ABERDEEN HARBOUR
EXPANSION PROJECT
November 2015

Volume 2:
Environmental
Statement

SECTION 2: PHYSICAL ENVIRONMENT

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CHAPTER 6: MARINE PHYSICAL ENVIRONMENT

6. MARINE PHYSICAL ENVIRONMENT

6.1 Introduction

The main purpose of this chapter is to provide baseline information and to describe potential impacts on the marine physical environment attributed to the construction and operation of the proposed Aberdeen Harbour Expansion Project. The main approach and methods to this element of the Environmental Impact Assessment (EIA) have been agreed in advance with key regulators, including Marine Scotland Science, Scottish Natural Heritage (SNH) and Aberdeen City Council.

The marine physical environment encompasses coastal and marine processes, including the natural cycle of waves, tides and tidal currents, sediment transport, suspended sediments and the resulting effects on sedimentary and geomorphological processes. The construction and presence of anthropogenic structures such as quays and breakwaters on the sea surface, water column and/or seabed has the potential to influence and modify the flow of water and the characteristics of waves, potentially resulting in changes to seabed morphology and composition.

6.1.1 Rationale for Baseline Description, Numerical Modelling and Impact Assessment

This chapter compiles and characterises all relevant coastal and offshore data sources within a desktop study, drawing on site-specific and regional data from oceanographic, geophysical, geotechnical and environmental surveys. Numerical modelling has also been undertaken to complement existing baseline surveys and to assess potential changes to the marine physical environment during the construction and operating phases of the proposed development.

6.1.2 Supporting Studies

Although this chapter deals principally with the physical marine environment, other chapters within this ES provide supplementary background information to coastal and marine aspects. These are summarised in Table 6.1.

Table 6.1: Technical studies and ES chapters relevant to marine physical environment

Chapter/Technical Study	Relevance to Marine Physical Environment
Chapter 3: Description of the Development	A description of the construction methods and design of the Aberdeen Harbour Expansion Project
Chapter 12: Benthic Ecology	Particular reference to seabed grab samples, seabed sediments and habitats within and around the coastal and marine study area
Chapter 8: Flood Risk and Surface Water	A review of storm surge scenarios and potential flooding
Chapter 16: Socio-economics	A description of coastal recreational activities
Chapter 10: Nature Conservation	An overview of designated sites and nature conservation objectives

This chapter should also be read in conjunction with the following supporting oceanographic, geological, ecological and numerical modelling technical studies which form a key part of the marine physical environment chapter.

- Chapter 6: Marine Physical Environment ES Appendices:
  - 6-A: Oceanographic Works;
  - 6-B: Hydrodynamic Modelling and Coastal Processes Assessment;
  - 6-C: Ground Investigation Report for Bay of Nigg Harbour Development;
  - 6-D: Geophysical and Bathymetry Surveys; and
  - 7-D: Sediment Plume Modelling.
- Chapter 12: Benthic Ecology and ES Appendices:
  - 12-A: Intertidal Benthic Ecological Characterisation Survey; and
  - 12-B: Subtidal Benthic Ecological Characterisation Survey.

The proposed Aberdeen Harbour Expansion Project will be built within and just offshore of Nigg Bay, located approximately 1 mile south of the existing Aberdeen Harbour. The largest predicted change to the marine physical environment attributed to the development will likely result in a significant reduction in wave energy and tidal current speeds within Nigg Bay, particularly due to the sheltering effect of the breakwaters. These changes to hydrodynamics will potentially modify sediment transport processes and sediment deposition, including the potential for localised scour at the base of the breakwaters.

As agreed with Scottish regulators, including SNH and Marine Scotland Science, during the early phases of consultation and scoping, the key sensitive marine physical receptor is the Nigg Bay Geological Site of Special Scientific Interest (SSSI), located along the southern section of Nigg Bay (refer to Chapter 10: Nature Conservation for further information). A summary of consultation relevant to this chapter is discussed in Section 6.3.

6.2 Policy, Legislation and Guidance

The following key guidance, policy and legislation documents have been used to inform this chapter (Table 6.2).

Table 6.2: Guidance, policy and legislation used to inform the Marine Physical Environment chapter

Source/Year	Guidance/Policy/Legislation
CIEEM, 2010	Guidelines for Ecological Impact Assessment in Britain and Ireland (Marine and Coastal)
Defra, 2009	UK Climate Projections 2009
Department of Trade and Industry (DTI), 2004	Strategic Environmental Assessment Area 5 (SEA 5: Conservation; Geology)
Foundation for Water Research (FWR), 1993	A Framework for Marine and Estuarine Model Specification in the UK
Joint Nature Conservation Committee (JNCC)	Guidelines for selection of earth science SSSIs http://jncc.defra.gov.uk/pdf/earthscienceSSSI.pdf
SNH, 2013	A handbook on environmental impact assessment: Guidance for Competent Authorities, Consultees and others involved in the Environmental Impact Assessment Process in Scotland. 4th Edition
SNH	Nigg Bay SSSI Maps, Site Management Statement, Operations Requiring Consent and SSSI Citation

6.3 EIA Scoping Responses

A summary of scoping opinions and responses from key stakeholders regarding the marine physical environment is presented in Table 6.3. Information on where these comments are addressed (where directly relevant) is also provided.

Table 6.3: Summary of Scoping Opinions and Responses

Consultee	Date	Summary of Consultation	Where addressed in ES
Marine Scotland Science	19 September 2013	Coastal processes (including wave, tides, littoral currents and sediment transport with and without the development) must be modelled and evaluated in the ES.	For a description of the baseline coastal and marine environment, refer to Section 6.5. For a description of coastal modelling outputs refer to Section 6.6 and ES Appendix 6-B: Hydrodynamic Modelling and Coastal Processes Assessment.
		Different options for the proposed harbour and breakwater layout should be presented in the ES.	A brief Design Envelope is presented in Section 6.4. For more detailed information see Chapter 3: Description of the Project.
SNH	20 August 2013	The impact of the sedimentation south of the southern breakwater should be considered in the ES.	Changes to sediment transport and sedimentation attributed to the southern breakwater are described in Section 6.4. Full technical details can be found in ES Appendix 6-B: Hydrodynamic Modelling and Coastal Processes Assessment.
		There is a potential for direct impacts to Nigg Bay SSSI during temporary construction works, it is important that the temporary construction areas are included in the ES.	An overview of the construction design is presented in Section 6.4. The potential impacts of construction works on the Nigg Bay SSSI are discussed in Section 6.7.3.

6.4 Design Envelope

The harbour will require construction of two breakwaters, dredging of the bay and navigation channel, land reclamation and building of approximately 1,500 m of new quay. Further information is provided in Chapter 3: Description of the Development.

A summary of the key engineering design parameters that are relevant to marine physical processes are summarised in Table 6.4. For a detailed description, refer to Chapter 3: Description of the Development.

Table 6.4: Proposed design envelope

Current Environmental Conditions	Oceanography	High-energy coastal section, offshore wave heights can exceed 10 m. Water depths range from approximately 0 m to 20 m below Chart Datum (CD).
	Coastal Characteristics	Small headland embayment coastal section comprising mostly a sand and gravel beach and bay flanked by two granitic headlands. The nearshore area off the headlands is mostly rocky seabed.
	Seabed Type	Surface sediments are mostly sand, except near headlands where seabed is rocky. Sandy areas are often underlain by a combination of glacial till and/or granite (metamorphosed) bedrock. An infilled palaeo-channel, presumed to be the ancestral Dee River, crosses the centre of the bay from east to west.
Breakwaters		Two shore-connected rubble mound breakwaters to be constructed off Girdle Ness (northern) and Greg Ness (southern) headlands. Each breakwater will be over 650 m long with a maximum crest level 12 m above CD. A quay wall will be built along the lee of the northern breakwater. The primary armour of the new breakwaters will be designed using concrete armour units. The primary armour on the seaward side of the breakwater will be built to withstand 1:200 year wave conditions.
Dredging and Land Reclamation		Proposed dredging activities include deepening and maintenance of the harbour basin to 9 m below CD; the East Quay and outer access navigation channel will be dredged and maintained to 10.5 m below CD. Dredging methods include a combination of trailer suction hopper dredging and backhoe dredging.
Quay Construction		A 400 m long solid quay will be built around the eastern side of the bay and will continue approximately 300 m along the north, where the construction will change to an open quay to complete 500 m on the northern side and 300 m on the eastern side. The quays and paved backup areas will provide over 140,000 m^2 of working space.
Coastal/Seabed Footprint		Total harbour area is anticipated to be 0.87 km^2.
Other works	Storm Water and Discharge Pipes	The existing short storm water outfall on the northern boundary and the United Fish Industries (UFI) discharge pipe will remain in their current locations (and will be reinforced as necessary). The Marine Scotland water intake pipe will be relocated.
	Forecasted Traffic	The traffic forecasted to use the new harbour on an annual basis is approximately 550 commercial vessels; 1,700 Platform Supply Vessels (PSV)/Offshore vessels; 40 Diving Support Vessels (DSV) and 33 cruise ships; this is in addition to the traffic currently using the existing harbour, which will continue to use the existing harbour.

6.5 Study Area, Data Sources and Baseline Characterisation

6.5.1 Study Area

The study area encompasses the coastal and shallow marine area of Nigg Bay, an undeveloped coastal segment located south of Aberdeen. From a coastal and marine physical environment perspective, the main study area extends approximately from Girdle Ness headland in the north to Greg Ness headland in the south, and from approximately the Mean High Water (MHW) line along the coast to approximately 25 m water depths, located some 1 km to 2 km offshore (Figure 6.1). This study area overlaps with the site specific marine surveys (geophysical surveys, benthic grab samples and metocean instrumentation locations), the development boundary and numerical modelling requirements.

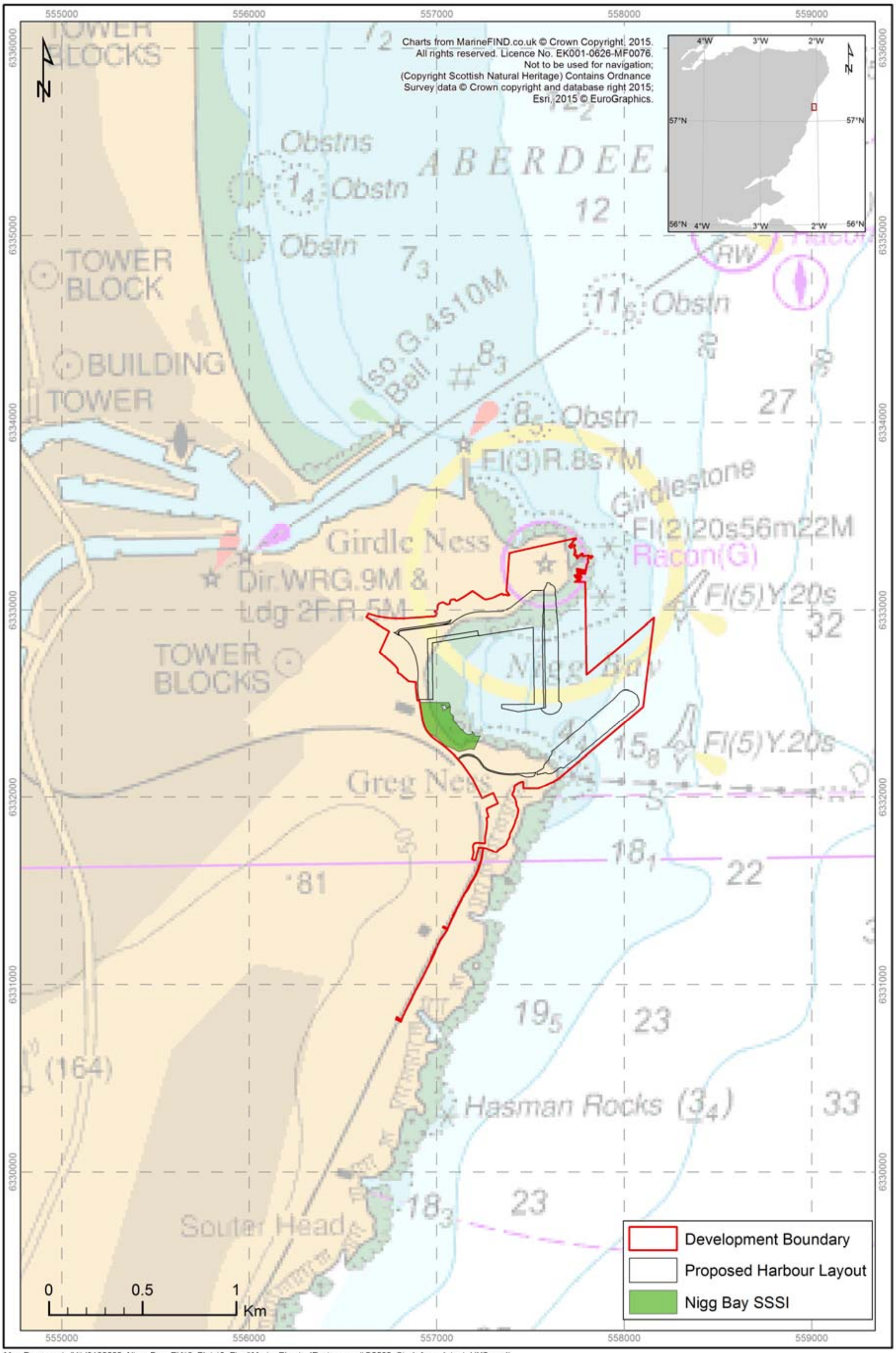

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Figure 6.1: Study area showing proposed harbour outline, Nigg Bay SSSI and Development boundary

6.5.2 Baseline Studies

Sources of information used to inform baseline characteristics and the assessment for the marine physical environment are summarised in this section. These include a combination of site-specific and regional surveys, regional monitoring programmes, numerical modelling and other scientific publications and reports. The main topics covered in this chapter include oceanography, bathymetry and coastal and marine geology. The data sources summarised in Table 6.5 are divided into reports/desktop studies and site-specific and regional field surveys.

