelling approach to the project.

3.2.1 Wave transformation modelling

All wave scenarios will be modelled using the industry-standard SWAN (Simulating WAves Nearshore) model. SWAN is a third generation wave model capable of simulating the following nearshore wave transformation processes:

- Wind-wave interactions, which is the transfer of wind energy into wave energy, leading to the growth of waves

- Shoaling, which is the build-up of energy as a wave enters shallow water, causing an increase in wave height
- Refraction, which is the change in wave speed as waves propagate through areas of changing depth, causing a change in wave direction
- Wave breaking, which is the destabilisation of a wave as it enters shallow water, causing broken waves with the characteristic whitewash or foam on the crest
- Wave dissipation, which limits the size of waves through white-capping, bottom friction and depth-induced breaking
- Diffraction, which is the spreading of wave energy behind structures, headlands and islands, which causes waves to change direction.

SWAN calculates steady state wave conditions for specific inputs of wave height, period and direction at an offshore boundary, and wind speed and direction applied across the model domain surface. Water levels can also be configured to account for tidal/surge variations.

Development of the model will involve several stages, including construction of a wave model grid, interpolation of a bathymetric dataset, calibration, joint probability analysis and extreme event modelling. To ensure accurate wave growth the model domain encompasses the majority of the Irish Sea, with land boundaries along North Wales, Western England, Southern Scotland and Eastern Ireland.

The wave transformation model will calculate the nearshore wave characteristics, which will be coupled to a wave overtopping model to calculate the required defence geometric components for each design (refer to Section 3.2.2). A range of wave and sea level combinations will be modelled, as identified within the joint probability analysis, for the return periods of 1, 5, 10, 20, 50, 100 and 200-years, with and without an allowance for climate change.

3.2.1.1 Limitations

While considered state-of-the-art, wave modelling has some inherent uncertainty, partly due to numerical assumptions. SWAN has a number of known limitations[17] for instance in a 2D simulation, wave-induced set-up is calculated based on approximate equations which are only applicable to open coastlines, wave-induced currents are not calculated within the model, wave diffraction in front of reflecting obstacles is calculated in a comprehensive manner. In order to manage this inherent risk, several allowances will be incorporated into the wave modelling procedure, such as:

- Wave conditions will be extracted from the model at a suitable distance offshore from the seven sites to ensure the absence of wave setup calculations does not affect nearshore wave conditions. These nearshore wave conditions will then be used within overtopping modelling, which does account for wave setup.
- If currents are found to be significant they will be provided as an input along boundaries. While SWAN does not calculate the currents directly, they will be incorporated into transformation calculations if input in this manner.

[17] SWAN internet description, accessed on 70/07/2013 from:
http://swanmodel.sourceforge.net/online_doc/swanuse/node4.html

