9 PHYSICAL ENVIRONMENT AND SEDIMENT DYNAMICS

9.1 The table below provides a list of all the supporting studies which relate to the physical environment and sediment dynamics assessment. All supporting studies are provided on the accompanying CD.

Details of study	Location on supporting studies CD
Benthic survey for Phase 1 of the MeyGen tidal stream energy project, Inner Sound, Pentland Firth (ASML, 2011)	OFFSHORE\Seabed interactions
MeyGen EIA Coastal Processes Modelling – Modelling setup, calibration and results (DHI, 2012)	OFFSHORE\Seabed interactions
Report of Survey for Atlantis Resources Corporation for Site Survey Stroma. JN3475 (IXSurvey, 2009)	OFFSHORE\Seabed interactions

9.1 Introduction

9.2 This section assesses the effects of the Project on the physical environment and sediment dynamics. The specialists that have contributed to this assessment include:

- Danish Hydrological Institute (DHI) – sediment morphology modelling; and
- Xodus – baseline description, general impact assessment and the Environmental Statement (ES) section write up.

9.3 During the array construction there will be a physical disturbance of the seabed associated with turbine installation, including effects from drilling activities. During the operation and maintenance phase, it is likely that the presence of the turbines will cause local changes to the tidal stream speed and wave regime, which in turn could modify the sediment dynamics of the area.

9.4 Effects on the physical environment and coastal processes may result in indirect effects on benthic ecology, marine cultural heritage, navigation and shipping. Any such effects have not been discussed here, but are addressed in Section 10, Section 16 and Section 15 respectively.

9.2 Assessment Parameters

9.2.1 Rochdale Envelope

9.5 In line with the Rochdale Envelope approach, this assessment considers the maximum ('worst case') project parameters. Identification of the worst case scenario for each receptor (i.e. Environmental Impact Assessment (EIA) topic) ensures that impacts of greater adverse significance would not arise should any other development scenario be taken forward in the final scheme design. Table 9.1 describes the detail of the project parameters that have been used in this assessment and explains why these are considered to be worst case. The potential impact from alternative Project parameters has been considered in Section 9.10.

Project parameter relevant to the assessment		'Maximum' Project parameter for impact assessment	Explanation of maximum Project parameter
Turbines	Number	86 turbines	The physical processes model simulates energy extraction from an 86MW array based on 86, 1MW turbines (with 20m rotor diameter). The physical processes model uses a drag coefficient to simulate energy extraction by the turbine. The drag coefficient is based on the rotor diameter and rated capacity of the turbine. Due to the resolution of the model, using a small number of larger, higher rated capacity turbines to simulate an 86MW array would not influence the results.
	Layout	86 turbines; an indicative turbine layout has been used to inform the modelling (see Figure 5.6)	An indicative layout for 86 turbines has been used to inform the modelling. The indicative layout is based on 45m cross-flow spacing and 160m down-flow spacing.
	Rotor diameter	20m	The physical processes model simulates energy extraction from an 86MW array based on 86, 1MW turbines (with 20m rotor diameter). The physical processes model uses a drag coefficient to simulate energy extraction by the turbine. The drag coefficient is based on the rotor diameter and rated capacity of the turbine. Due to the resolution of the model, using a small number of larger, higher rated capacity and diameter turbines to simulate an 86MW array would not influence the results.
	Rated power of turbines	1MW	The physical processes model simulates energy extraction from an 86MW array based on 86, 1MW turbines (with 20m rotor diameter). The physical processes model uses a drag coefficient to simulate energy extraction by the turbine. The drag coefficient is based on the rotor diameter and rated capacity of the turbine. Due to the resolution of the model, using a small number of larger, higher rated capacity and diameter turbines to simulate an 86MW array would not influence the results.
	Number of blades per rotor	N/A	Number of rotor blades does not influence the physical environment and sediment dynamics impact assessment.
	Minimum clearance between sea surface and turbine blade tip	N/A	Sea surface clearance does not influence the physical environment and sediment dynamics impact assessment. As the physical processes model is depth averaged this parameter will not influence the modelling undertaken.
	Clearance of turbine blade tip to seabed	N/A	Seabed clearance does not influence the physical environment and sediment dynamics impact assessment. As the physical processes model is depth averaged this parameter will not influence the modelling undertaken.
	Decommissioning	All turbines removed at decommissioning	All turbines will be removed at decommissioning.
Turbine support structure	Maximum amount of drill cuttings released into the marine environment	86 monopile Turbine Support Structures (TSSs)	The drilled monopile TSS will result in the maximum release of drill cuttings to the marine environment. Assuming the maximum number of 86 TSSs, the maximum amount of drill cuttings that can be generated from turbine support installations is 17,200m^3 (total for 86 TSSs).
	Maximum seabed	86 Gravity Base	The GBS TSS will result in the largest seabed footprint.

Project parameter relevant to the assessment		'Maximum' Project parameter for impact assessment	Explanation of maximum Project parameter
	footprint	Structure (GBS) TSS	Each GBS TSS has a maximum footprint of 40m x 30m. The total footprint for 86 turbines is 0.103km^2.
	Operations and Maintenance	No removal of TSSs required for routine operations and maintenance	It is assumed that no replacement or major TSS overhaul involving removal is required during the operational life of the Project.
	Decommissioning	86 Monopile	86 Monopile TSSs will be cut at the seabed. The bottom of the piles below the seabed will remain in-situ.
Cable connection to shore	Maximum cable footprint on seabed	86, 120mm unbundled cables each 1,300m in length with split pipe armouring	The maximum physical area of the seabed occupied by the cables is 0.027km^2. Based on a maximum 1.3km of cable from Horizontal Directional Drill (HDD) bore exit to turbine, and a cable diameter of 120mm (x2 to account for split pipe armouring) for 86 turbines.
	Decommissioning	86, 120mm unbundled cables, each 1,300m in length	All cables laid on the seabed will be fully removed at decommissioning.
Cable landfall	Maximum amount of drill cuttings released into marine environment	29, 0.6m HDD bores, drilled from either Ness of Quoys or Ness of Huna	The majority of drill cuttings generated from the drilling of the HDD bores will be returned to shore and not discharged to sea; however it is estimated that the contents of the last 10m of each bore could be discharged to sea at seabed breakthrough. Of the two potential HDD scenarios, the greatest potential volume of cuttings discharged to sea at breakthrough will result from last 10m of 29 boreholes of 0.6m diameter (82m^3).
Onshore Project components	-	N/A	As there are no proposed works in the intertidal area along the coast the onshore aspects of the Project do not influence the physical environment and sediment dynamics impact assessment.

Table 9.1: Rochdale Envelope parameters for physical environment and sediment dynamics assessment

9.2.2 Area of assessment

9.6 It is also important to define the geographical extent of the area of assessment. The focus of the physical environment and sediment dynamics assessment is potential impacts in the Project area and adjacent waters, the surrounding coastline and seabed.

9.2.3 Modelling assessment

9.7 In order to undertake the assessment, a modelling study was undertaken. For full details of the modelling approach, see Section 9.4.4.

9.3 Legislative Framework and Regulatory Context

9.8 In addition to EIA guidance published by Marine Scotland and SNH there are no specific EIA guidelines yet developed for the assessment of physical environmental impacts from tidal stream projects. However, the physical environment and coastal processes EIA guidelines developed by the Centre for Environment, Fisheries and Aquaculture Science (CEFAS) for offshore wind farms (CEFAS, 2004) are largely applicable, as are those developed by COWRIE, also for offshore wind farms (COWRIE, 2009). Additional consideration should be given to potential turbulence and wake effects for tidal turbines. The CEFAS guidelines highlight that direct impacts on hydrodynamics and sediment dynamics should be considered, along with secondary effects including water quality and benthic ecology (Section 10).