Table 6.5: Baseline data sources

Metocean and Bathymetry	**Reports and desktop studies** Hydrodynamic Modelling and Coastal Processes Assessment (ES Appendix 6-B) UK Met Office Hindcast wave data Atlas of UK Renewable Energy (BERR, 2008)
	Field surveys Oceanographic Works (ES Appendix 6-A) Nigg Bay high-resolution bathymetry survey (ES Appendix 6-D)
Coastal and Marine Geology	**Reports and desktop studies** MAREMAP Seabed Sediments & Quaternary maps and regional reports DTI Strategic Environmental Assessment Area 5 (SEA 5: Conservation; Geology) Coastal Cells in Scotland: Cell 2 – Fife Ness to Cairnburg Point (Ramsay and Brampton, 2000) Landscape Character of Aberdeen, SNH Review (Nicol et al, 1996)
	Field surveys Subtidal and Intertidal Benthic surveys of Nigg Bay (ES Appendices 12-A and 12-B) High-resolution geophysical and geotechnical survey of Nigg Bay (ES Appendix 6-D) Ground investigation of Nigg Bay (ES Appendix 6-C)

A map showing the distribution and location of field surveys and relevant instrumentation is shown in Figure 6.2.

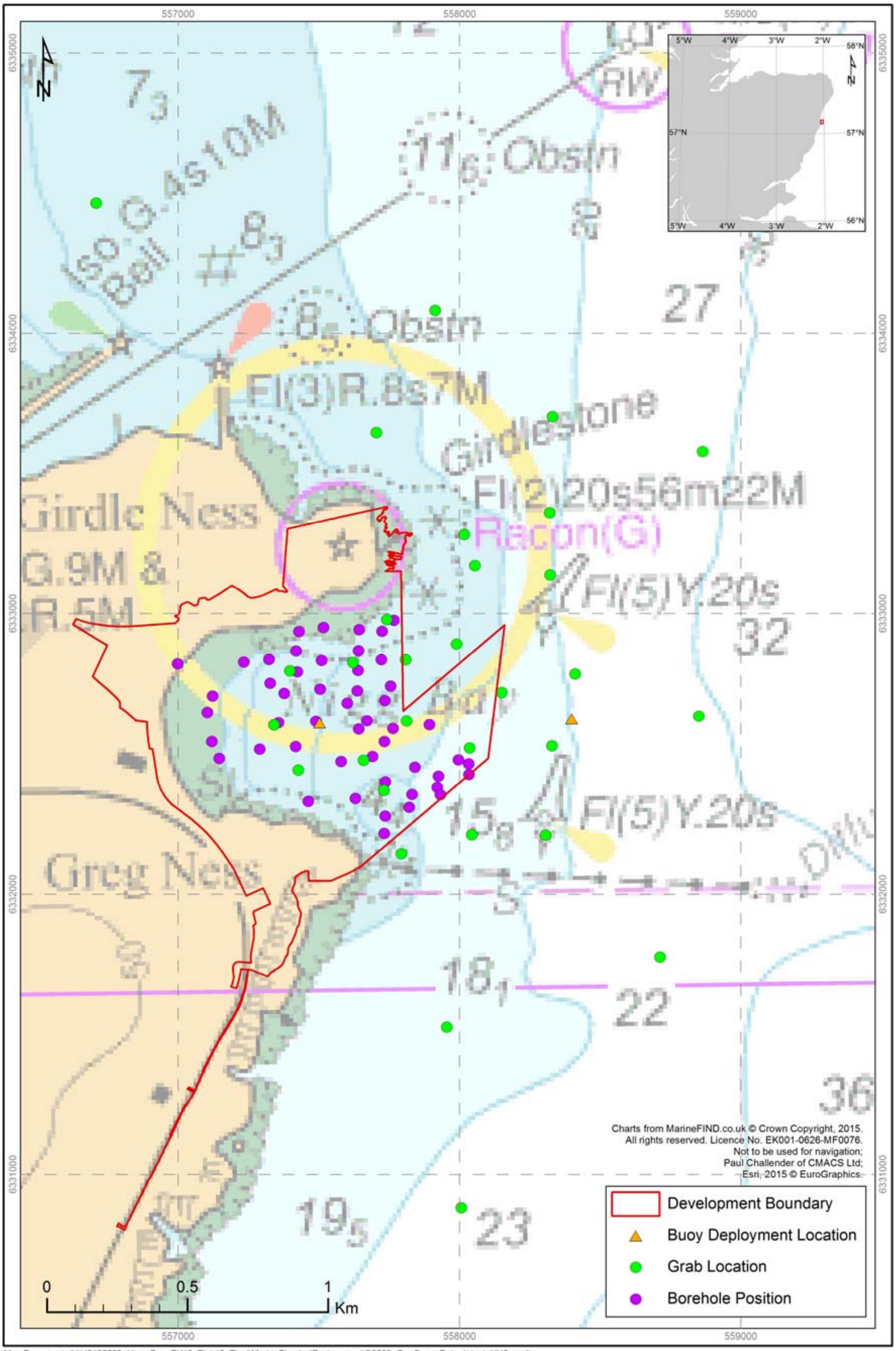

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Figure 6.2: Location and extent of site specific oceanographic, geophysical, geotechnical and seabed grab sample data

6.5.3 Baseline Characterisation

This section provides a baseline summary of the oceanographic, bathymetric and coastal/marine geological characteristics of the study area. The data are compiled from a range of field studies, reports and scientific publications (listed in Table 6.5).

6.5.3.1 Oceanographic Conditions

General Description

This part of the North Sea is a high-energy coastal zone, predominantly due to the large waves and strong winds which commonly occur in this part of the world, especially in the winter months. According to the UK Renewables Atlas (BERR, 2008), the mean annual significant wave height (H_s) offshore of Aberdeen in 55 m water depth is 1.27 m, with a corresponding mean winter H_s of 1.56 m. Hindcast wave and numerical modelling data for Aberdeen (1986 to 1994) show the dominant wave approach direction to be from the northeast, occurring approximately 40% of the time (Ramsay and Brampton, 2000).

Spring and neap tidal ranges in 12 m water depth are 3.47 m and 1.75 m, respectively (BERR, 2008). Mid-depth peak flows are 0.72 m/s during a mean spring tide and 0.37 m/s for a corresponding mean neap tide (BERR, 2008).

Results of Field Survey Work

A four-month meteorological and oceanographic field campaign was conducted in Nigg Bay from 20 February to 11 June 2015 (see ES Appendix 6-A: Oceanographic Works). The oceanographic monitoring programme comprised the deployment of two seabed frames, referred to as west and east, located in 5 m and 20 m water depth, respectively (shown on Figure 6.2 as 'Buoy Deployment Locations'). The seabed frames housed a range of oceanographic instrumentation. The main metocean parameters relevant to this chapter which were collected during the four-month long monitoring study included:

- Wave statistics;
- Tidal levels;
- Current directions and velocities;
- Suspended Sediment Concentrations (SSC); and
- Meteorological data (wind speed and direction).

High quality data were obtained from both seabed frames and the meteorological station, although due to unacceptable tilt range of the west site during the second deployment wave, current and acoustic backscatter results were considered invalid.

Waves

A range of sea state conditions were captured during the oceanographic monitoring campaign. H_s at the offshore east location ranged from 0.1 to 4.0 m, with a corresponding average H_s of 0.6 m and a maximum wave height (H_{max}) of 6.7 m. At the nearshore west location, H_s ranged from 0.1 to 3.2 m, with a corresponding average H_s of 0.6 m and a H_{max} of 4.8 m (Figure 6.3). The largest wave heights were measured on the 11 March and 3 May to 4 May 2015. The largest waves approached from the south-east, between approximately 120°T to 150°T; this was also generally the most common wave approach direction. Bi-modality (waves approaching from two different directions simultaneously) was not observed during the monitoring period. Maximum wave periods of up to 21 seconds and 14 seconds were captured at the west and east locations respectively. The longer wave periods at the nearshore west location are likely attributed to filtering out of shorter wave periods within the more sheltered embayment location.

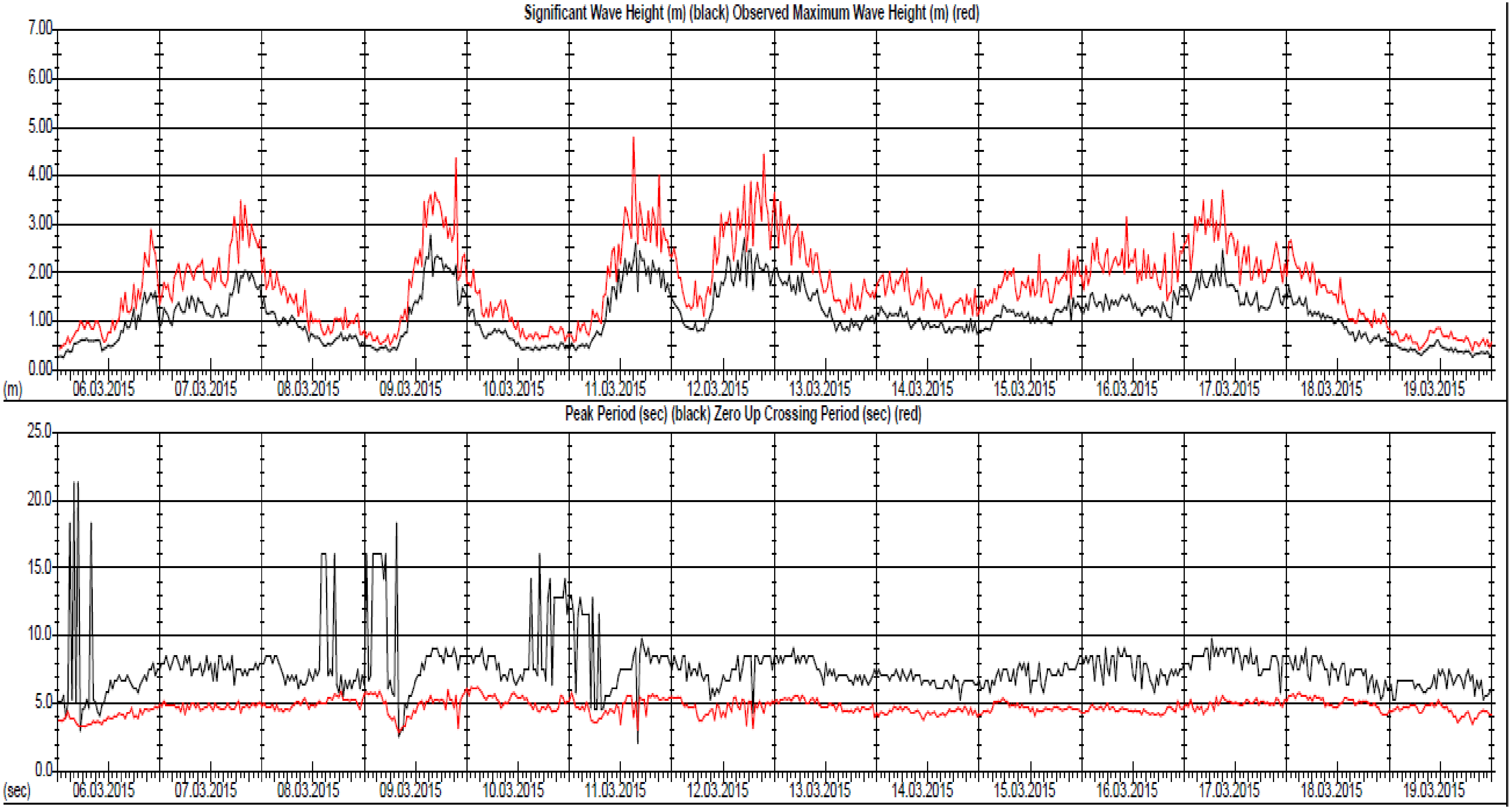

Figure 6.3: Wave heights and corresponding wave periods measured at inshore west location between 6 March and 19 March 2015

Tides

The study area can be classified as mesotidal and semi-diurnal (i.e. mean spring tides range between 2 m to 4 m and occur twice a day). Mean spring tidal ranges were 3.48 m in the east and 3.47 m in the west, agreeing well with published BERR (2008) tidal data. Tidal currents are highly rectilinear and orientated almost north-south (171/351°T). Maximum non-tidal residuals (wind attributed surges) were up to 0.78 m for both locations, observed on the 10 March 2015.