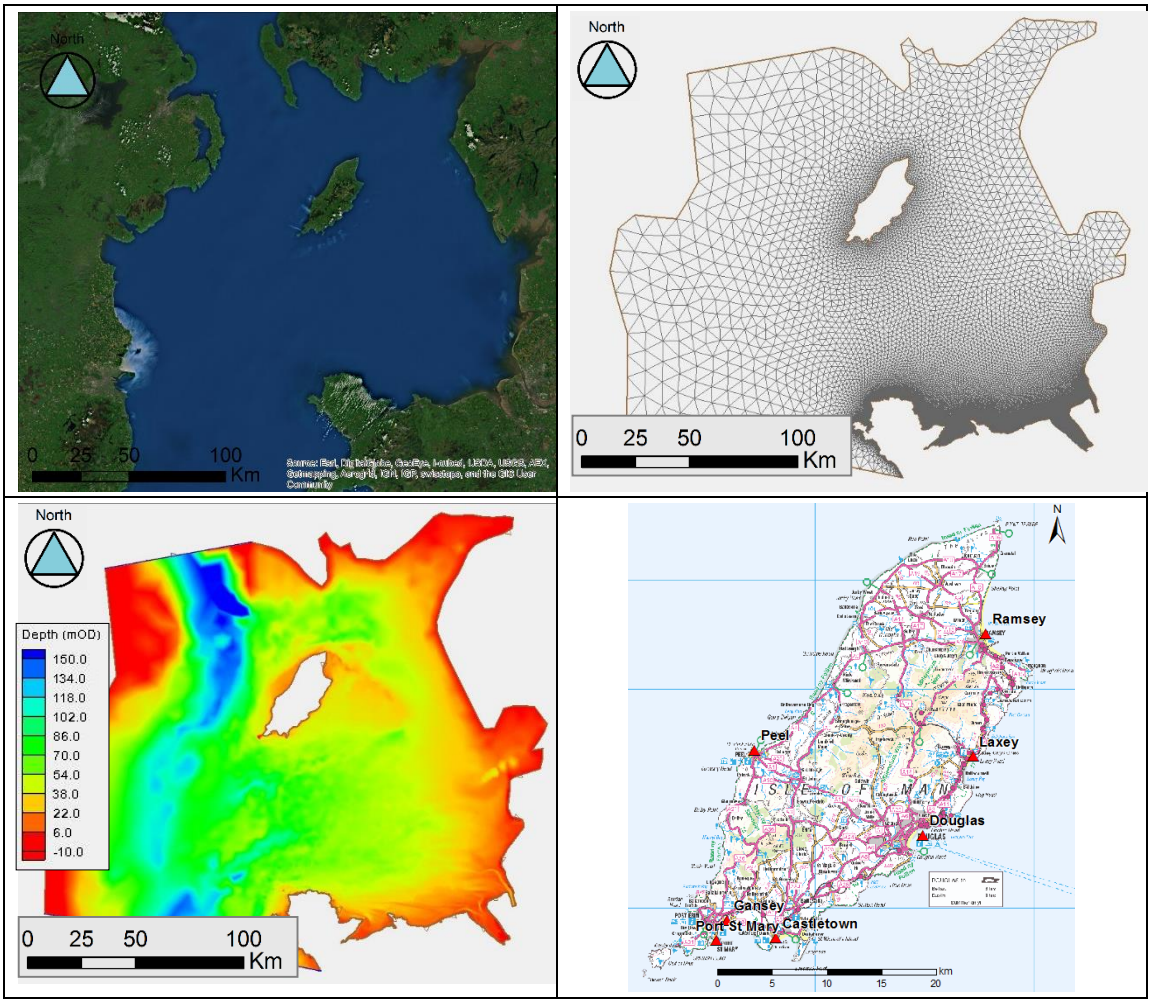


Figure 3-1: SWAN model computational grid, showing: Top left: Extent. Top right: Computational mesh. Bottom left: model bathymetry. Bottom right: Port locations of Isle of Man (Contains Ordnance Survey data © Crown copyright and database right 2014.)

3.2.2 Wave overtopping modelling

Wave overtopping modelling is proposed to be undertaken using the Neural Network calculation tool contained in the industry standard EurOtop. This manual is considered best practice within the UK for wave overtopping calculations. The Neural Network tool was selected as it provides the most suitable methodology to assess composite defences and allows for detailed schematisation of slopes.

The Neural Network requires detailed geometric information on 15 of the defence characteristics, including crest height, armour height, armour width, berm elevation, berm width, upper slope, lower slope and roughness. Each of the proposed overtopping defence options will be schematised within the Neural Network by establishing these parameters based on either the existing or proposed structure geometry, with the nearshore beach profile based on the available bathymetry. The resulting schematised profile for each defence options will be similar to that in Figure 3-2, developed for a similar coastal design project.

The Neural Network tool will be used to calculate the rate of overtopping for each option based on the nearshore wave conditions calculated through the wave transformation model for the return periods of 1, 5, 10, 20, 50, 100 and 200-years. The wave overtopping results will be used in an iterative manner to refine the concept options to meet the proposed design criteria specified in section 2.5.

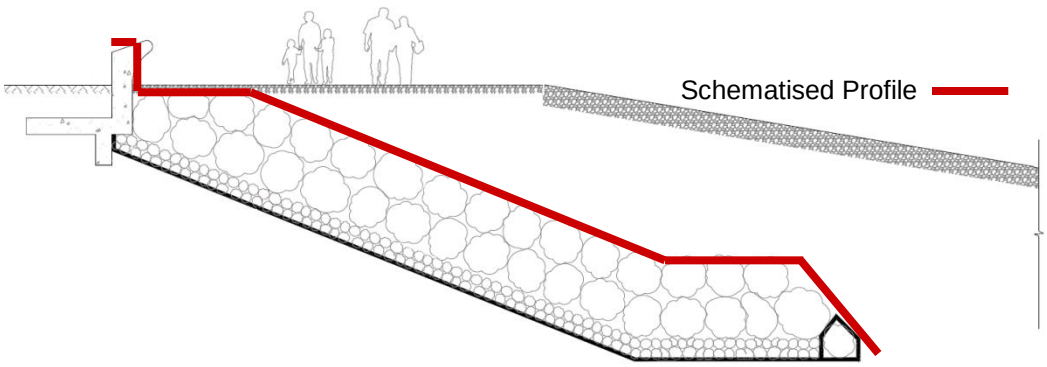


Figure 3-2: Example model schematisation for the Neural Network tool.