9.4 Assessment Methodology

9.4.1 Scoping and consultation

9.9 Since the commencement of the Project, consultation on physical environment and sediment dynamics issues has been ongoing. Table 9.2 summarises all consultation relevant to the physical environment and sediment dynamics. In addition, relevant comments from the EIA Scoping Opinion are summarised in Table 9.3, together with responses to the comments and reference to the ES sections relevant to the specific comment.

Date	Stakeholder	Consultation	Topic / specific issue
7th April 2011	Marine Scotland and SNH	Pre-Scoping meeting	EIA surveys and studies required and the data needs for each EIA study.
26th May 2011	Marine Scotland and SNH	Submission of document for comment	Submission of proposed modelling scope of work for review and comment by Marine Scotland and SNH.
27th May 2011	Marine Scotland, statutory consultees and non statutory consultees	Submission of EIA Scoping Report	Request for an EIA Scoping Opinion from Marine Scotland and statutory consultees and request for comment from non statutory consultees.
30th June – 2nd July 2011	Local stakeholders	Public Event - EIA Scoping	Public event to collate information/opinions on proposed EIA scope.
6th July 2011	Marine Scotland	Teleconference	Scope of the coastal processes modelling. Discussion regarding the data inputs, proposed scenarios and expected outputs.
31st September 2011	Marine Scotland, The Highland Council, statutory consultees and non statutory consultees	Receipt of EIA Scoping Opinion	Receipt of response to EIA Scoping Report and other comments from non statutory consultees.
3rd October 2011	Marine Scotland	Project update meeting	Report on EIA progress including presentation of modelling results.
6th – 7th December 2011	Local stakeholders	Public Event – pre application consultation	Public event to communicate the findings of the EIA to local stakeholders.

Table 9.2: Consultation undertaken in relation to physical environment and sediment dynamics

Name of organisation	Key concerns	Response	ES section within which the specific issue is addressed
Marine Scotland	General comments relating to clarification of modelling approach and expected scenarios.	Modelling approach was approved by Marine Scotland prior to receiving EIA Scoping Opinion and commencement of modelling.	See Section 9.4.4 Modelling study.
Scottish Environmental Protection Agency (SEPA)	The ES should include information on the possible impacts of construction activities on water quality, as well as coastal processes in the longer term. Any potential impacts from suspended sediment should be compared to natural background levels and water quality standards (e.g. Shellfish Waters Directive).	There are not expected to be any impacts to water quality or coastal processes in the long term, because the scale of the development is not expected to alter the baseline hydrodynamic or wave regime significantly enough to cause any changes.	See Section 9.6 Impacts during Construction and Installation.
SEPA	If dredging is required, details should be provided in the ES.	Not proposed.	NA
SEPA	If coastal defences are required, details should be provided in the ES.	Not proposed.	NA
SEPA	There may be a need to address the	Cumulative impacts are	See Section 9.11

Name of organisation	Key concerns	Response	ES section within which the specific issue is addressed
	cumulative effects of devices/arrays on coastal processes depending upon array density and location with respect to existing renewable and coastal developments.	considered, but due to the level of detail available from other projects, it is only possible to assess the potential impacts qualitatively. Changes to the hydrodynamics and waves outside of the Project area are negligible and as a result it is extremely unlikely that significant cumulative impacts will occur.	Cumulative Impacts.
SEPA	If the Project includes impoundments or tidal barrage, detailed modelled must be undertaken.	Not proposed.	NA
SEPA	Coastal processes should be assessed as part of the ES, which should include a baseline assessment of coastal and sedimentary processes operating in the area, including sediments, hydrodynamics, sedimentary environment, sedimentary structures and typical suspended sediment concentrations.	A baseline assessment of coastal and sediment processes was compiled from a variety of sources, including a geophysical and bathymetric survey, current meter deployments, sediment sampling and other historical documents.	See Section 9.5 Baseline Description.
Royal Yachting Association (RYA)	In the EIA Scoping Document the maximum current speeds in the Inner Sound were much higher than expected (3.4-4.0ms^{-1}).	Current meters deployed in 2011 have confirmed that current flows in the Inner Sound regularly exceed 4.5ms^{-1}.	See Section 9.5.4 Currents.
Scottish Natural Heritage (SNH)	The ES should include an initial Environmental Mitigation and Monitoring Plan (EMMP).	The outline EMMP has been developed as part of the EIA and is presented in the ES.	See Section 25 EMMP.
SNH	The ES should include potential impacts from the operational and maintenance phase.	No significant impacts on the physical environment and coastal processes are identified from the operational and maintenance phase.	See Section 9.7 Impacts during Operations and Maintenance.
SNH	The ES should include potential impacts from the decommissioning phase.	No significant impacts on the physical environment and coastal processes are identified from the decommissioning phase.	See Section 9.8 Impacts during Decommissioning.
SNH	There is a recommendation that expert advice should be sought from an experienced coastal geomorphologist.	The modelling undertaken to support the EIA has been conducted by DHI whose staff includes a geomorphologist.	N/A

Table 9.3: Scoping comments relevant to physical environment and sediment dynamics

9.4.2 Desk based study

9.10 The study has been undertaken by researching and reviewing any documents and datasets relevant to the Inner Sound of the Pentland Firth. Data were collated from the following sources:

- Numerous oceanographic surveys within the Project area;
- Geophysical survey report of the Inner Sound, iXSurvey (2009);
- Admiralty Tide Tables, Admiralty Tidal Stream Atlases, UKHO (1986a, 1986b, 2005);
- UK Digital Marine Atlas Project (Version 3.00), BODC (1998);
- Atlas of UK Marine Renewable Energy Resources, BERR (2008);
- Wave and tidal modelling studies, DHI (2009a, 2009b, 2012);
- MeyGen Tidal Energy Project EIA Scoping Document, Xodus (2011); and
- Pentland Firth and Orkney Waters MSP RLG for Marine Renewable Energy, Marine Scotland (2009).

9.4.3 Field survey

9.11 A number of field surveys have been undertaken over the last few years which have enabled the Inner Sound to be characterised to a high degree. These have included surveys of water depth, geophysics, current regime, water levels, turbulence, benthic communities and sediment sampling. Further details are provided in Table 9.4.

Type of survey	Time period	Instrument used	Variables measured	Data collected by
Current	April 2009	300 kHZ Acoustic Doppler Current Profiler (ADCP) and moving vessel current transects	Current speed and direction at 1m bins throughout the water column.	Atlantis
Benthic	October 2009	TV tow and camera	Visual record of seabed.	Marine Scotland
Bathymetry, Geophysical	September 2009	Multi-beam echo sounder, side scan sonar, pinger sub-bottom profiler, magnetometer	Water depths, seabed composition, bedform profiles, depth of seabed sediment, and presence of anomalies.	Atlantis
Coastal geology field study	November 2009	Visual survey	Coastal geology field survey.	Atlantis
Benthic	May 2010	TV tow and camera	Visual record of seabed.	Marine Scotland
Current	October 2010 to July 2011	Vessel mounted 300 kHz RDI ADCP	Current speed and direction along transects.	ERI
Seabed structure	November 2010 and July 2011	Vessel mounted starfish 450F sidescan sonar	Image of the seabed.	ERI
Currents, waves and turbulence	July 2011	Bottom mounted RDI 1200 kHz ADCP Bottom mounted Acoustic Wave and Current (AWAC) 600 kHz ADCP	Current speed and direction throughout water column. Some quantification of turbulence. Wave heights.	MeyGen
Benthic	July 2011	Helley-Smith bedload sampler Petersen grab sampler Niskin bottle Video and still photography	Sediment bedload. Sediment particle size distribution. Suspended sediment.	MeyGen

Table 9.4 : Summary of oceanographic data collected in the Inner Sound to date

9.4.4 Modelling study

9.12 A sediment transport modelling study was adopted for this EIA because of the proximity of large-scale sediment features alongside the turbine deployment area, including mega-rippled sand banks, gravel waves and areas of accumulated sediment. These regions of sediment have the potential to impact other receptors indirectly if the installation of the array were to fundamentally change the flow patterns in the Inner Sound.