Currents

Site specific oceanographic current data results shown in Figure 6.4 are based on both locations for the first deployment period (20 February to 6 April) and only on the east location for the duration of the metocean campaign (20 February to 11 June). The flood-ebb tidal signal is often distorted during high-energy conditions, with residual velocities of up to 0.56 m/s.

Tidal current speeds at the more sheltered and nearshore west location were approximately one third of those recorded at the offshore east location. The maximum observed tidal current speeds were 0.55 m/s and 1.34 m/s at the west and east locations respectively. The residual or non-tidal component of the current velocity is relatively high compared to the tidal component throughout the deployment period, reaching up to 0.34 m/s at the west location (during deployment 1) and 0.56 m/s at the east location. A clear rectilinear flood/ebb pattern with a major axis of 171/351°T was observed at the east location, with southerly flood and northerly ebb flow directions.

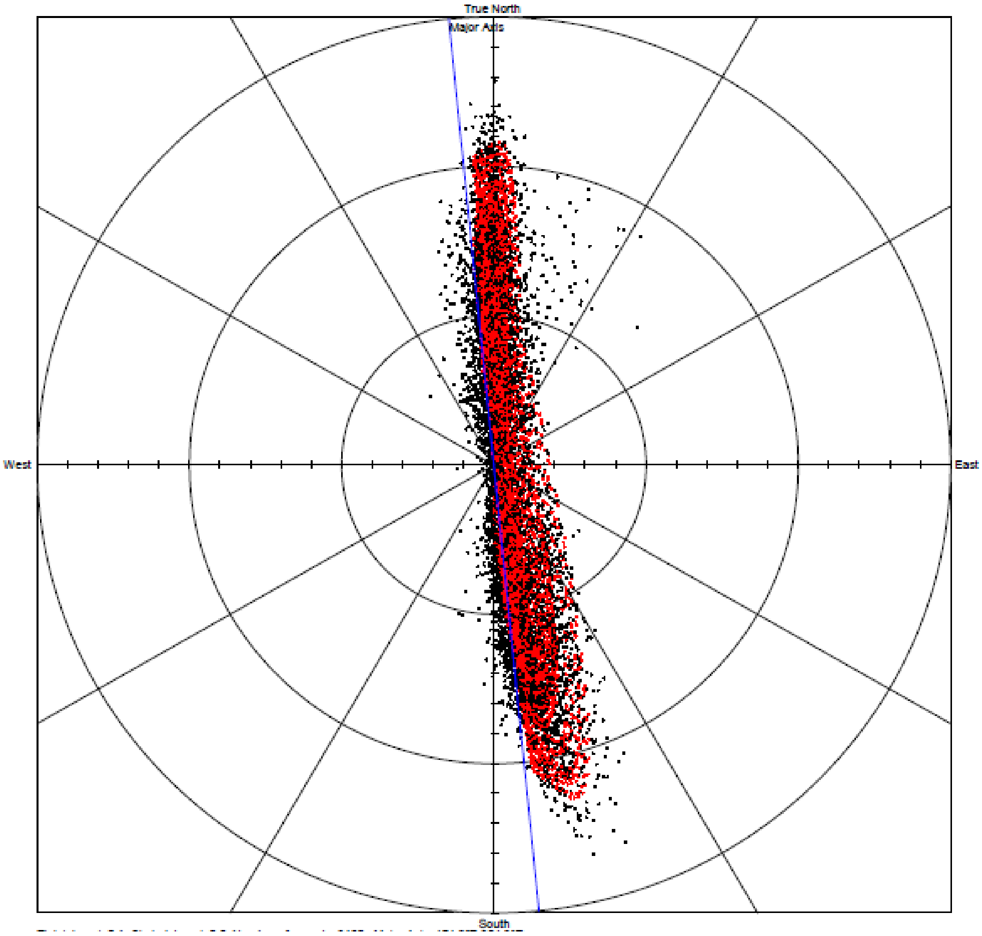

Figure 6.4: Current data speed and direction scatter plot (east location during deployment 1). Each circle interval represents 0.5 m/s

Suspended sediment concentrations (SSCs)

SSCs were measured using a combination of Optical Backscatter (OBS) and Acoustic Backscatter (ABS) instruments. Due to differences in measurement properties and the presence of fine sediments in the water column, significant differences in SSCs were observed between both instruments. A summary of minimum, mean and maximum concentrations are presented in Table 6.6. High SSCs often correlated with high-energy events, although sometimes high SSCs were also measured during calm sea states. These events may be attributed to additional influences such as fresh-water runoff and outfall discharges.

Table 6.6: Summary of SSC for east and west locations

	Value	West [mg/l]	East [mg/l]
OBS (West D1-D2; East D1-D2)	Minimum	5	7
	Mean	144	24
	Maximum	899	529
	Standard Deviation	174	31
ABS (West D1; East D1-D2)	Minimum	3	4
	Mean	18	25
	Maximum	126	82
	Standard Deviation	7	16

Meteorology

Wind speeds of up to 15.3 m/s (Beaufort Force 7) and gust speeds of up to 20.3 m/s (Beaufort Force 8) were measured by the meteorological station. The most common wind direction was from the south-west (240^{o}T to 250^{o}T), in line with dominant long-term wind directions across the UK. The highest wind speeds were associated with winds from the south and south-west during the measurement period.

6.5.3.2 Bathymetry

A high-resolution bathymetry survey of Nigg Bay and the vicinity was undertaken by Caledonian Geotech in 2012 (see ES Appendix 6-D: Geophysical and Bathymetry Surveys). Nigg Bay can be broadly classified as a headland embayment coast, with rocky headlands forming the margins of the bay.

Measured water depths across the proposed development site and wider study area range from a minimum of ±1 m CD nearshore to a maximum of 22 m CD offshore in the east (Figure 6.5). Depth contours across the centre of Nigg Bay are generally shore-parallel, with a gradual deepening towards the east (seaward). Small mobile bedforms are visible offshore, especially around 14 m to 20 m depths. These are mostly orientated east-west and perpendicular to dominant tidal current directions, which flow north to south and vice versa (Figure 6.4).

Water depths are more variable off the headlands located north and south of Nigg Bay, where the seabed is made up of ancient and weathered bedrock, resulting in greater variability and steeper seabed gradients. Finer sediments such as sand are not present off the headlands, presumably having been winnowed out and transported offshore due to the higher energy conditions which are common off rocky headlands.

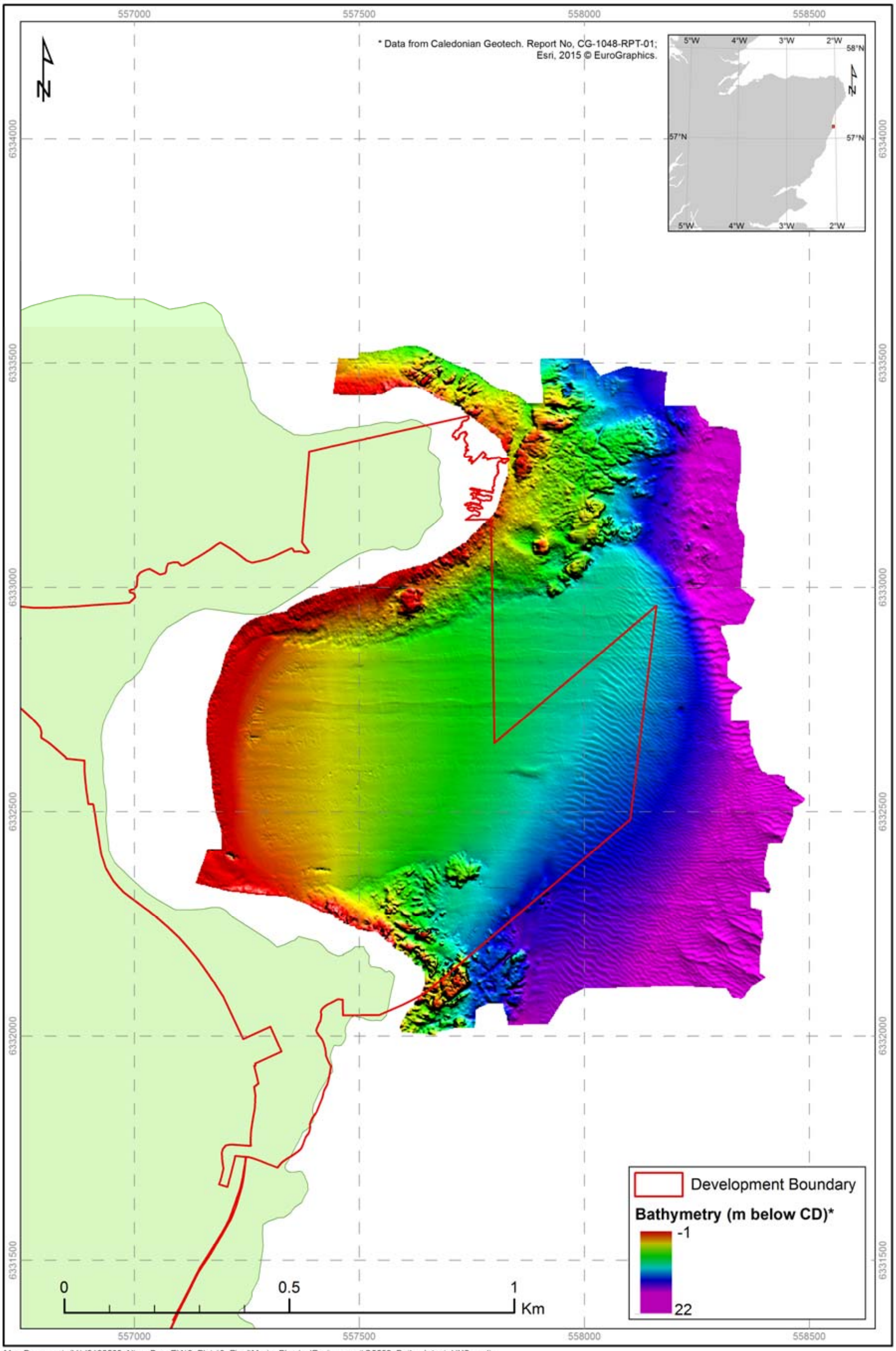

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Figure 6.5: High-resolution multibeam bathymetry of the study area

6.5.3.3 Geology

Coastal and marine geology is often divided into three main units, controlled by the age and makeup of the rocks and sediments. These are, from the most recent to oldest: seabed sediments, quaternary geology and solid geology. These are summarised below, with a focus on the study area and development boundary region.

Seabed Sediments

The regional seabed sediments around Aberdeen are made up of sand, with coarser material such as sandy gravel and gravel located further offshore beyond the development boundary. The superficial sediments located within Nigg Bay are classified as marine beach deposits (MAREMAP, 2015).

From a local perspective, the seabed within and around Nigg Bay can be broadly divided into two main classes:

- A mostly sandy seabed with small bedforms in deeper water; and
- A rocky seabed in and around the headlands located to the north and south.

A (geophysical) sidescan sonar survey of Nigg Bay, undertaken in 2012 (ES Appendix 6-D: Geophysical and Bathymetry Surveys), coupled with a benthic grab sampling and underwater video survey undertaken in 2015 (ES Appendix 12-B: Subtidal Benthic Ecological Characterisation Survey), present a detailed picture and understanding of the seabed sediments and other main features in the study area. The sidescan sonar survey identified two main acoustic seabed types:

- A low acoustic reflectivity seabed along the nearshore and in the centre of the bay, classified as a sandy seabed with sand waves located offshore; and
- A high acoustic reflectivity seabed off both headlands, classified as rocky/gravelly seabed (Figure 6.6).

The sandy sediments tend to become thicker towards the mouth of the bay.

The sidescan sonar survey results agree well with the seabed grab sampling and underwater video survey, confirming that Nigg Bay seabed sediments are mostly sand (Figure 6.7). Thirty seabed grab samples and underwater video were collected across the study area as shown in Figure 6.2. The 30 samples were mostly made up of fine sand, although medium (8 samples) and coarse sand (1 sample) were also present. The sediments were moderately well, well or very well sorted; and only Station 27 off Girdle Ness in the north was poorly sorted, comprising 9.4% gravel. Gravel percentages were low, and where present, were made up fine shell material and located close to the headlands. Mud content was also low, with the muddier samples located inshore within Nigg Bay (Samples 1, 2, 5 and 7) and to the north of Aberdeen Harbour (Sample 10). Mud still only comprised 4.7% to 6.3% of the sediment fraction at these stations.