3.2.2.1 Limitations

The EurOtop manual, and its associated tools such as the Neural Network, is considered to be the best practice guidance in the UK for overtopping calculations. Nevertheless, wave overtopping modelling has some inherent uncertainty and all of the overtopping tools have limitations to their accuracy. Empirical equations used by the tools have been derived from physical model data, which has some intrinsic scatter. The accuracy of the overtopping should only be regarded as being within, at best, a factor of 1-3 of the actual overtopping rate, with the largest deviations being for small overtopping discharges[18].

In order to manage this inherent risk, once the preferred design is selected it is recommended that the option is taken forward to 3D physical modelling to verify and refine its performance.

3.3 Engineering design methodology

The primary objectives of both the modelling and engineering phases are:

- to identify a suite of possible options to reduce coastal risk at each of the seven locations;
- to refine the initial set of proposed options to a level that is sufficient to allow detailed analysis of the expected wave overtopping discharges; and
- to allow comparative analysis of the relative suitability of each option at each location.

It is intended that the level of design detail will constitute a 'concept design' and the design drawings developed will incorporate all key level, dimension and construction material information (e.g. width, height, crest level, foundation level).

In general, the design process will involve five stages, as detailed below. These stages are in place to ensure that the design process is fully quality assured and compliant with all relevant design standards and guidance.

1. We have already developed proposed design input criteria which are discussed in Section 2 of this scoping study. These criteria provide details of the overall design brief, the guidance and standards of protection targets that will be used to develop the design and the main assumptions.
2. For each design concept, we will develop an individual Technical Note providing a full description of the design process and including all calculations and justifications associated with key decisions. This document will ensure that DoI are aware of how all design elements have been developed and the basis for key decisions.
3. To ensure compliance with the CDM Regulations, and to ensure that Health and Safety is at the heart of the design process, a designer's risk assessment will be completed at the start of the design process. The designer's risk assessment (referred to as a Design Hazard Inventory) will examine the risks associated with all the design elements and look for opportunities to eliminate risks. If a risk cannot be eliminated then mitigation measures

[18] Pullen, T., Allsop, W., Bruce, T., Kortenhaus, A., Schuttrumpf, H & van der Meer, J (2007) 'Wave overtopping of sea defences and related structure: Assessment manual'. Accessed from www.overtopping-manual.com

will be considered. The Design Hazard Inventory will be a live document that is continuously reviewed and updated as the design process progresses.

4. A Sustainability Review for the proposed designs will be completed. This will ensure that climate change adaptability forms an integral part of the proposed solution. During this stage we will also take account of the initial findings from the environmental scoping review and ensure the outputs from this study are incorporated within the designs developed.
5. Following completion of the steps outlined above, we will produce relevant design drawings for the proposed options. The design drawings will also clearly highlight any risks associated with the scheme as determined by the various risk assessment processes detailed above.

The sections below outline the proposed method for the individual design concepts options.

3.3.1 Design risk

As discussed in Section 3.3 all design elements will consider design risk as a fundamental requirement of the design process. The foreseen risks and the method of mitigation or risk reduction will be recorded using a designer's risk assessment in line with the CDM Regulations. Any risks that cannot be mitigated will be described on the design drawings to ensure that they are brought to the attention of any other parties / contractors who may become involved with the project. It is important to note that the level of detail required for this project constitutes conceptual design and therefore the level of detail provided for possible design and construction risks will be comparable. If any of the options are taken forward to detailed design, a more detailed review and quantification of all risks will be required.

3.3.2 Design detail

The level of design detail required for this study is considered to be sufficient to allow the selection of the most suitable option based on key criteria. This will broadly constitute conceptual design as defined in RIBA Plan of Work 2013 Stage 2. The drawings will include a plan and general arrangement of the proposed layout of the options, denoting form, scale, and finishes of the works and its interaction with the existing structures. Cross section drawings will be produced showing critical elements of the proposal, to a level of detail appropriate to produce representative defence costs.