9.13 The mobility of the seabed is dependant on the local current and wave conditions, and the local sediment characteristics. The strong tidal currents are thought to be the main cause for the persistent sedimentary features in the Inner Sound, scouring any mobile sediment from the central channel, and tending to deposit it where the current speeds naturally decrease or where large eddies are formed, such as in the lee of Mell Head on Stroma. Large-scale sediment transport is likely to occur under storm conditions, when wave action increases turbulence near the bed, influencing sediment suspension.

9.14 The object of the modelling study was therefore to establish a calibrated baseline model capable of matching the existing current speed, direction and bedload sediment concentrations measured in the Inner Sound, which could then be used to quantify the effects on the physical processes brought about by the tidal array, under calm and storm conditions. Full details of the modelling study are provided on the supporting studies CD (DHI, 2011). The method can be broken down as follows:

- Build a calibrated hydrodynamic and morphological model, which is capable of accurately representing current speed and direction, and bedload samples within the Project domain (against surveyed currents);
- Build a wave model capable of running waves across the Project domain;
- Run the tide, wave and morphology models with no turbines, under both calm and storm scenarios, to establish a number of baseline cases which other model output can be compared to; and
- Run the tide, wave and morphology models having added a representation of the maximum 86 turbine array into the model, to see how flow patterns, wave heights and bedform features are influenced by the array, under calm and storm conditions.

9.15 The model scenarios shown in Table 9.5 were chosen following consultation with Marine Scotland, and represent the full suite of modelling carried out. An easterly, westerly and north-westerly storm event were chosen because these directions allow maximum wave propagation to the site. A calm scenario was not run for the wave model, because by definition, the calm scenario requires there to be no wind forcing, which is a fundamental component of the wave model.

Model	Existing baseline	86 turbines
Tidal	1 x calm 1 x easterly storm event 1 x westerly storm event 1 x north-westerly storm event	1 x calm 1 x easterly storm event 1 x westerly storm event 1 x north-westerly storm event
Wave	1 x easterly storm event 1 x westerly storm event 1 x north-westerly storm event	1 x easterly storm event 1 x westerly storm event 1 x north-westerly storm event
Sediment Transport	1 x calm (tide only) 1 x easterly storm event 1 x westerly storm event 1 x north-westerly storm event	1 x calm (tide only) 1 x easterly storm event 1 x westerly storm event 1 x north-westerly storm event

Table 9.5: Summary of coastal process modelling scenarios

9.16 It should be noted, the modelling carried out here is far-field modelling, so it will not capture small-scale processes including micro-eddies, turbulence, wake effects and other near-field effects associated with near-turbine processes. However, the purpose of the modelling study is not to investigate those small-scale processes; it is to investigate bulk sediment transport over the Project area, so the level of detail has been chosen accordingly. The model was calibrated against a selection of the surveyed currents and bedload samples described in Table 9.4, as recommended by the relevant guidelines (CEFAS, 2004; COWRIE, 2009).

9.17 It should also be noted that the model is depth-averaged, so the effective drag formulation used to represent the turbines in the tidal model will reduce the current speeds throughout the entire water column, not just to the depth of the turbine. In reality there is more than 8m of clear water above the turbines, so while it is likely that flow will be reduced in the lower two-thirds of the water column where the turbines sit, flow above the turbines may not be so impeded. This means that when compared to real surface currents, the predicted current increases and decreases may be a conservative overestimate.

9.4.5 Significance criteria

9.18 The EIA process and methodology are described in detail in Section 8. Each assessment section is, however, required to develop its own criteria for the sensitivity of receptor and magnitude of impact aspects since the definition of these will vary between different topics. For physical environment and sediment dynamics, the significance criteria used in this section is based on the methodology described in Section 8 but the sensitivity of the receptor and magnitude of impact are defined in Table 9.6 and Table 9.7 respectively.

9.19 The consequences of impacts are then considered by reference to the relevant criteria in the EIA Regulations. The significance of impacts in relation to the EIA Regulations is defined in Section 8, Table 8.2.

Sensitivity of receptor	Definition
Very High	▪ The physical environment has very little ability to absorb change without fundamentally altering its present character. ▪ Is of very high environmental value or of international importance (e.g. United Nations Educational, Scientific and Cultural Organisation (UNESCO) World Heritage Site (WHS)).
High	▪ The physical environment has little ability to absorb change without significantly altering its present character. ▪ Is of high environmental value or of national importance (e.g. Site of Special Scientific Interest (SSSI), Geological Conservation Review (GCR) site).
Medium	▪ The physical environment has moderate capacity to absorb change without significantly altering its present character. ▪ Is of moderate environmental value or of regional importance.
Low	▪ The physical environment is tolerant of change with only minor detriment to its present character. ▪ Is of low environmental value or of local importance.
Negligible	▪ The physical environment is tolerant of change without perceptible detriment to its present character or is of negligible environmental value.

[1] *GCR: Geological Conservation Review site, a non-statutory designation for geological and geomorphological sites of national or international importance for earth science conservation (JNCC, 2011).*

Table 9.6: Definitions for sensitivity of receptor

Magnitude of impact	Definition
Severe	▪ There would be fundamental changes to the baseline condition of the receptor. ▪ Little or no recovery anticipated. ▪ Impact highly likely to occur.
Major	▪ There would be a substantial but non-fundamental change to the baseline condition of the receptor.

	▪ Recovery anticipated after several years following decommissioning. ▪ Impact likely to occur.
Moderate	▪ There would be material but non-substantial changes to the temporary or permanent baseline condition of the receptor. ▪ Good recovery potential following decommissioning (approximately 2 years). ▪ Impact will possibly occur.
Minor	▪ There would be detectable but non-material changes to the baseline condition of the receptor (or a change that is temporary in nature). ▪ Temporary alteration or effects confined to a small percentage of receptor, with rapid recovery. ▪ Impact unlikely to occur.
Negligible	▪ An imperceptible and/or no change to the baseline condition of the receptor. ▪ Impact extremely unlikely to occur.
Positive	▪ An enhancement to the baseline condition of the receptor.

Table 9.7: Definitions for magnitude of impact

9.20 The receptors assessed in this topic are unconventional when compared against receptors in other topics, because they don't have any intrinsic sensitivity associated with them. They are most important for the secondary effects and significance they have to other receptors.

9.4.6 Data gaps and uncertainties

9.21 The geophysical survey which produced the seabed sediment maps covered the region local to the Project site. However, some sedimentary bedforms extended beyond the surveyed area, so their full extent is unknown.

9.22 The wave characteristics presented in this section have been derived from the best available data at the time, but better data will be available after the completion of a detailed wave modelling study of the Inner Sound which is ongoing at the time of writing. When available, this data will help inform extreme and average wave heights in the Inner Sound, which in turn will have an effect on sediment transport in storm conditions.