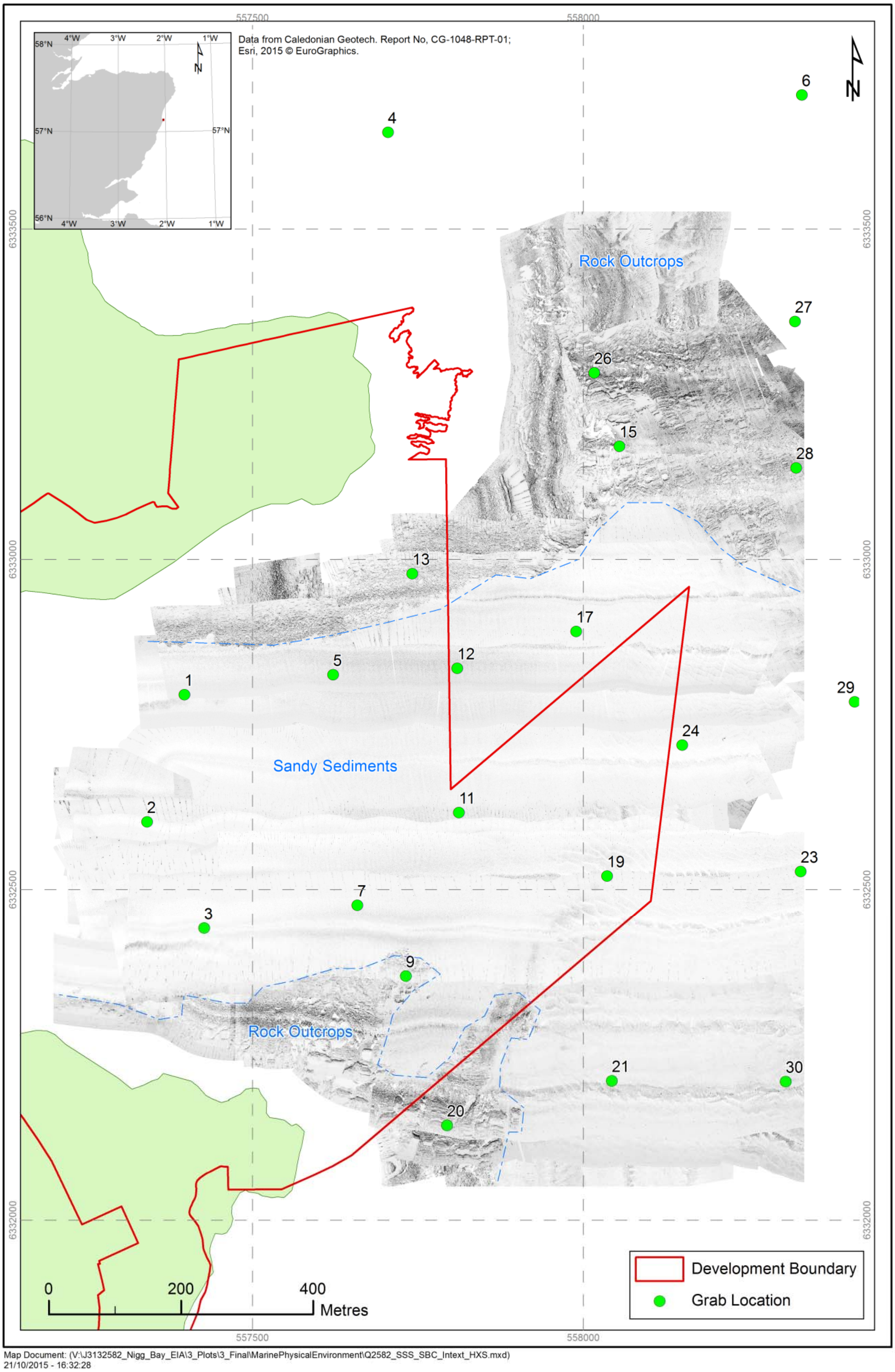


Figure 6.6: Sidescan sonar mosaic, seabed characterisation and location of 30 benthic seabed grab samples within the development boundary

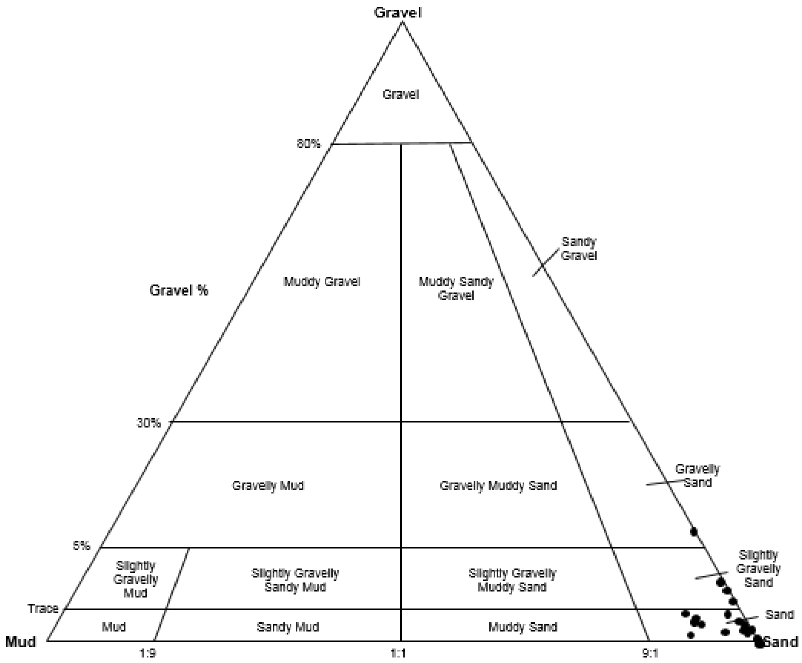


Figure 6.7: Tri-plot showing distribution of mud, sand and gravel for 30 seabed grab samples collected within the study area (Folk Classification)

Quaternary and Solid Geology

The quaternary period, covering approximately the last 2 million years, was marked by several glacial and interglacial cycles, resulting in significant sea level fluctuations and climatic variations (Holmes et al, 2004). The intermittent presence of thick ice sheets and significant changes in sea level left a profound mark on the geology of Scotland, including Nigg Bay.

The geological material lying directly underneath the more recent seabed sediments is made up of dense glacial meltwater deposits (sand and gravel with clay) and very dense glacial till, made up of clay or sandy clay with significant amounts of gravel, cobble and boulder material (also known as 'Boulder Clay'). The thickness of these glacial sediments ranges from 1 to 37 m (ES Appendix 6-C: Ground Investigation for Bay of Nigg Harbour Development).

There is also strong seismic and borehole evidence of an infilled and buried palaeochannel which traverses Nigg Bay from west to east (ES Appendices 6-C: Ground Investigation Report for Bay of Nigg Harbour Development and 6-D; Geophysical and Bathymetry Surveys (BGS, 1986)), attributed to the former location of the River Dee. The thickest glacial sediments are associated with this ancient river channel, which may extend up to 1 km offshore (BGS, 1986).

The south-west section of Nigg Bay has been classified as a Site of Special Scientific Interest (SSSI) (shown on Figure 6.1) due to the presence of a well-defined and continuous sequence of glacial sediments which are exposed along the cliffs. It has been suggested that some of the material making up the SSSI has been transported from as far away as Scandinavia (Nicol et al., 1996).

The solid, or bedrock, geology which underlies the stiff quaternary glacial sediments within Nigg Bay is made up hard granitic gneiss, originally a sedimentary unit associated with shallow seas. During the subsequent Caledonian Orogeny (a significant mountain building event which took place from the late Cambrian to the Silurian, approximately 500 million years ago), the shallow marine sediments were exposed to heat and pressure-associated metamorphism, converting them into igneous rock (Holmes et al, 2004). This bedrock unit is sometimes exposed on the seabed surface and is associated with the headlands. It is located either directly at or below the surficial seabed sediments or directly underneath the glacial sediments, continuing beyond the extent of the boreholes. It is greater than 40 m thick and the upper and younger rock is often more weathered and fractured than the rock located deeper down (ES Appendix 6-C: Ground Investigation Report for Bay of Nigg Harbour Development).

A representative borehole from within Nigg Bay illustrating the sequence of surficial seabed sediments underlain directly by much older bedrock is presented in Figure 6.8.

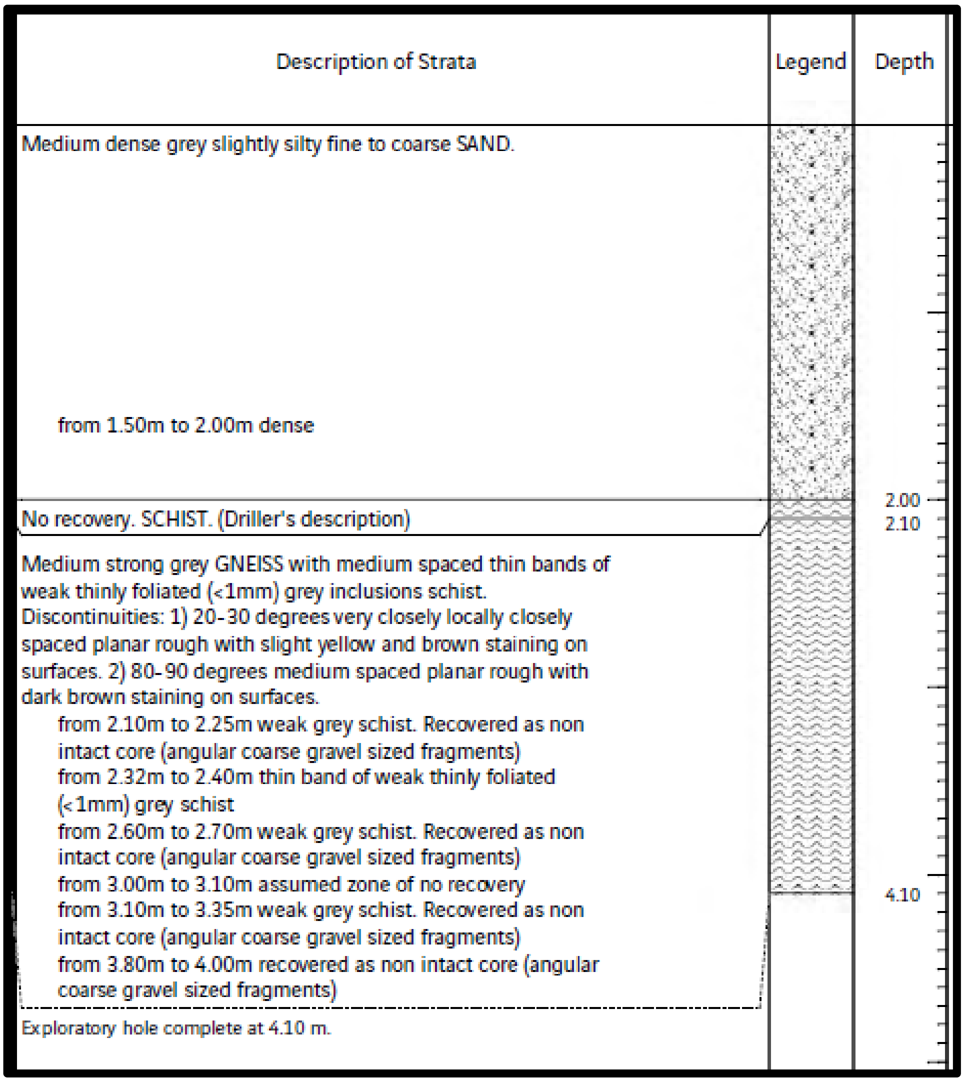


Figure 6.8: A representative 4.1 m long geological borehole (D98)

6.5.3.4 Seismic Activity

The Strategic Environmental Assessment (SEA) of Area 5, which includes the coastal and offshore area of Aberdeen, concludes that: "*SEA5 shows very little modern earthquake activity and appears to be at low but not entirely negligible risk from future earthquake activity that could affect development* *operations*" (Holmes et al, 2004). Development operations in this case refers to offshore oil and gas activities, but is deemed relevant to any largescale coastal construction projects.

6.5.3.5 Coastal Characterisation

Nigg Bay is an east-facing semi-enclosed headland embayment coastal segment, located about 850 m south-south-east of the current harbour mouth of the River Dee. It is approximately 950 m long from north to south, and is located along the former location of the ancestral Dee River (Nicol et al., 1996). The rocky headlands bordering each side of the bay are made up of old mid-Cambrian metasedimentary rock. The site also includes the Nigg Bay Geological SSSI, discussed later in this section.