Drawings will not include construction details, which might include fixing details or reinforcement detail for example, or features which would otherwise be determined during the detailed design phase and appropriate to detailed design drawings. All drawings will be produced in AutoDesk's AutoCAD format, and be provided to you in this and Adobe portable document file (pdf) formats. The former, allowing ease of use by yourselves and third parties. The latter for ease of circulation to third parties.

3.3.3 Possible solutions to reduce coastal risk

A number of options have been proposed for both harbour and open coast environments to reduce the risk posed by coastal processes. This list is by no means exhaustive and some or all of these options may or may not be suitable at each of the seven sites. The suitability of these options will be considered on a site by site basis based on the technical assessment, topography, existing infrastructure and key stakeholder requirements. The lists have been included to provide examples of the potential solutions.

Table 3-1: Possible options to reduce coastal risk

Harbour environments	Open coast environments
Raise harbour walls	Raise/adapt existing sea walls
New set back walls	New setback wall
Demountable barriers	Permeable revetment
Tidal gates	Beach recharge

The suggested methodologies for the design of these options are explained below, but are subject to refinement during options development.

3.3.3.1 Harbour environment - Raise harbour walls, setback walls and demountable flood barriers

In the development of the design of raised harbour, set back walls or demountable flood barriers, the defence crest level will be determined by using 1 in 200-year still water level in 100 years time including an allowance for climate change in combination with a freeboard allowance. All flood walls will specify an impermeable core and conceptually consider the use of a sheer key to offer greater stability against sliding. While the structural stability will not be directly assessed, all designs will be reviewed by a structural engineer to assess their relative suitability.

In the design of demountable flood barrier systems, a careful consideration of the likely design life of the demountable components will be made. This will ensure the whole life costs of the demountable options are comparable with the other more permanent solutions.

3.3.3.2 Harbour environment - Tidal gates

The use of tidal gates could prove an effective method of reducing the still water flood risk at source rather than containing within the existing infrastructure. Here, gates will be shut at low tide, to prevent the high water level inundating the coastal towns.

The crest height of the gates will be calculated using the 1 in 200-year still water level including an allowance for climate change and the inclusion of the recommended freeboard.

However, in the conceptual design of tidal gates, it will be important to consider the risk of a fluvial event occurring in combination with a high still water level. No joint probability analysis or fluvial modelling has been allowed for within this commission. In order to evaluate the feasibility of a tidal gate option, the following conservative method is proposed:

Estimate total storage capacity

1. Estimate the volume held in the harbour basin at empty.
2. Take the water level of MLWN plus 10% to account for the atmospheric increase in water level at low tide during a storm event.
3. Subtract this volume from the total volume available in the harbour basin to determine the total storage capacity.

Estimate total fluvial flood volume

4. Take the flood hydrograph from a 1 in 100-year flood and a 1 in 200-year flood.
5. Conservatively assume that the hydrograph peak will coincide with high tide (or when the gate will be closed). The gates will be assumed to be closed for a period of 8 hours, covering a period of low tide, to high tide and two hours on the ebbing tide. This should allow for the water level to recede below a typical spring tidal level and allow for the differential head on the upstream side of the gate to reduce to below that on the downstream, coastal side of the gate.
6. Estimate the maximum discharge resulting from the flood covering four hours either side of the hydrograph peak to get the total fluvial flood volume.

Calculate the feasibility of the tidal gate option

7. Subtract the total fluvial flood volume from the total storage capacity to identify if there is sufficient capacity in the basin to allow for a large fluvial event coinciding with a high still water level.

Where the fluvial flood volume exceeds the total storage capacity, one or more of three options will be commented upon during option development, the use of tidal gates in combination with:

- raised harbour walls;
- flood storage and relief channels upstream; or
- the use of tidal gates is unsuitable at the location.

It should be noted that the proposed methodology is subject to alterations based on improvements and efficiencies found during option development and would warrant much more detailed analysis during a subsequent design stage (outside current scope)

3.3.3.3 Open coast environment - Raise / adapt existing sea walls

Raised sea walls will look to retrospectively fit an additional parapet to increase the defence freeboard. The efficiency in wave overtopping reduction could be further enhanced through the

use of a wave return to deflect wave energy seawards. This solution will be required to meet the agreed tolerable thresholds for overtopping. Numerical wave overtopping modelling will be undertaken using the Neural Network component of industry standard EurOtop. Wave overtopping calculations and design modifications will be undertaken iteratively to reach an optimum design that minimises wave overtopping to the desired tolerance for all of the potential combinations of variables tested in the wave transformation model.