9.23 There is not yet a standard technique for representing turbine structures in current and wave models, so the best available method has been used here. Work is currently ongoing to develop a standard approach, but this was not available at the time of writing.

9.5 Baseline Description

9.5.1 Designations

9.24 Two statutory and two non-statutory designated sites relevant to this section lie within 5km of the study area, as detailed in Table 9.8 and shown in Figure 9.1.

Site name	Designation	Category	Distance & direction
John o' Groats	SSSI, GCR[i]	Palaeontology	2.5km, east
Duncansby to Skirza Head	GCR	Coastal geomorphology	4.5km, east
Duncansby Head	SSSI	Aggregations of breeding birds, coastal geomorphology, maritime cliff	4.5km, east

Table 9.8: Summary of designated sites within 5km of the Project area

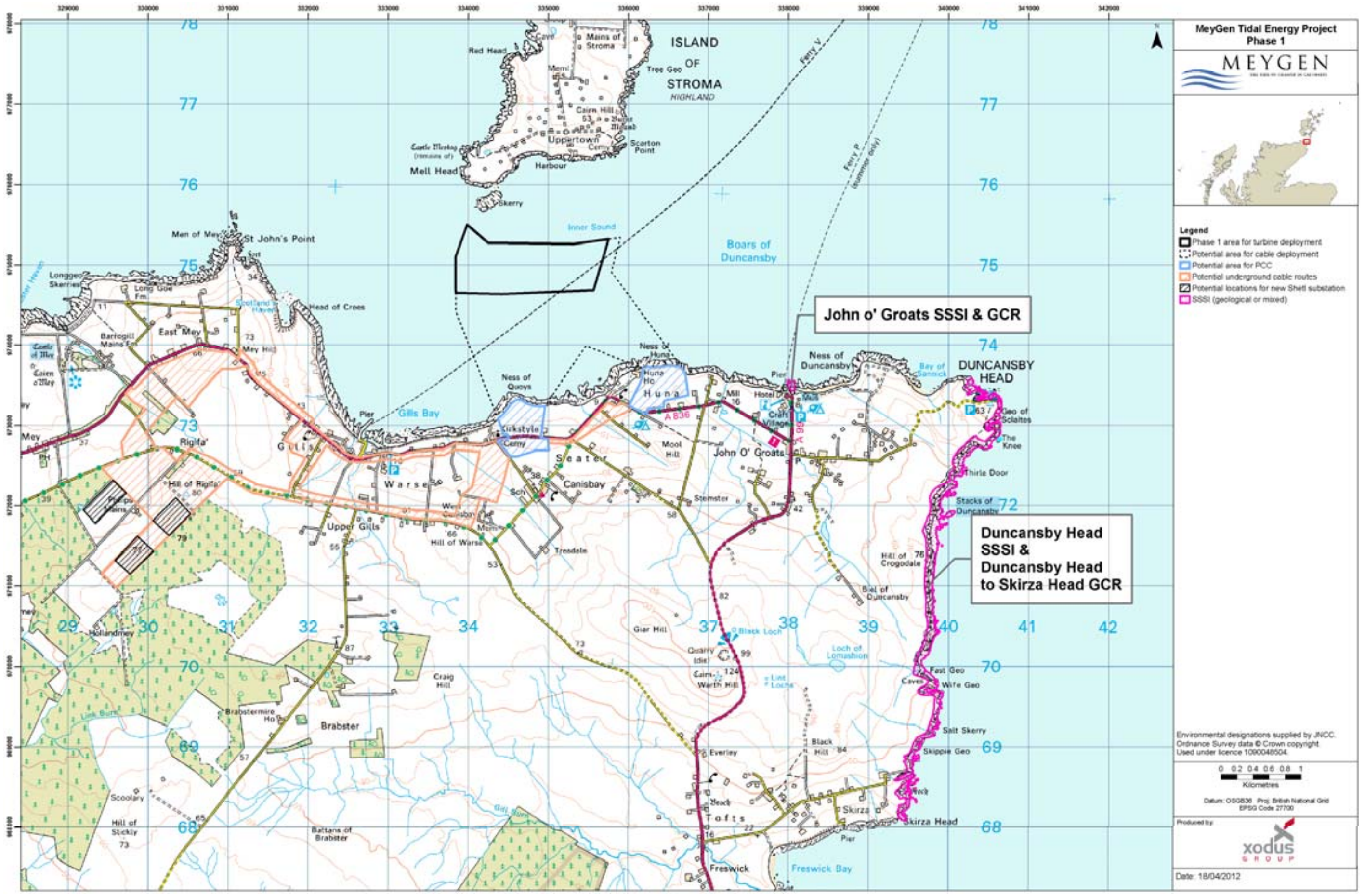


Figure 9.1: Geologically important designated sites within 5km of the study area

9.5.2 Bathymetry

9.25 Water depths within the turbine deployment area vary between approximately 31m to 49m below LAT (Gills Bay), as shown in Figure 9.2 and Figure 9.3. The vertical scale in Figure 9.3 has been exaggerated by a factor of fifteen to allow the bathymetric features to be identified more easily. The majority of the area is relatively flat having a water depth between 31.5 and 38m, but fissures in the bedrock up to 10m deep occur in the site, particularly at the western end south of Mell Head. The Admiralty contours plotted on Figure 9.2 are derived from a single-beam dataset collected in 1984, and agree well with the more recent 2009 multi-beam bathymetry survey.