Nigg Bay can be classified as a typical headland embayment coast, comprising an indented and coarse, moderately sediment-rich, coastal segment constrained between two exposed, ancient, rocky headlands (Ramsay and Brampton, 2000). Shoreward from the headlands, much of the coast is covered with a mixture of sand, cobble and boulders, consisting of wind-blown sand and remnants of older glacial material (Holmes et al, 2004).

An intertidal benthic survey of Nigg Bay was undertaken by CMACS in 2014 in order to characterise its main habitat and biotopes (ES Appendix 12-A: Intertidal Benthic Ecological Characterisation Survey). The shoreline along Girdle Ness and Greg Ness headlands is predominantly elevated steep rock, indented with gulleys, and scattered with boulders. The bedrock is covered by a mixture of barnacles, seaweed and mussels.

The northern and southern sections of the bay are made up of a combination of boulders and cobbles, while the upper shore behind the bay is also very coarse, consisting of boulders, cobbles and gravels, often coupled with broken concrete, rubble and tarmac. The intertidal part of the centre of the bay is mostly mobile sand and scattered rocks. Representative aerial photographs are shown in Figure 6.9.

Figure 6.9: Representative aerial views of Nigg Bay: Greg Ness (left) and centre of bay, landward view (right)

Nigg Bay Geological SSSI

The Nigg Bay SSSI is located along the southwest and upper part of the bay, and is known for its scientifically important geological exposures along the cliffs (JNCC, 2011; Ramsay and Brampton, 2000). According to the SNH Site Management Strategy, the Nigg Bay SSSI is a classic and important location for Quaternary geology stratigraphy, providing characteristic glacial deposits of northeast Scotland, covering the Late Devensian glaciation between approximately 33,000 years to 15,000 years ago. It has been recognised as a key reference site for glacial deposits and processes since the 19th century.

The cliff section, representing numerous ice advances, has six separate horizontal units. These units are as follows (from bottom to top): *basal (*lower) sands and gravels, which are believed to have originated from as far away as Scandinavia during an earlier glacial stage; bands of red and grey till; and upper sand and gravel units. These upper sand and gravel units, deposited by melting glaciers and rivers, mark the retreat and final stage of the last ice-sheet which covered large swathes of Great Britain.

The base of the cliff is covered with a range of rubble, concrete, tarmac and pavement slabs. This consented tipping practice was undertaken specifically for coastal management purposes, in effect to slow down coastal erosion. This has resulted in vegetation growth on the cliff, which has subsequently obscured some of the cliff exposures. Since 1999, the cliff has been mostly untouched, allowing natural processes to dominate. Occasional vegetation clearing has been carried out to expose some sections of the cliff for scientific purposes. According to SNH, the key management objectives of the SSSI are to maintain visibility and access to the site and its exposure. Further information about the conservation objectives of Nigg Bay SSSI is presented in Chapter 10: Nature Conservation.

A photograph of Nigg Bay SSSI is shown in Figure 6.10.

Figure 6.10: View of the Nigg Bay geological SSSI (Dawson, 2009)

6.5.3.6 <u>Sea Level Change and Storm Surges</u>

The Intergovernmental Panel on Climate Change (IPCC) predicts that global sea-levels will rise 0.12 m to 0.95 m higher than their 1990 level by the year 2100, attributed mostly to melting of large ice-sheets and thermal expansion of oceans. However, due to isostatic rebound since the last Ice Age, the coast of Scotland has been rising and as a result, is expected to be at the lower end of sea-level rise predictions (UKCP, 2015; Ramsay and Brampton, 2000). In general, sea-level change is not expected to have a large impact on embayment beaches along the northeast coast of Scotland.

Storm surge increases are predicted to rise by approximately 0.9 mm a year over the UK, although these are unlikely to be distinguishable from natural variability, especially along open sea and high-energy coasts like those off Aberdeen (UKCP, 2015).

6.6 Numerical Modelling

6.6.1 Introduction

Numerical modelling of hydrodynamics, waves and sediment transport processes has been undertaken to support the ES. The main purpose of the modelling was to assess potential changes to baseline coastal and marine processes attributed to the construction of the Aberdeen Harbour Expansion Project.

This section provides an overview of the modelling results, with an emphasis on the largest predicted changes within the Design Envelope. The outputs presented here include storm surge events, 1 year in 200 year events and climate change scenarios. For a full discussion of model methods and results, refer to ES Appendix 6-B Hydrodynamic Modelling and Coastal Processes Assessment.

6.6.2 Methodology

The first phase of any numerical modelling exercise is typically to generate a bathymetric grid of the seabed, replicating the seabed topography, depths and key coastal and marine features. This element was undertaken using Intertek's Aberdeen Coastal Model (ACM), a validated and calibrated model grid which was updated for this project (Figure 6.11). The ACM was accepted by key Scottish regulators as being fit for purpose.

A number of hydrodynamic, wave and sediment transport simulations under baseline, construction and in-place development scenarios were run using Mike 21 software, an industry standard and professional modelling software that is well-recognized and used globally. These 'before and after' hydrodynamic, wave and sediment transport processes, coupled with future climate change scenarios (through to 2100), were subsequently compared to evaluate relative changes to baseline conditions and to identify potential impacts. A summary of all of the model scenarios for hydrodynamics and coastal processes is presented in Table 6.7.

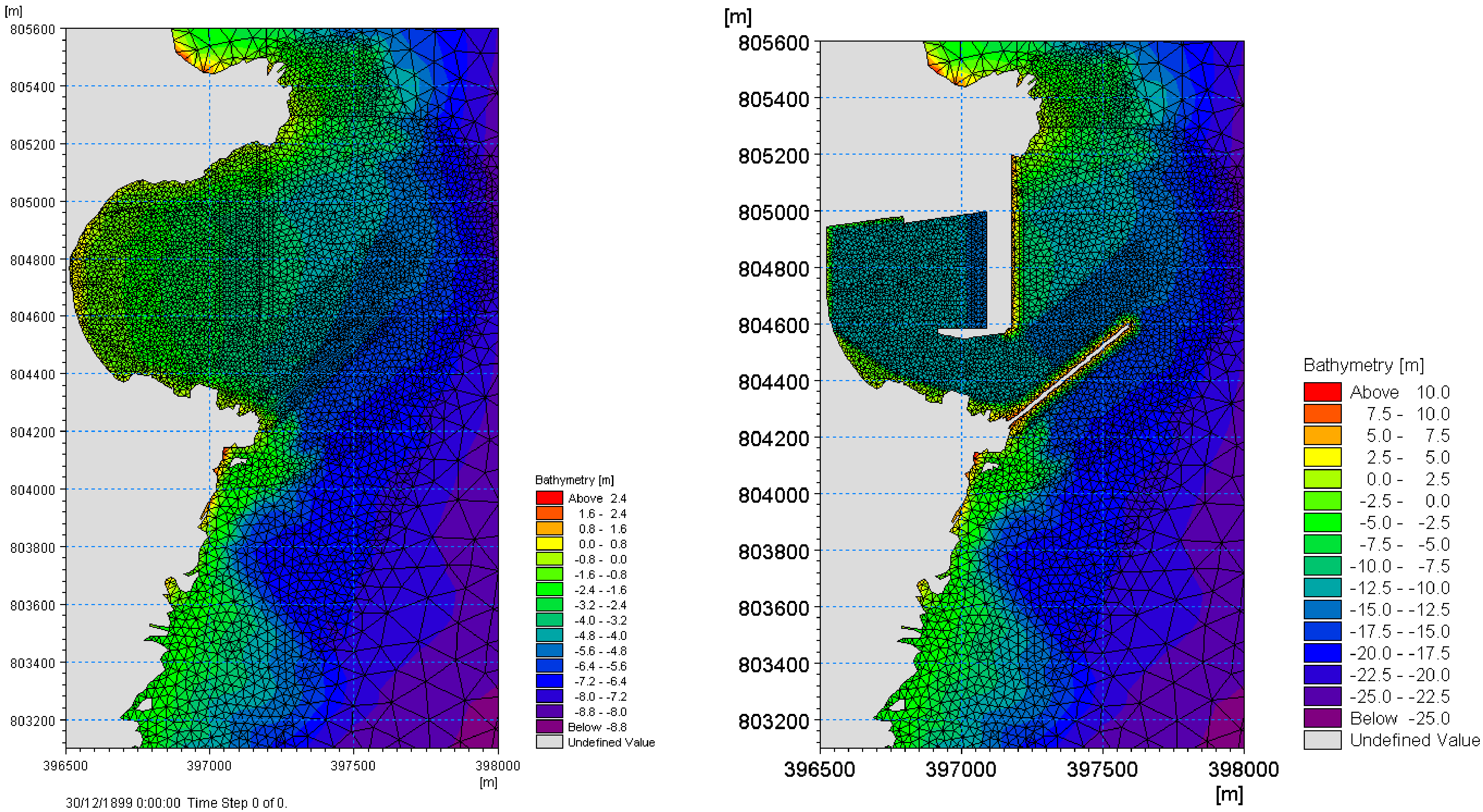


Figure 6.11: Baseline (left) and in-place construction (right) model mesh and bathymetries used for numerical model simulations

7Table 6.7: Summary of numerical modelling scenarios

Table 3-1: Modelled HD Scenarios

Environmental scenario	Tidal Conditions	Fluvial Discharge	Storm Surge Level
Average	Mean spring/neap tidal cycle	Mean	No storm surge event
Storm	Mean spring	High fluvial discharge (10-percentile)	No storm surge event
Extreme	High spring	1:200 year discharge event	1:200 year storm surge event

Table 6.7: Summary of numerical modelling scenarios continued

Table 3-2: SW model environmental scenarios

Environmental scenario	Return period (years)	Fluvial Discharge	Incident directions
Average	Annual mean (50 %ile)	Mean	45º, 90º, 135º
Annual	1:1	Mean	45º, 90º, 135º
Extreme	1:200	1:200 year discharge event	45º, 90º, 135º

Table 3-3: Modelled wave conditions derived from ReMap model data

Mean Wave Direction (degree)		0	45	90	135	180	225	270	315
50 %ile	Hs (m)	0.96	0.86	1.09	1.00	1.01	0.85	0.82	0.87
	Tp (s)	6.75	6.75	7.00	6.00	5.00	5.25	3.50	3.50
95 %ile	Hs (m)	2.20	2.01	2.68	2.62	2.21	1.73	1.72	1.77
	Tp (s)	8.75	9.00	9.25	7.75	6.75	6.75	4.50	4.75
97 %ile	Hs (m)	3.09	2.98	3.88	3.65	3.03	2.30	2.18	2.30
	Tp (s)	9.50	9.25	10.25	8.75	7.50	7.50	5.25	5.25
99 %ile	Hs (m)	3.81	3.83	4.73	4.53	3.69	2.73	2.65	2.86
	Tp (s)	9.75	9.50	10.50	9.25	8.25	8.00	5.50	5.75

Table 3-7: Future (changing) climate projections applied

Parameter	Baseline Condition (2015)	Future Condition (2100)
Sea-level rise (m)	0	+ 0.306 m
Wave height (m)	X	1.1x
Storm surge (m)	X	+ 3.17 m

6.6.3 Results

The results of baseline and development hydrodynamic modelling are presented concurrently within each section. A description of baseline conditions is followed by a discussion of modelled changes to baseline hydrodynamic conditions attributed to the proposed development.

6.6.3.1 Water Levels

Hydrodynamic modelling of water levels suggests that maximum changes attributed to the development are approximately 11 mm above baseline conditions inside the proposed harbour. Considering that baseline mean spring and neap tidal ranges are 3.7 m and 1.8 m, a predicted 11 mm change represents a change of +/- 0.3% and 0.6% respectively relative to current baseline conditions. Maximum changes to water levels under a storm surge scenario are shown in Figure 6.12. The figure shows that the largest predicted increases (red) of approximately 10 mm are located inside the harbour whereas a maximum decrease in water levels (dark blue) of approximately 10 mm is predicted south of the proposed development.