For the raised sea wall options, a maximum defence crest elevation increase of 500mm will be applied due to the unknown structural capacity of the existing structures. The standard of protection that this 500mm increase will offer will be commented on, but may not conform to the design standards listed in Section 2.8.2. In locations where retrospective defence raising would provide too great a technical risk, due to the poor condition of the asset, we will look to re-design the sea wall to bring the defences in line with current design standards.

3.3.3.4 Open coast environment - New set back wall

The purpose of a set back wall will be to contain the overtopped water that exceeds the defence crest level. The design of this option will depend on the current baseline overtopping rate. The proposed methodology for this option would be as follows:

Calculate total overtopped volume during storm

1. Calculate baseline overtopping rate.
2. The baseline overtopping rate is calculated at high tide, which will reduce either side of high tide.
3. Assuming the worst overtopping occurs in a period two hours before and after high tide calculate the total overtopped volume (overtopping rate * time * 0.7)[19].

Calculate drainage capacity

4. Design the drainage in the front sea wall at 10m centres (but assuming a 50% redundancy) to convey a proportion of the flood volume.
5. Subtract this drained volume from the total overtopped volume to get the required storage volume.

Calculate required height of set back wall

6. Design the height of the wall to store the required storage volume.
7. Add the freeboard allowance for hard defences.

In locations where the front sea wall is at promenade level, the set back wall may be exposed to direct wave action. Here the wall will be designed to withstand the associated wave loadings.

3.3.3.5 Open coast environment - Permeable revetment

In the development of the design of a permeable revetment option, we propose to adopt methods from the industry standard rock manual[20], including the use of the Van der Meer formula for rock armour design and grading selection. For this solution, the goal of the design is to limit wave overtopping to below the agreed threshold and to ensure that the structure will remain stable during the design event.

To aid in the design of this structure, numerical wave overtopping modelling will be undertaken using the Neural Network component of industry standard EurOtop. Wave overtopping calculations and design modifications will be undertaken iteratively to reach an optimum design that minimises wave overtopping to the desired tolerance for all of the potential combinations of variables tested in the wave transformation model.

During the design process we will investigate possible armour types, considering rock armour, concrete blocks or proprietary armour units (e.g. accropods). The aim of this process will be to optimise armour characteristics; i.e. those which balance the armour sizing, limit overtopping and remain structurally stable (which is a function of the proposed angle of the revetment). By

[19] The 0.7 coefficient reduces the maximum overtopping rate (calculated at high tide) to a more representative value for the period of worst overtopping. This has been calculated by Alexander Dane for a site in Kent, but is considered representative for the majority of storms.

[20] CIRIA (2007), The Rock Manual: The Use of Rock in Hydraulic Engineering method of design

considering the required armour stability and revetment slope, we will develop a design that optimises the quantity of armour required and therefore provides the most cost effective solution.

3.3.3.6 Open coast environment - Beach recharge

For the development of the beach recharge option, it will be necessary to undertake a staged approach to the design of a stable beach and one that is capable of limiting overtopping rates to the agreed threshold. To do so, we will undertake wave transformation modelling to calculate the nearshore wave conditions and wave overtopping modelling to determine the design beach characteristics (i.e. beach width, crest level, slope, etc).

Following this we will design the construction profile and natural beach profile required to meet these overtopping thresholds. This process will be addressed iteratively until we have determined the minimum beach design that is required to ensure that the overtopping threshold limits are not exceeded.

During placement of beach grade material, inevitable losses occur. The construction profile will reflect these expected losses, incorporating a representative overfill factor than the required profile for wave overtopping reduction. In addition, a consideration of the requirement of longshore control structures will be made and included within the design.

3.4 Environmental desk study

A concise environmental scoping study will be undertaken to identify the key environmental characteristics of the seven sites. This information will used to appraise the potential environmental impacts and benefits of each of the proposed concept designs. This will ensure that the concept design and options appraisal processes are informed by wider environmental and sustainability considerations. The output from this process will be documented in a concise Environmental Report. This report will also outline the scope of environmental surveys and studies that would be required as part of a subsequent environmental assessment process should any of the proposed concept designs be taken forward for detailed design, together with the likely planning and environmental consenting requirements of relevance.