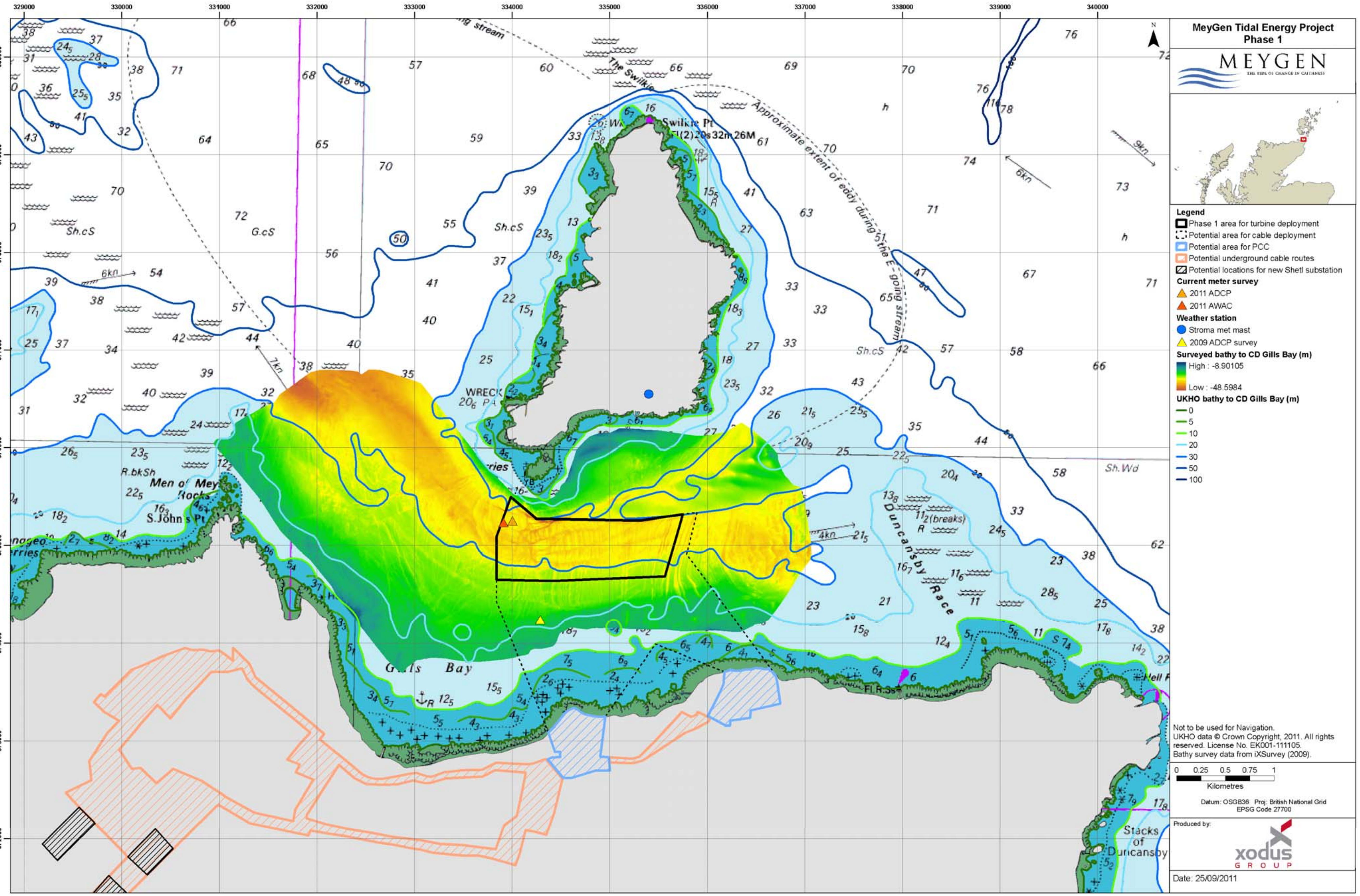


Figure 9.2: Bathymetry overview

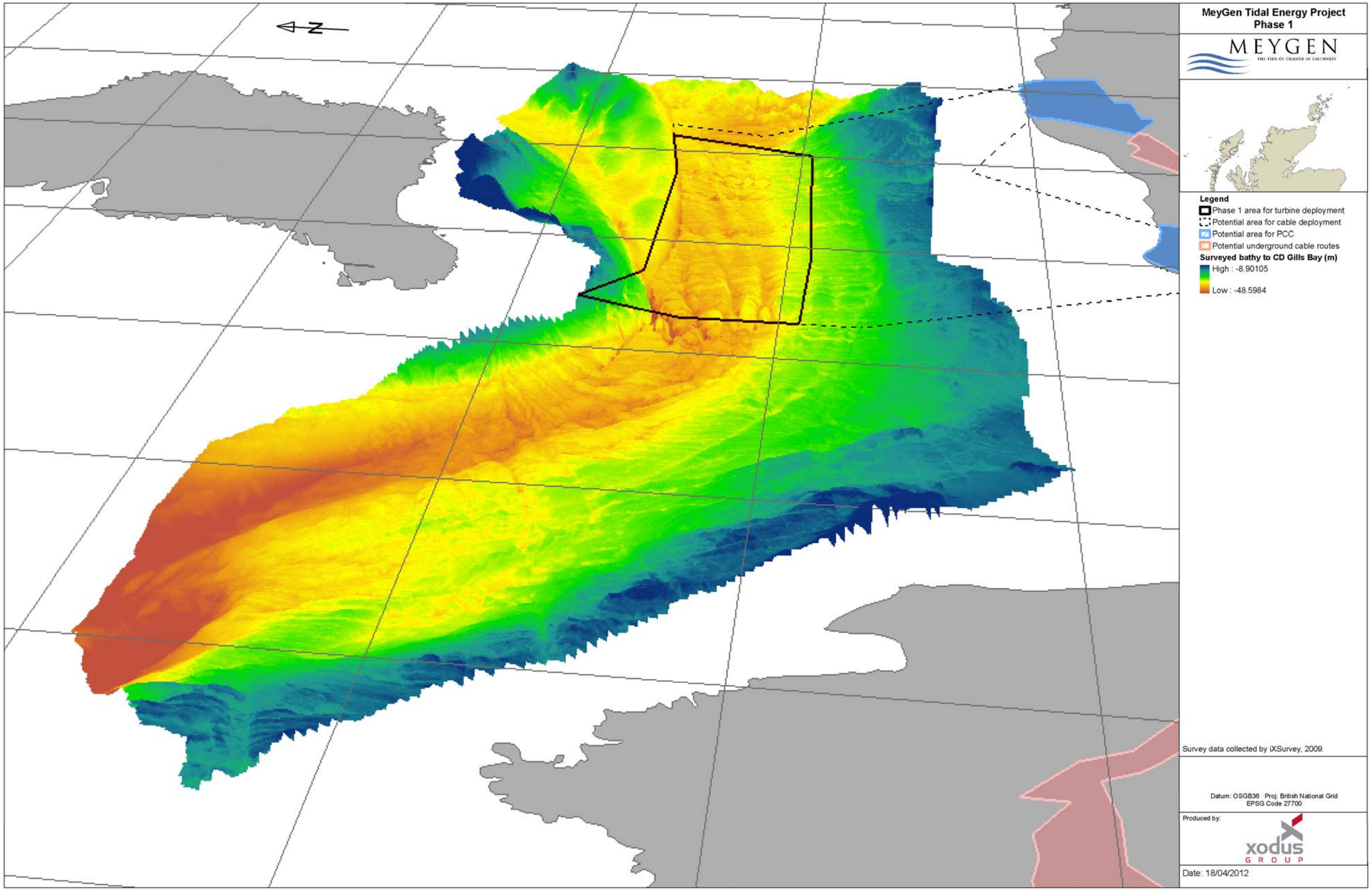


Figure 9.3: 3D bathymetry image

9.5.3 Water levels

Tidal

9.26 Water levels throughout the region are dominated by the semi-diurnal tide propagating from the North Atlantic. The mean spring tidal range within the Project area is approximately 3.0m, as summarised in Table 9.9, which combines data from Admiralty Tide Tables and the recent current meter survey carried out in 2011 (UKHO, 2005; EMU, 2011).

Tidal height (rel. to CD)	Wick (m)	Duncansby Head (m)	Stroma (m)	ADCP survey (m)	Gills Bay (m)	Scrabster (m)
Highest Astronomical Tide (HAT)	4	-	-	4.7	-	-
Mean High Water Spring (MHWS)	3.5	3.1	3.1	4.4	4.2	5
Mean High Water Neap (MWHN)	2.8	2.4	2.3	3.6	3.5	4
Mean Sea Level (MSL)	2	no data	1.9	2.9	2.7	3.1
Mean Low Water Neap (MLWN)	1.4	no data	1.3	2.2	2	2.2
Mean Low Water Spring (MLWS)	0.7	no data	0.9	1.4	1	1
Lowest Astronomical Tide (LAT)	0	-	-	0	-	-
Mean Spring Tidal Range (MSTR)	2.8	no data	2.2	3.0	3.2	4
Mean Neap Tidal Range (MNRT)	1.4	no data	1	1.3	1.5	1.8
CD to ODN	-1.71	no data	-	-	-2.19	-2.7

Table 9.9: Summary of water levels at nearby tidal ports (and from the 2009 ADCP survey)

9.27 The tidal wave floods from west to east through the Project site, before turning south and propagating down the North Sea coast of Scotland. The tidal wave slows down considerably as it passes through the Pentland Firth, such that despite the Agreement for Lease area only being 6km in length, High Water at the east end occurs approximately 20 minutes after High Water in the west (UKHO, 2005).