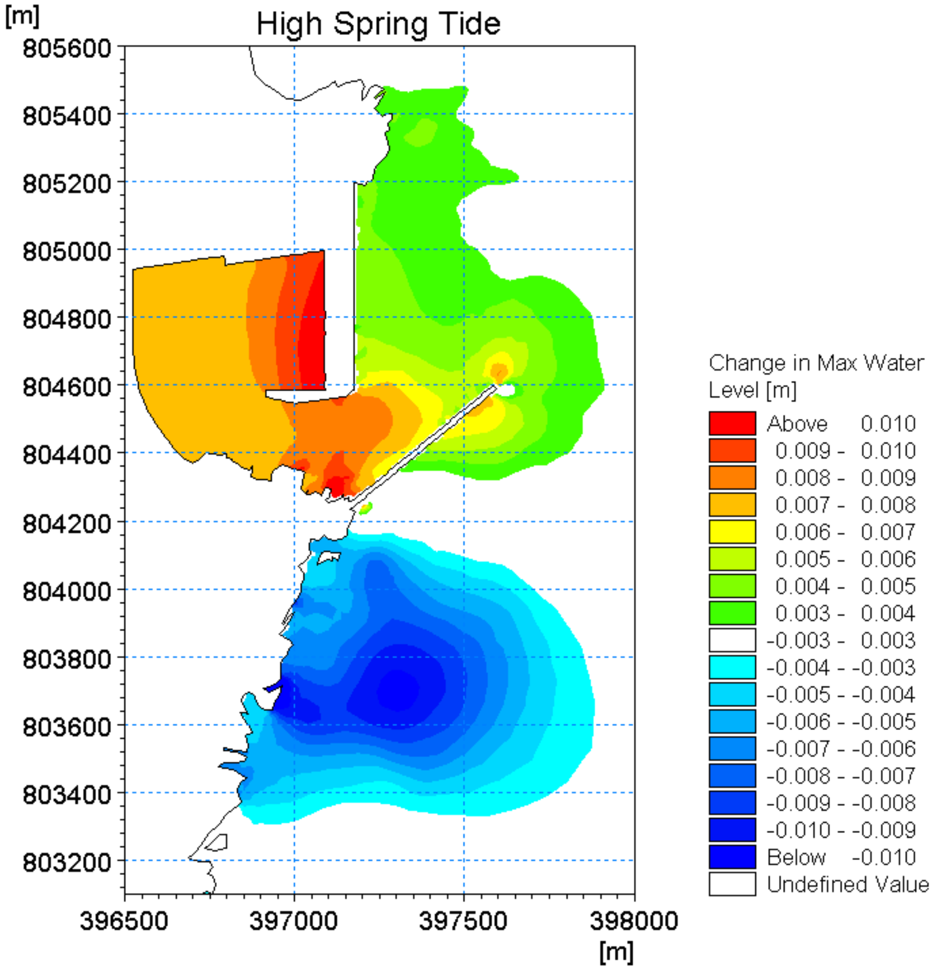


Figure 6.12: Maximum predicted change in water levels during storm surge scenario

6.6.3.2 Tidal Currents

The main purpose of building a harbour and associated large breakwaters is to provide safe berthing and navigation conditions for vessels. As a result, significant changes in tidal current speeds and directions are expected once the development is in place, especially since baseline tidal current speeds are moderately high around the headlands and tidal eddies are known to be present.

A presentation of peak spring tidal currents for baseline conditions (top), and a predicted change in spring tidal currents with the development in place (bottom) is presented in Figure 6.13. Modelled baseline spring tidal current speeds within Nigg Bay range from approximately 0.1 m/s to 0.2 m/s, with a clockwise rotation around the bay. The presence of the breakwaters during the operational phase reduces the tidal current speeds by approximately 0.1 m/s to 0.2 m/s, in effect almost eliminating tidal currents inside the proposed harbour.

Modelled baseline spring tidal currents are highest off Girdle Ness headland to the north, reaching close to 1.0 m/s; these current speeds are predicted to remain relatively unchanged once the breakwaters are in place. The largest reduction in current speeds attributed to the development is approximately 0.3 m/s to 0.4 m/s along the length of the southern breakwater. It is also worth noting a predicted increase in tidal current speeds of up to 0.1 m/s above baseline conditions, directly seaward of the southern breakwater (Figure 6.13, bottom).

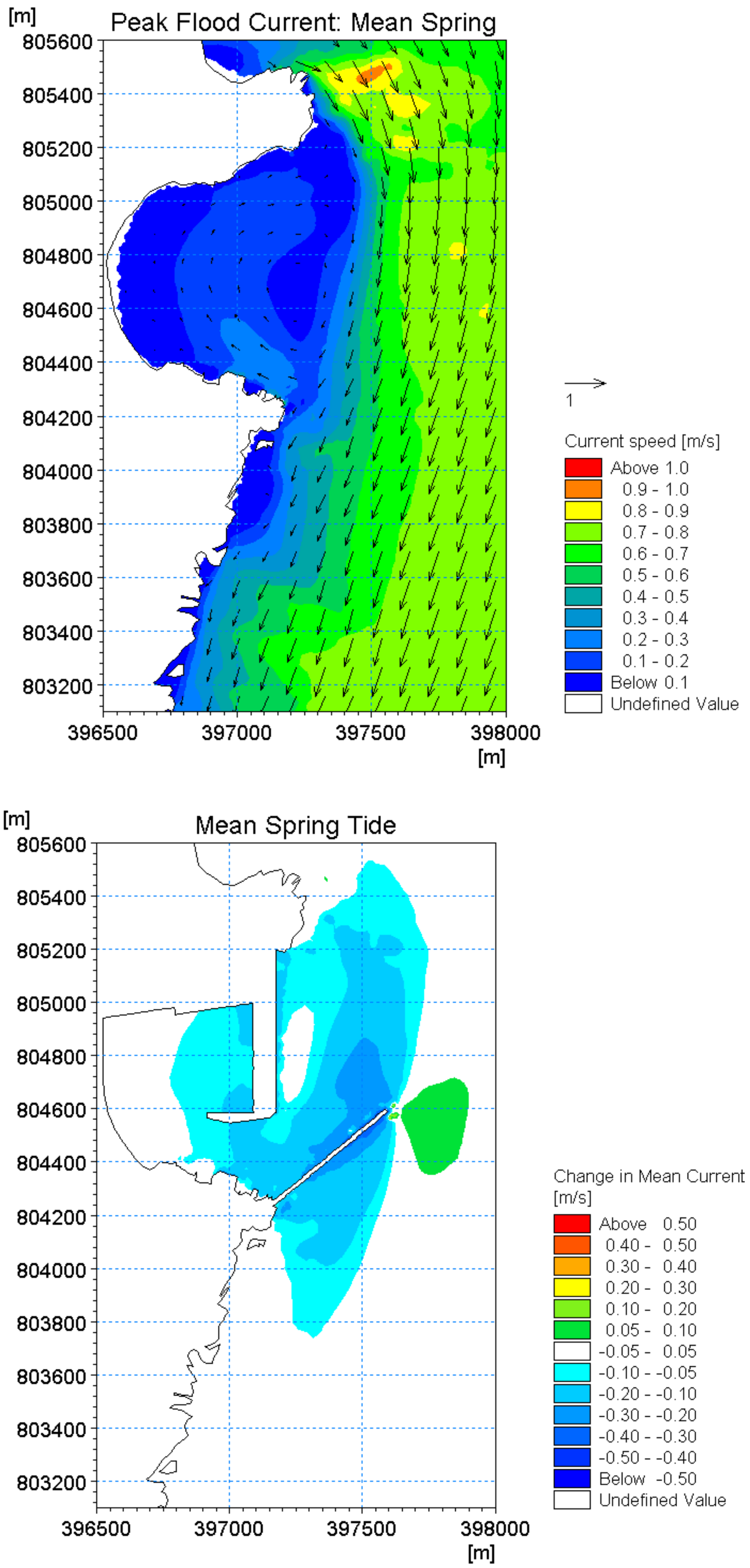


Figure 6.13: A comparison of spring tidal currents for baseline (top) and predicted change in current speeds during operational phase (bottom)

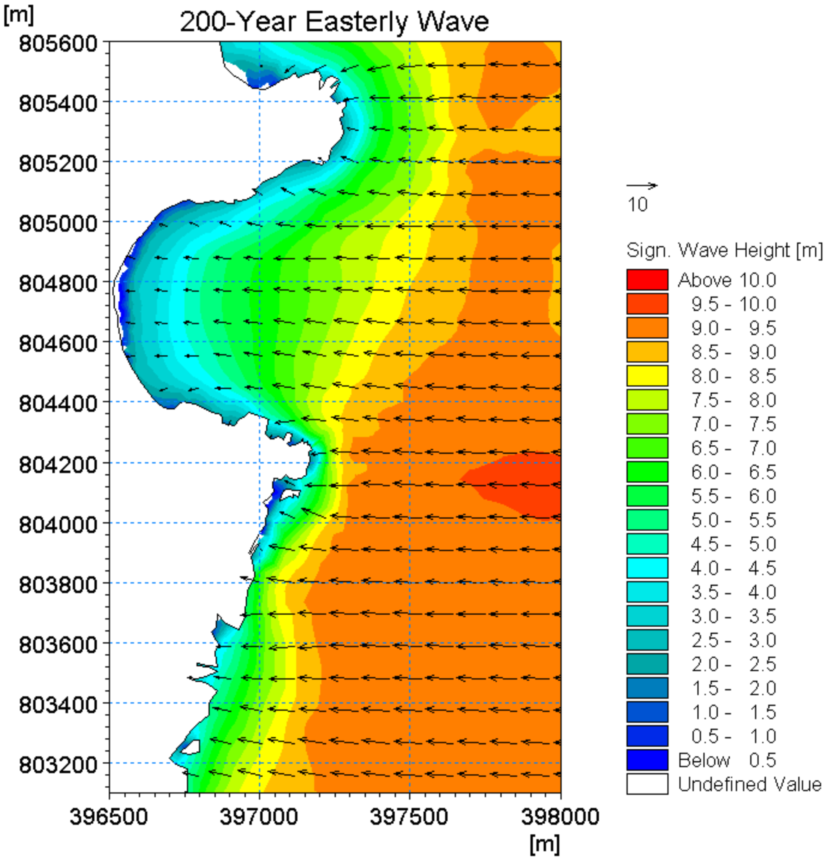
6.6.3.3 Wave Heights

The proposed breakwaters are designed to significantly reduce wave heights inside the harbour.

Offshore wave heights and wave periods used for 1 in 200 wave events from the east used for model input are 10.45 m and 13.6 seconds, respectively. These are derived from 35 years (1980 to 2015) of UK Met Office ReMap Data.

Baseline significant wave heights (H_s) under a 1 in 200 year event and approaching from the east are shown in Figure 6.14 below, top. Wave dynamics are greatly influenced by coastal features, such as embayments and headlands, and water depths. As predicted, the largest wave heights are located offshore, reaching heights of up to 10 m. Predicted wave heights along the shallow foreshore of Nigg Bay are approximately 1.0 m and 5.0 m in the centre of the bay.

The presence of the breakwaters has a major effect on baseline conditions (Figure 6.14, bottom), with wave heights in the lee of the breakwaters reduced by up to 7.5 m. Wave heights in the centre of the bay are reduced by 5.0 m, effectively eliminating any wave action inside the harbour once the proposed development is in place. An increase in H_s of around 1.0 m is only predicted to occur on the seaward side of the breakwaters. H_s are not predicted to change significantly beyond the direct influence of the harbour and breakwaters, i.e. no far-field effects to H_s are expected.



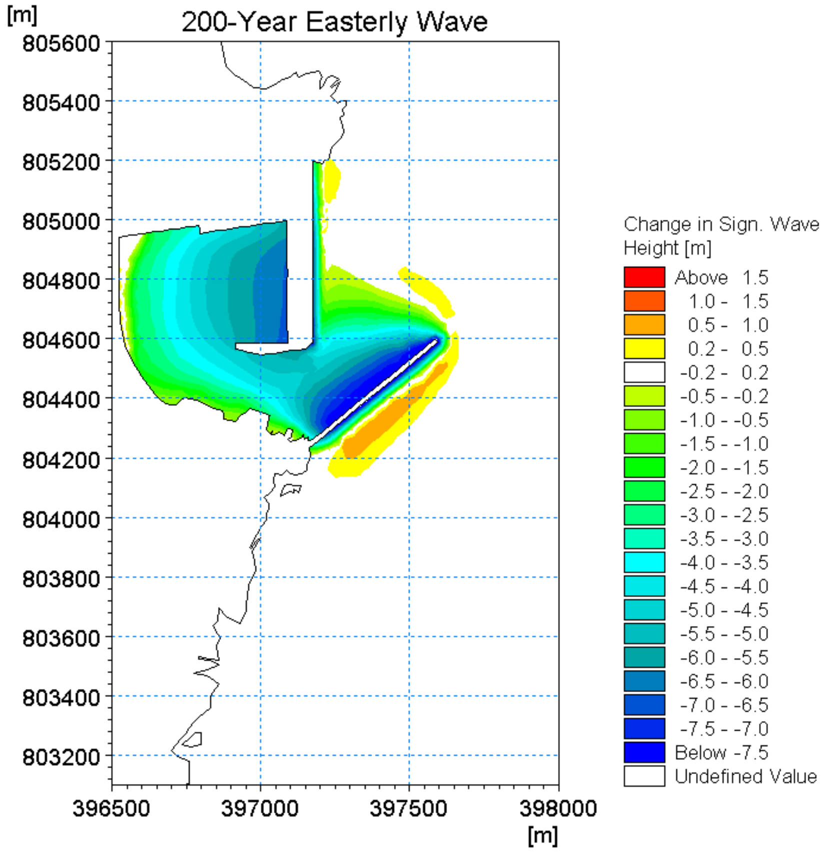


Figure 6.14: A comparison of baseline 1 in 200 wave event from the east (top) and predicted change in H_s under the same conditions under operational phase (bottom)

6.6.3.4 Sediment Transport

Sediment transport is governed by a combination of sediment type, tidal currents and wave action. The seabed sediments are mostly fine sand within Nigg Bay, which is easily mobilised and transported under spring tides and/or high energy events. Sediment transport directions are mostly influenced by wave approach direction, i.e. waves from the north generate southerly currents with clockwise circulation around Nigg Bay and waves from the south produce northerly currents with counter-clockwise circulation inside the bay.