In summary, the Environmental Report will:

- Identify the existing key baseline environmental conditions of each site;
- Appraise the potential significant environmental impacts of the proposed concept designs on notable environmental features;
- Outline the potential mitigation measures required to minimise the significance of any adverse impacts;
- Set out further environmental assessment work required should the project be taken forward into the design phase; and
- Identify the organisations that would need to be consulted with to inform the detailed design phase.

3.4.1 Baseline information collection

A site walkover survey of each site will be undertaken to identify key environmental features that have the potential to be affected by the project. This survey will be augmented by a desk study and consultation exercise with key stakeholders.

A search of existing online data sources will be undertaken to obtain information on potential sensitive environmental receptors that could be affected by the proposed scheme. Online information sources that will be searched include:

- Environmental, heritage and social information contained on the Isle of Man Government website (http://www.gov.im/)
- Manx National Heritage website (http://www.gov.im/mnh/)
- Biodiversity records provided by the National Biodiversity Network (NBN) Gateway (http://data.nbn.org.uk/)
- Manx Wildlife Trust website (http://www.manxwt.org.uk//)
- Isle of Man tourism website (http://www.visitisleofman.com/)

A literature review will also be undertaken to obtain published information of relevance to the project. To ensure the review accesses a broad range of literature sources, several web search engines will be used to identify relevant information.

Consultation will also be undertaken with the following organisations to obtain information of relevance to this project:

- Isle of Man Government, Department of Environment, Food and Agriculture
- Isle of Man Government, Department of Infrastructure
- Manx National Heritage

Information will be collected where available in relation to the following topic areas:

- Biodiversity and nature conservation;
- Historic environment
- Water quality and water resources
- Landscape and visual amenity
- Contaminated land
- People and material assets
- Tourism, recreation and amenity.

3.4.2 Appraisal of potential environmental benefits and impacts

A high-level appraisal will be undertaken of the proposed concept designs to identify potential significant environmental impacts. The outcomes of this process will be summarised in an appraisal matrix. This will identify the environmental features that have the potential to be affected by each of the proposed concept designs, and will consider whether these effects are likely to be significant. We will establish the likely zone of influence for the scheme and will identify environmental features and issues requiring more detailed assessment. We will also seek to identify potential cumulative effects where there is a risk that such impacts could occur. We will provide a description of the potential mitigation measures that could be applied to avoid an impact or reduce impact significance and potential environmental enhancement opportunities that could be delivered through the implementation of each of the concept designs.

3.4.3 Conclusions and recommendations

The Environmental Report will set out a summary of the potential environmental risks and opportunities associated with each of the proposed concept designs. It will also provide a series of recommendations for the scope of future environmental assessment work likely to be required for each of the concept designs together with the planning and environmental consenting requirements of relevance. The outcomes of this environmental scoping study will be used to inform the MCA assessment of the concept designs to ensure the potential environmental effects are fully considered during the options appraisal process.

3.5 Cost assessment

In order to provide an accurate construction cost estimate it is proposed that a marine construction contractor is engaged to provide advice on the pricing element. We will consult with Raymond Brown Construction, who have extensive experience in the field of marine and coastal engineering construction. By engaging with a construction contractor early in the process we will be able to identify any ‘buildability’ opportunities and constraints which will ensure that the construction cost assessment is as accurate as possible. As all the options will only be developed to a conceptual design stage we would suggest that a minimum optimism bias (risk element) of 60% is applied to the cost development process. In addition if required by the DoI we will also consult with a local IoM contractor to ensure that the costs developed accurately reflect the local market.

3.6 Options appraisal and selection

It is recognised that selection of the preferred option at each location may be complex. In order to aid the decision making process we propose the use of a MCA assessment.

MCA is a matrix-type appraisal tool, whereby each option will be assessed on its ability to meet key project criteria. MCA is a useful tool for the comparative assessment of options and allows quantification of the benefits of each option. Each option is scored against key criteria to provide a clear numerical assessment of how well the options meet the specific objective. The criteria against which the options are assessed will be developed in conjunction with the DoI and is likely to include elements such as technical performance and viability, economic viability, environmental impact, landscape/visual impact, community impacts.

Following selection of the preferred options a presentation will be made to the DoI, describing the proposed schemes and the reasons for its selection.

3.7 Final reporting

Following completion of the concept design the final deliverables will be issued. These will comprise a set of concept design drawings for all the developed options. The drawings will be accompanied by a design report detailing the development methodology, description and analysis of results from all data collection, numerical modelling, engineering design development and options appraisal. This report will provide a record of the entire design process and contain all associated calculations and data collected.

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