Storm surge

9.28 Storm surges occur at irregular intervals in response to meteorological forcing, particularly the passage of low pressure systems. A positive storm surge of about 1.5m (not taking into account tidal level) might be expected to occur in the area approximately once every 50 years (Marine Scotland, 2009).

9.29 It has not been possible to find any long-term storm surge data recorded within the Inner Sound, so tidal levels recorded at the nearby port of Wick are used to give an indication of the order of magnitude of storm surge heights. Long-term tide gauge data supplied by the British Oceanographic Data Centre (BODC) at Wick shows maximum surge heights of 1.11m over a 20-year period (the data were supplied by the BODC as part of the function of the National Tidal & Sea Level facility, hosted by the Proudman Oceanographic Laboratory and funded by the Environment Agency and the Natural Environment Research Council). The maximum values during this period have been summarised below in Table 9.10, which show that the maximum surge combined with the maximum tidal high water could produce a water level of 5.11m at Wick.

Variable	Tide (m)	Surge (m)	Surge + Tide (m)
Max	4.0	1.11	5.11
Min	0	-0.74	-0.74
All values recorded at Wick, and heights are relative to Chart Datum (CD)			

Table 9.10: Summary of extreme water levels at Wick

9.5.4 Currents

General description

9.30 The Pentland Firth lies close to the boundary between the North Atlantic and North Sea tidal systems. The incoming North Atlantic tidal wave reaches the Orkney Islands several hours before the North Sea tidal wave, causing a net flow of water from west to east on the flood tide. The interaction of the two tidal systems results in a dynamic and energetic tidal regime throughout the area of interest. However, this flow is strongly modified by local conditions of water depth and topography. This has the effect that the flood tide is not in the opposite direction to the ebb tide throughout the Project area (Dacre *et al*, 2001; Marine Scotland, 2009).

9.31 There are widespread and highly energetic tidal races, eddies and areas of general turbulence throughout the Firth. Just beyond the western end of the site off St John's Point on the Scottish mainland, the Merry Men of Mey is one of the most significant oceanographic features in the Firth. This is an area of tidal racing that occurs on the west-going ebb, particularly when opposed by westerly wind or waves. The feature can extend right across the width of the Firth, and is characterised by strong flows and significant standing waves which frequently break and have been reported to exceed 10m in height on occasion (UKHO, 1997; Marine Scotland, 2009). A similar race forms off Duncansby Head coincident with the beginning of the south-east-going current, known as the Duncansby Race.

9.32 Currents within the Inner Sound have a clear flood ebb pattern, while the Island of Stroma generates extensive eddies on its downstream side during both flood and ebb flows.

Surveyed currents

9.33 A number of sources of current meter data exist within the Inner Sound, as summarised in Table 9.11. These include three moored ADCPs and two sets of moving vessel ADCP transects.

Type	Data owner	Variable measured	Duration	Easting	Northing
Moored ADCP	Atlantis	Currents	01/04/2009 – 31/04/2009	334291	974238
ADCP transects	Atlantis	Currents	04/04/2009	Inner Sound	Inner Sound
ADCP transects	ERI	Currents	Various dates 2010 - 2011	Inner Sound	Inner Sound
Moored ADCP	MeyGen	Currents	21/06/2011-20/07/2011	334012	974919
Moored AWAC	MeyGen	Currents and waves	21/06/2011-20/07/2011	334307	974736

Table 9.11: Summary of current meter deployments

9.34 The current meters deployed by MeyGen in 2011 were placed at one of the highest flow regions within the Inner Sound, as shown in Figure 9.2 and Figure 9.4. This data has been harmonically analysed and re-predicted over a 20 year period, and can be used to obtain maximum current speeds at the site of the moored instruments. This data showed that the current flows in the Inner Sound regularly exceed 4.5ms^{-1} and may exceed 5ms^{-1} during an equinoxial tide (EMU, 2011).

9.35 The plot in Figure 9.5 shows current speeds recorded by the AWAC device during a neap tide, varying with depth and tidal state. The current speed profiles exhibit a fairly uniform pattern with depth, and show no evidence of stratification as would be expected in a region of such strong tidal flow. The speeds are greatest at the surface, and slowly decrease towards the bed, largely following the 1/7th power law (Soulsby, 1997).