Residual sediment transport calculations are used to estimate potential areas of sediment deposition or erosion for a given location. Figure 6.15 presents the modelled outputs for sediment deposition and erosion for the Aberdeen Harbour Expansion Project and surrounding areas for baseline (top) and operational phase (bottom) of the proposed development. Both outputs are very similar, which suggests that sediment transport processes, particularly outside of the direct influence of the harbour, will not be significantly modified. Furthermore, the rocky nature of the coastal region, particularly south of the southern breakwater, further inhibits any significant erosion or deposition since little or no sediment is available for mobilisation. However, given the significant decrease in wave and tidal current energy attributed to the harbour, sediment deposition is expected to take place within the near-field, i.e. within the harbour boundaries.

Predicted changes to hydrodynamics under climate change scenarios are of slightly higher magnitude than under present scenarios, although the spatial footprint of change is similar. Refer to ES Appendix 6-B: Hydrodynamic Modelling and Coastal Processes Assessment for further details and model results.

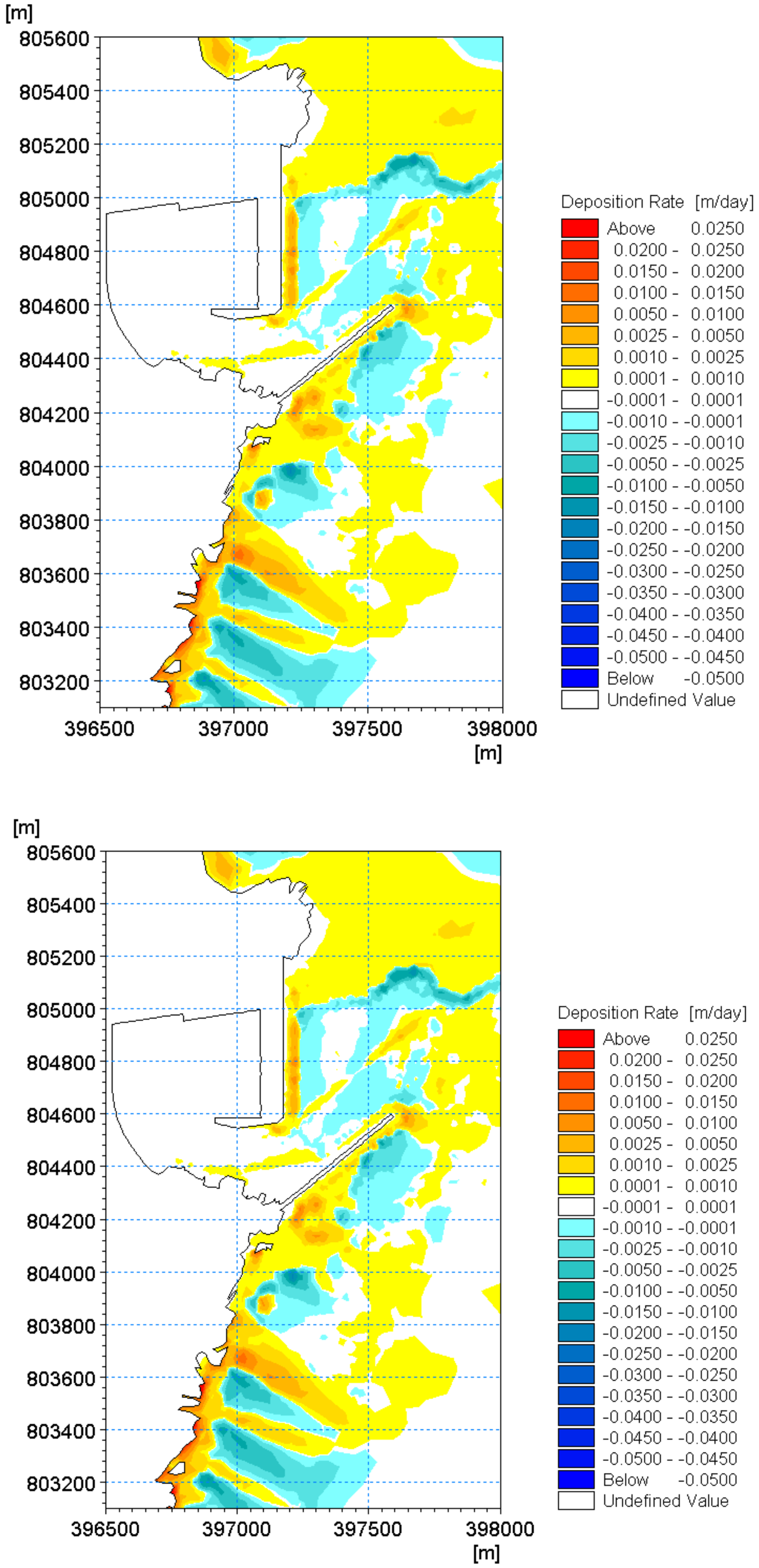


Figure 6.15: A comparison of sediment deposition and erosion rates (m/day) for baseline (top) and harbour operational phase (bottom)

6.6.3.5 Sediment Plumes

As part of the construction and operational phases of the development, which include harbour deepening and maintenance dredging respectively, fine sediments will be mobilised and re-suspended from the seabed in the form of suspended sediment plumes – with time these plumes will be redeposited on the seabed. The concentration and extent of sediment plumes is governed by a combination of sediment type and hydrodynamic conditions. In order to numerically model the dredging-associated plumes, a particle tracking numerical model, forming part of the larger Aberdeen Coastal Model, was used (see ES Appendix 7-D: Sediment Plume Modelling). Since the detailed construction methodology has not yet been developed (see Chapter 3: Description of the Development for further details of the 'Rochdale Envelope'), a highly conservative approach was undertaken, representing worst-case scenarios for both the construction and operational phases. Trailer-Suction Hopper Dredging (TSHD) and Backhoe dredging overspill scenarios were both assessed numerically. Sediment disposal and resulting plumes at the offshore disposal site are not considered here (refer to Chapter 7: Water and Sediment Quality for further details).

Modelled fine sand and very fine sand outputs for suspended sediment extent and deposition during TSHD and Backhoe overspill scenarios are presented in Figure 6.15 to Figure 6.19, respectively. The extent and deposition for both scenarios are localised, remaining within the confines of the proposed development and centred on the release location. This accumulated material (up to 1.0 m) will be dredged and removed with subsequent dredging operations.

Sediment plumes associated with mud size sediment during TSHD and Backhoe overspill are naturally predicted to form larger plumes than for sand-sized material. As can be seen from Figures 6.18 and 6.20, mud will be present both within the proposed development area and will be transported outside of Nigg Bay, with predicted deposition of 1 mm at Girdle Ness during a mean spring-neap scenario. Elevated mud concentrations are predicted to be as high as 35.6 mg/l, although baseline average concentrations within Nigg Bay have been shown to be 144 mg/l according to metocean ADCP data.

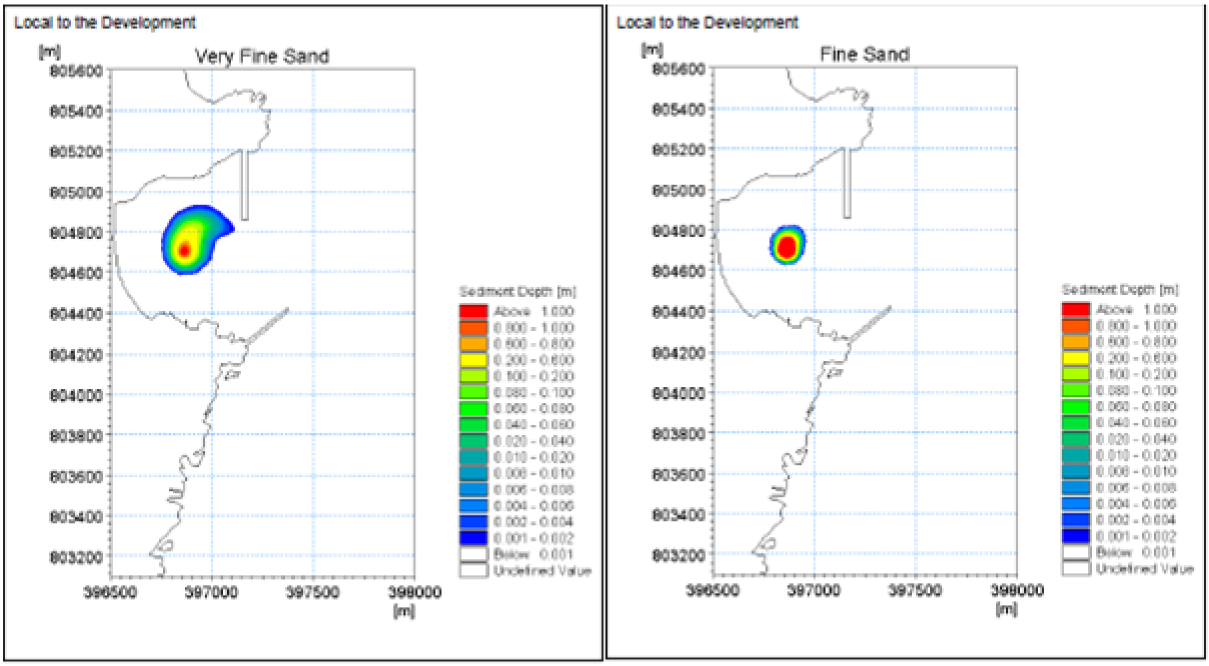


Figure 6.16: A comparison of sediment extent and deposition associated with TSHD overspill for very fine sand (left) and fine sand (right)

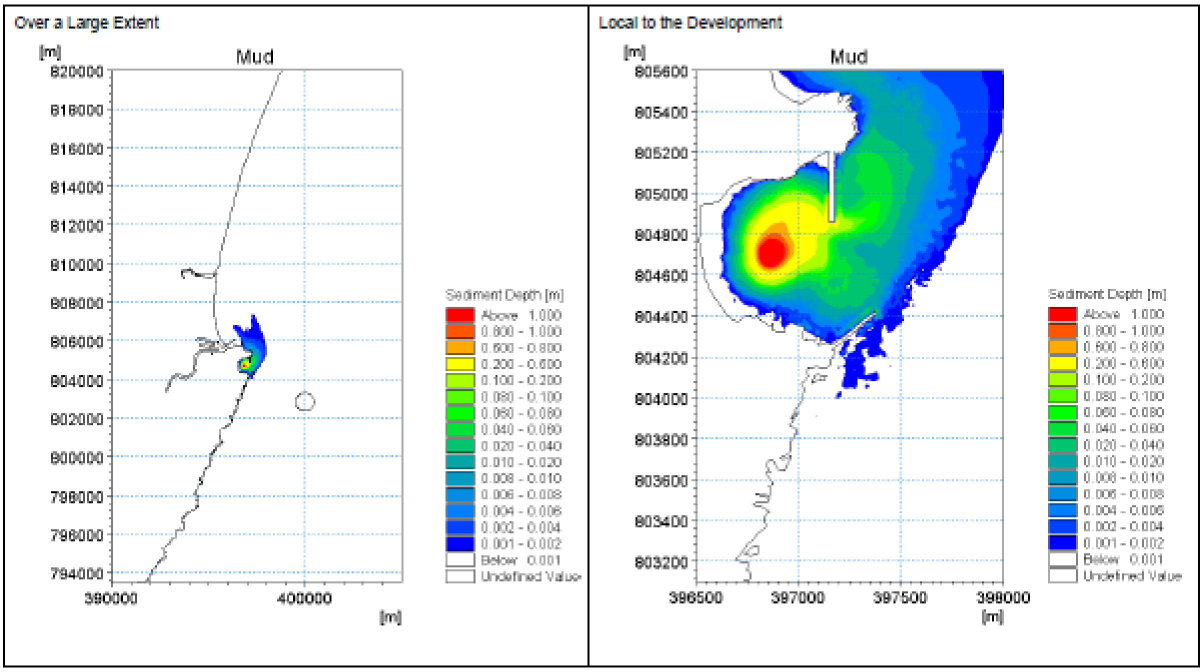


Figure 6.17: Mud extent and deposition associated with TSHD overspill from regional perspective (left) and local to the development (right)