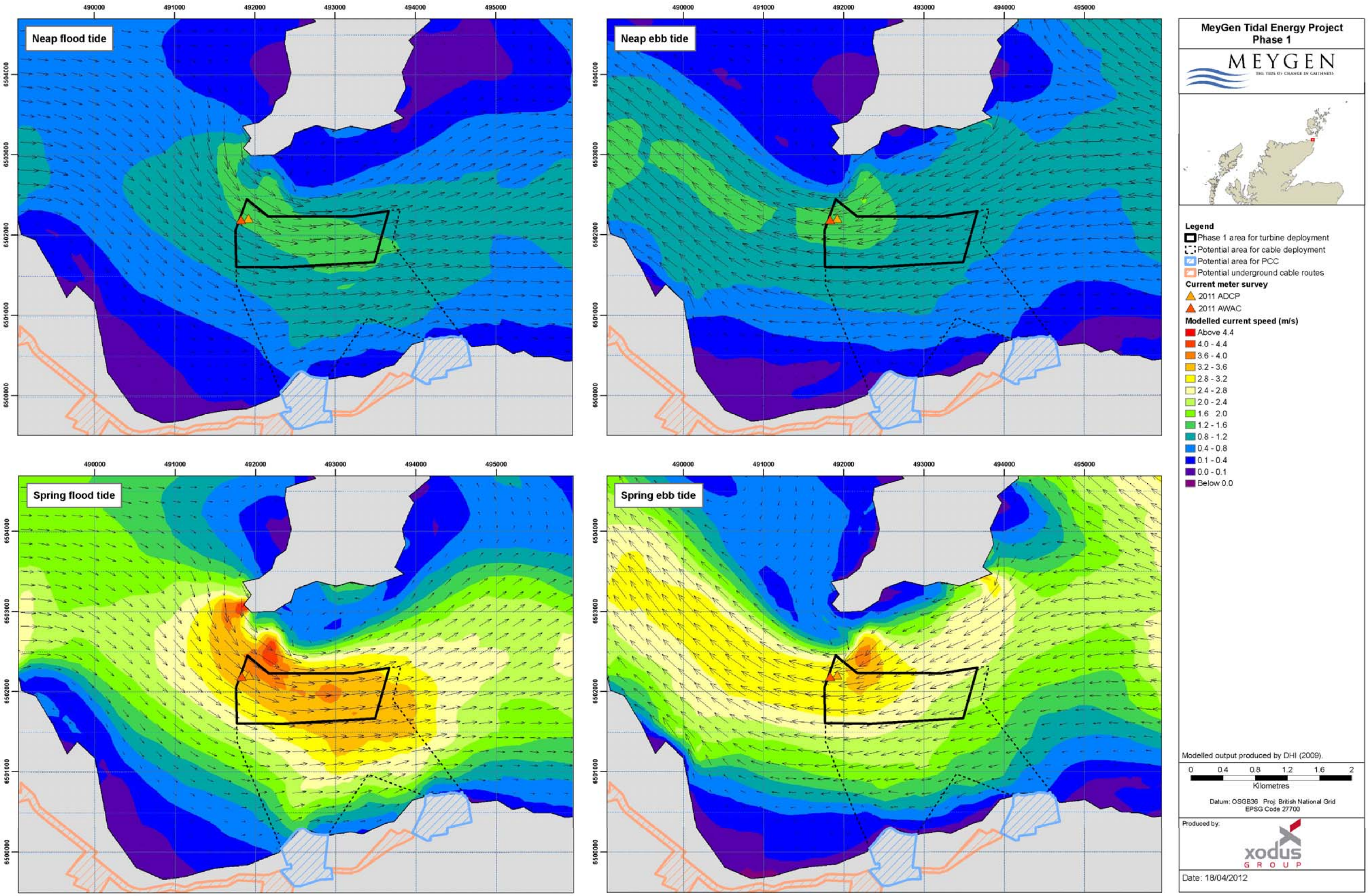


Figure 9.4: Hydrodynamic model of the Inner Sound – selected time steps

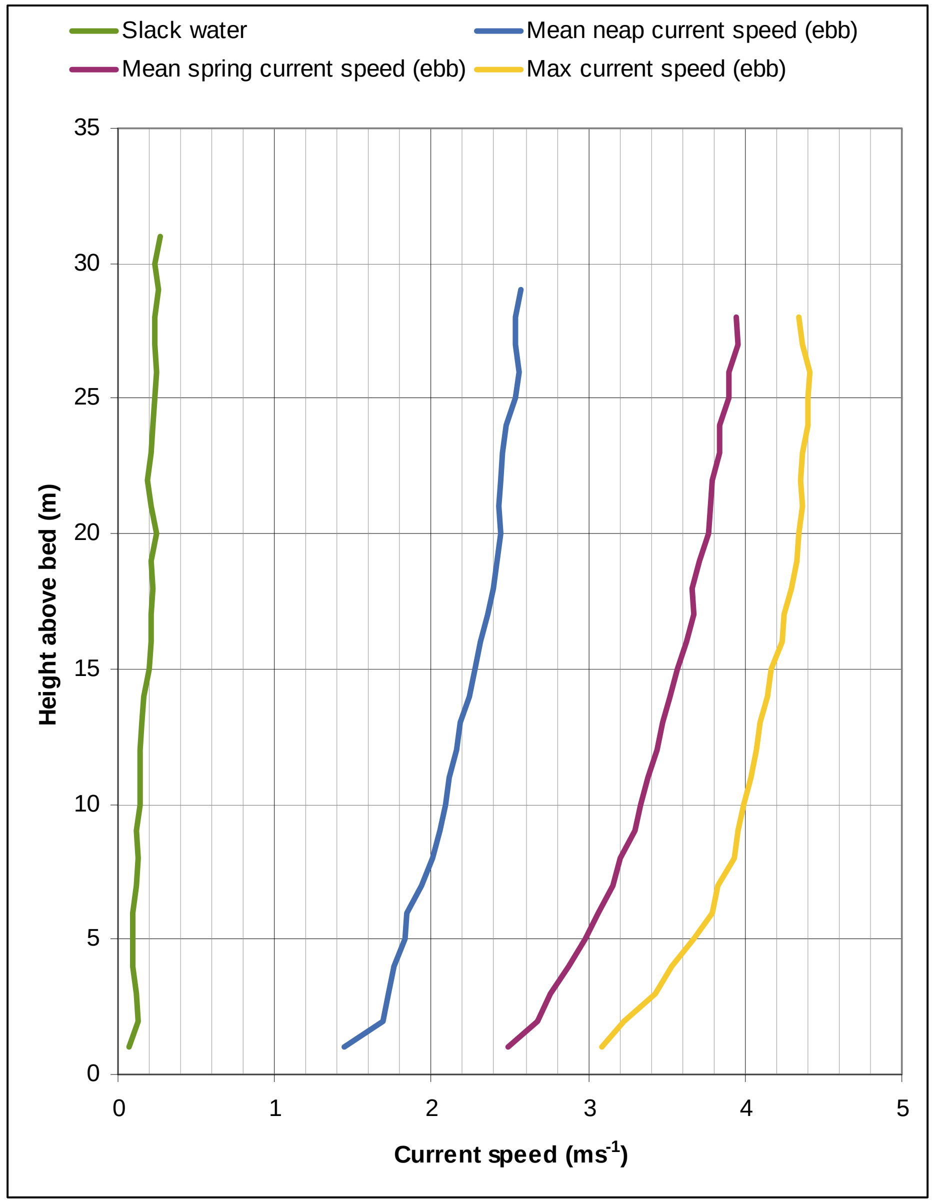


Figure 9.5: Range of current speeds at site of AWAC (EMU, 2011)

Hydrodynamic model

9.36 In order to understand the flow patterns and dynamics of the study area in greater detail, a hydrodynamic model was built covering the Pentland Firth and surrounding waters (DHI, 2009a). The model was calibrated using the moored 2009 and 2011 current meter data described in Table 9.11, and the plots in Figure 9.4 show peak flood and peak ebb timesteps for a neap and spring tide to show the detailed circulation patterns evident in the domain. The model is depth averaged, which is reasonable in this type of environment in which tidal flows are so dominant, and there is no vertical stratification of the water column (as shown in Figure 9.5).

9.37 A mean spring and a mean neap current speed, direction and water elevation time series, as extracted from the model at the location near the AWAC, are shown in Figure 9.6 and Figure 9.7 respectively.

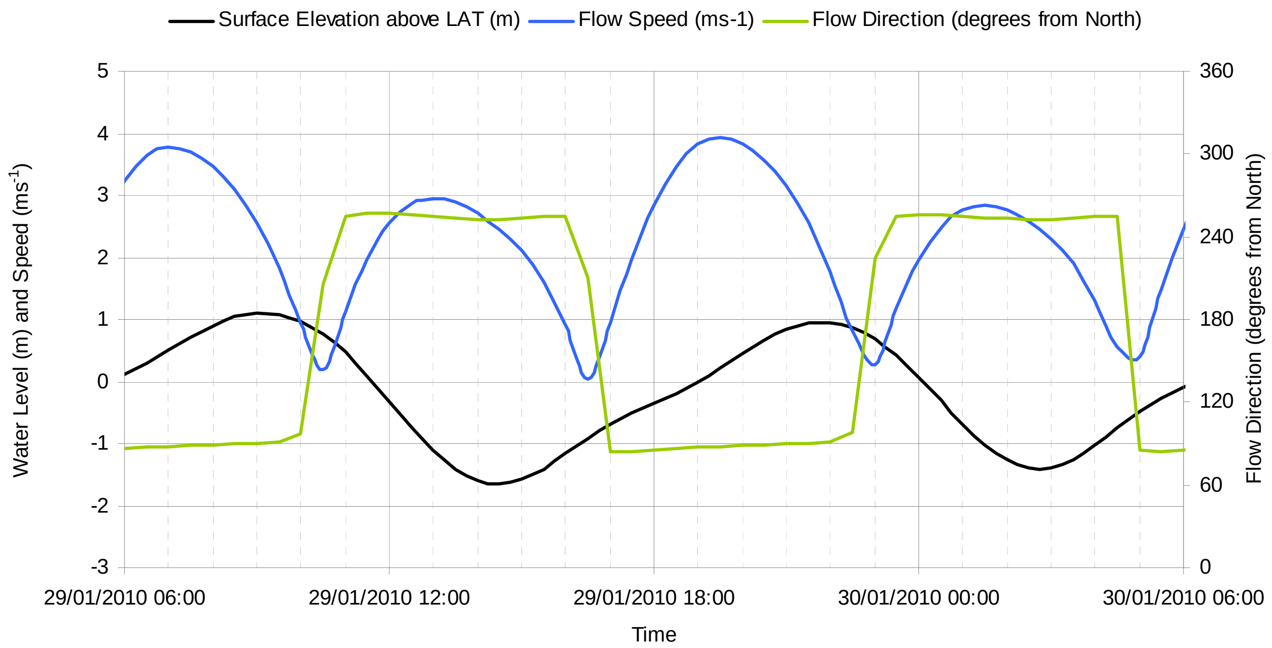


Figure 9.6: Mean spring tidal current

Non-tidal currents

9.38 Current flow within the area of interest is dominated by the semi-diurnal tide, but other, non-tidal flows will occur. The main components of non-tidal current flows are summarised below.