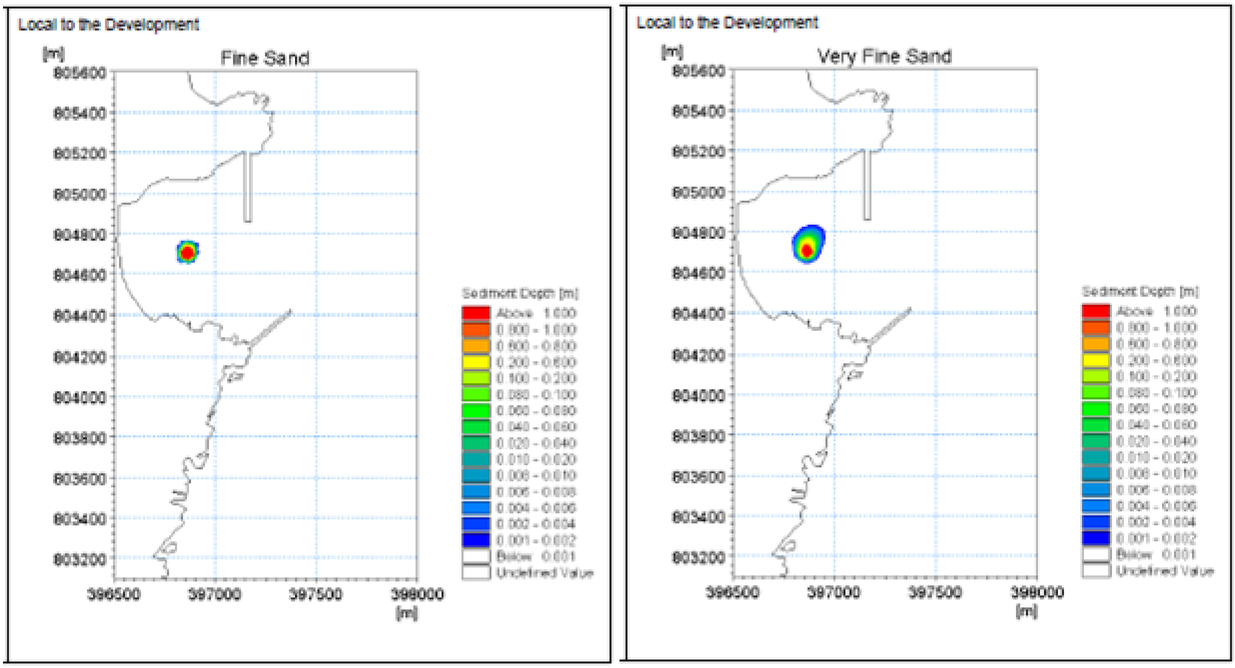


Figure 6.18: Backhoe overspill area and deposition for fine sand (left) and very fine sand (right)

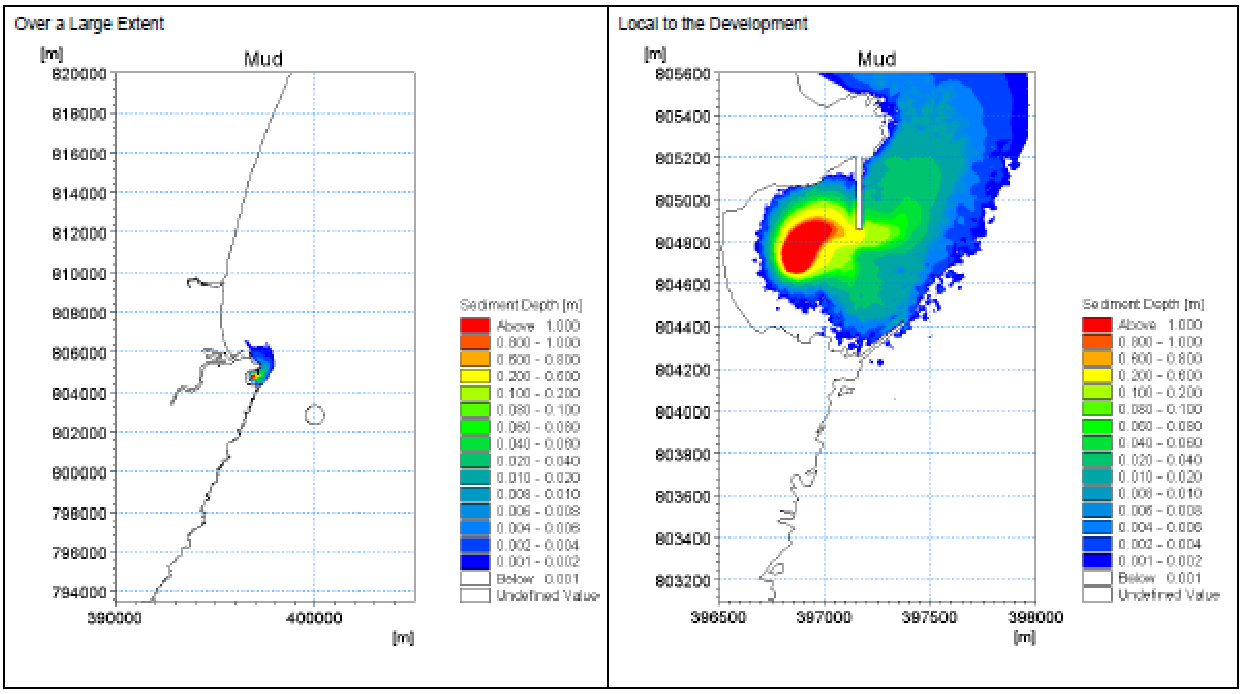


Figure 6.19: Mud extent and deposition associated with TSHD overspill from regional perspective (left) and local to the development (right)

6.7 Assessment of Effects

6.7.1 General Assessment Methodology

As this chapter is focussed on changes to physical processes, the only receptor of concern considered for assessment in this chapter is the Nigg Bay SSSI. The assessment of significance of effects in this chapter follows the methodology detailed in Chapter 5: Environmental Impact Assessment Process. The significance of potential effects considers the value of the receptor and the magnitude of effects upon the receptor. A key component of the predicted magnitude is the sensitivity of the Nigg Bay SSSI. A baseline description and management objectives for the SSSI are presented in Section 6.5.3.5.

The magnitude of an effect is typically assessed using its duration, extent and frequency. Table 6.8 presents the classification criteria for the magnitude of effects. Receptor sensitivity is used to define the susceptibility to the effect in question. Table 6.9 presents the classification criteria for the sensitivity of the receptor, which combines the capacity of the receptor to accommodate change, and its intrinsic value.

Table 6.8: Magnitude of effect

Category	Definition
Negligible	No detectable change, or change is within the natural variation
Minor	Small temporary or tolerable change from the baseline
Moderate	Partial loss or change to one or more key components of the baseline condition which may be temporary or permanent
Major	Near complete loss or major change to one or more key components of the baseline condition which is permanent.
Severe	Permanent loss of one or more components of the baseline condition

Table 6.9: Sensitivity of the receptor

Receptor Category	Definition
Very high	Receptors or features of the receptor which are international designations for nature and geological heritage. The receptor has no capacity accommodate the change due to impact.
High	Receptors or features of the receptor which are national designations for nature and geological heritage. The receptor has no capacity accommodate the change due to impact.
Moderate	Receptors or features of the receptor which are regional heritage designations for nature and geological heritage. The receptor has very low or partial capacity to accommodate the change due to impact.
Low	Receptors or features of the receptor which are of local value for nature and geological heritage. The receptor has partial capacity to accommodate the change due to impact.
Negligible	Non designated receptors or full capacity to accommodate change

The significance of predicted effects prior to the application of any mitigation is defined by combining the effect magnitude and receptor value criteria and is derived from the effect significance matrix presented in Table 6.10.

Table 6.10: Significance of effect

Magnitude of Effect	Nature Conservation Value, Socio-economic Value or Heritage and Cultural Value				
	Negligible	**Low**	**Medium**	**High**	**Very High**
Negligible	Negligible	Negligible	Negligible	Negligible	Minor
Minor	Negligible	Minor	Minor	Minor	Moderate
Moderate	Minor	Minor	Moderate	Moderate	Major
Major	Minor	Moderate	Moderate	Major	Major
Severe	Moderate	Major	Major	Major	Major

Any potential uncertainty in the effect significance is also included in the assessment, which can be either low, medium or high uncertainty.

A residual effect assessment is also included to address any proposed monitoring or mitigation measures to reduce the effect. A cumulative assessment will be undertaken in accordance with the approach set out in Chapter 5: EIA Process, Section 5.12.

6.7.2 Sources of Impacts and Effects

A source-receptor-pathway summary is presented in Table 6.11.

Table 6.11: Impacts and associated pathways for potential effects

Activity	Impact and Transmission Pathway	Receptor	Description of Potential Effects
Construction			
Breakwater and harbour construction	Direct impacts due to construction activities	Nigg Bay SSSI	Construction activities potentially affecting the physical integrity of the SSSI
Operation			
Physical presence of development	Changes to coastal processes	Nigg Bay SSSI	Changes to coastal processes potentially affecting the physical integrity of the SSSI

6.7.3 Sources of Impacts During Construction Phase

No effects on the Nigg Bay SSSI geological outcrops are anticipated to occur as a result of construction works. As can be seen in Chapter 3: Description of the Development, the only construction works that will take place within the SSSI area are coastal re-profiling works along the southern coast of Nigg Bay, in order to reduce internal waves. Any construction works at the foot of the cliffs (i.e. along the shore) will be designed to stabilise the cliffs and, coupled with the reduced energy reaching the shoreline due to the breakwaters, any potential erosion will be reduced significantly reduced. It is also important to note that the majority of construction activities will be confined to areas below MHWS, which means the spatial extent of the works will not overlap the geological features of Nigg Bay SSSI, which are located well above MHWS. For further details on construction activities and the SSSI, refer to Chapter 9: Ground Conditions and Contamination.

6.7.4 Sources of Impacts During Operational Phase

The dominant changes to the marine physical environment attributed to the operational phase of the development include baseline changes to waves, tidal currents, and sediment transport as described in Section 6.6.3. The main impacts arising from the presence of the breakwaters will be to significantly decrease wave heights and tidal currents within the harbour boundaries. These changes to hydrodynamics and coastal processes may have potential effects on the integrity of the Nigg Bay SSSI. The permanent presence of proposed sheet piling at the southern end of West Quay, along the northern end of the SSSI, may also have localised effects. However, the geological SSSI features of interest are located on the cliffs well above MHWS and will not be affected by coastal works confined to MHWS and below. For further details on construction activities and the SSSI, refer to Chapter 9: Ground Conditions and Contamination.

The magnitude of change to baseline hydrodynamic processes is assessed as major, given the large magnitude and permanent character of the changes introduced. The Nigg Bay SSSI is located on cliffs which are beyond the reach of coastal hydrodynamic processes under the majority of conditions, but may be affected by extreme storm events. Both the value and the sensitivity of the SSSI are considered to be **high**.

The new harbour will provide protection to the area immediately in front of the SSSI, which under current conditions is at substantial risk of erosion that would, over time, be likely to destabilise the cliff, resulting in adverse effects on the SSSI. As a result, the magnitude of effects upon the SSSI of these changes in hydrodynamics are assessed as **negligible**. While the value of the SSSI is **high**, the significance of the effect (derived from Table 6.10) of the development on the integrity of the SSSI is assessed as **negligible**, which is not significant in EIA terms.

There is a moderate level of uncertainty attached to this assessment, since the direct effects of a reduction in coastal processes on cliff erosion cannot be accurately predicted.

6.7.5 Mitigation and Monitoring Measures

No mitigation measures are proposed given the negligible significance of the assessed effects on the Nigg Bay SSSI. It is recommended, however, that ongoing monitoring of the site be undertaken, in collaboration with SNH. Visual monitoring of the SSSI and its key geological exposures will continue through the operational phase.

As per SNH management objectives of the Nigg Bay SSSI, exposure and visibility of the geological units should be made possible through periodic removal of any vegetation obscuring important parts of the site and access to the SSSI for scientific and academic purposes should also be made a priority. AHB will engage with SNH to devise a management programme for the SSSI, to include regular visual inspections, clearing of sections of vegetation, and access to the site. See Chapter 9: Ground Conditions and Contamination for further details of the monitoring and management measures that are proposed.

6.8 Cumulative Effects

The greatest change to hydrodynamics (including wave heights, tidal levels, tidal currents and sedimentation) will take place within the Aberdeen Harbour Expansion Project area i.e. within the breakwaters. Since these effects will be highly localised, and any other potential hydrodynamic impacts will not reach within the proposed harbour boundaries, no cumulative effects from other projects are predicted.

6.9 References

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