9.39 Storm surge currents are water movements driven by the passage of intense low pressure systems. In the area of interest, surge currents are most likely to travel from west to east along the north coast of the mainland, although the area may also be affected by southward-moving surges in the North Sea. Surge currents are unpredictable (outwith the timescales of accurate weather forecasts) and irregular in nature. They are usually assessed by considering the magnitude of current likely within a given return period. By way of indication, surge currents as high as 1.4m s^{-1} may occur in the Pentland Firth with a return period of 50 years. Along the north coast of the mainland and in the northern Orkney Islands, 50-year surge currents of 0.6 – 1.0m s^{-1} are more typical. As with tidal currents, surge currents will be strongly modified by local water depth and topography (Marine Scotland, 2009).

9.40 Surface wind-drift currents are caused by the entrainment of the surface water layers (typically only the top few metres) by the wind. These flows are different to general circulatory flows, which are caused by weather systems over larger space and time scales. Wind-drift currents will typically grow to no more than 2 or 3% of the wind speed (HSE, 2002) (i.e. a maximum of approximately 0.6ms-1 for a strong wind speed of 20ms-1). It is also likely that, since wind-drift currents only affect the top layer of the water column, they will be broken down by wave mixing (particularly if the waves are breaking) or strong three-dimensional flow features. These conditions are known to occur within many areas of the Pentland Firth, such as the Merry Men of Mey between Hoy and the Scottish mainland, and in the many races and eddies that occur around the Firth's islands and headlands at different stages of the tide (Marine Scotland, 2009).

9.41 General circulation currents cause a net transfer of water clockwise around the north coast of the UK. However, associated speeds are generally low, typically no more than 0.1 – 0.2ms^{-1} (HSE, 2002), so this component is relatively insignificant compared to the tidal currents in the Pentland Firth. Circulatory flows can vary considerably over short distances, and are usually greatest within a few kilometres of significant topographic features such as headlands, islands and banks (Marine Scotland, 2009).

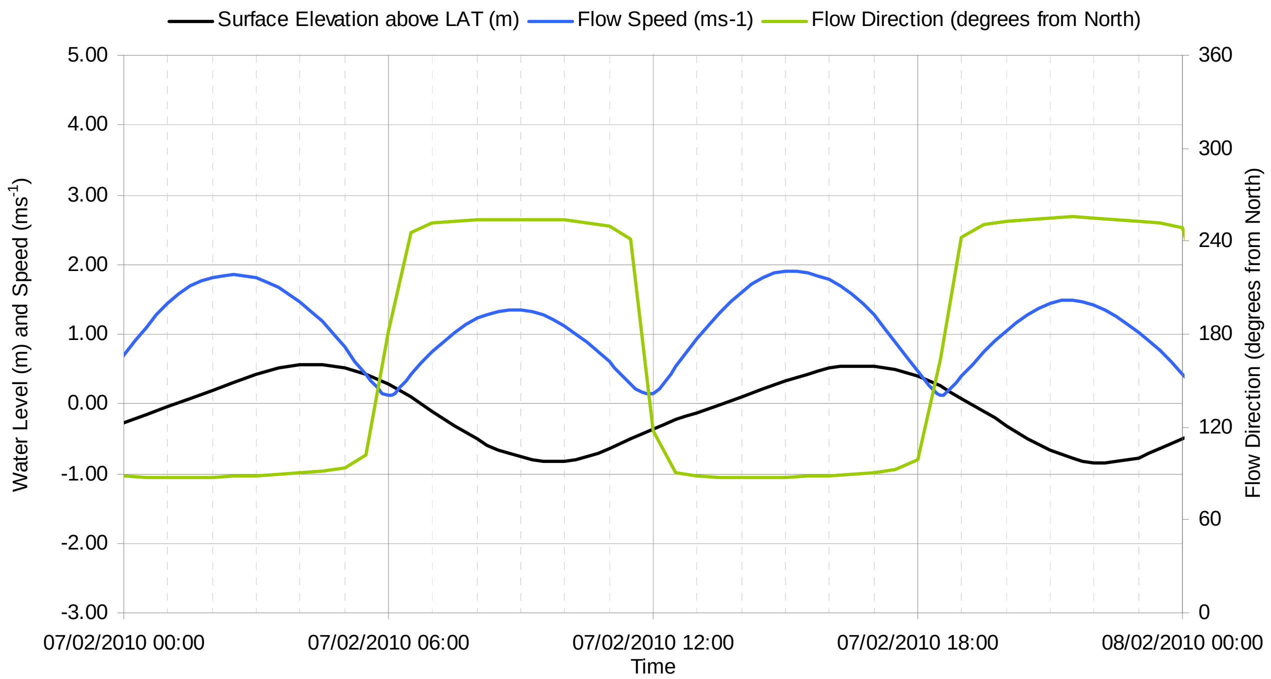


Figure 9.7: Mean neap tidal current

9.5.5 Waves

General description

9.42 The wave climate in the vicinity of the Project area is dominated by the passage of low pressure systems from west to east across the North Atlantic. Wave conditions are most severe (i.e. the wave field contains the greatest energy) in the exposed coastal areas to the west of the site, but although the highest and most frequent waves approach the Inner Sound from the west (UKHO, 2005), the coastal features and bathymetry of the Inner Sound are likely to cause these westerly waves to largely dissipate by the time they reach the Project site. Waves from the North Sea are less severe because a spit of shallower water extends north-east from Duncansby Head across the eastern end of the Inner Sound thus reducing their energy, but the open coastline on the eastern side of the Sound allows these waves to penetrate more easily into the Project area.

9.43 Waves are typically described in terms of a significant wave height, H_s (which is the average height of the highest one third of the waves in a given sea state), the wave period, T (which is the time taken for two successive wave crests to pass the same point), and the dominant wave direction.

9.44 There are very few known records of measured wave data along the North coast of Scotland, and there are no known records within the Inner Sound. Conclusions about the wave climate within the Inner Sound must therefore be drawn from data collected nearby and published reports. It should be noted that it is difficult to reach conclusions with a high degree of accuracy using this kind of approximation, because water depth and seabed topography both have important effects in modifying incoming waves. A detailed wave modelling study of the area is being undertaken at the time of writing, but results are not yet available.

Wave height and direction

9.45 A number of different data sources are presented to build a picture of likely wave heights in the Inner Sound.

9.46 Firstly, maps produced by BERR (BERR, 2008) present the mean significant wave height (H_s) across UK waters at different times of the year based on hourly model hindcast values over 7 years. The data is relatively coarse (the model resolution is 12km), but it still useful for showing that the most severe wave conditions are found to the west of the Inner Sound. The data from these maps has been summarised for the Inner Sound in Table 9.12, however it is important to recall that the constrained nature of the Sound and the local bathymetry are likely to significantly alter the wave heights presented, since waves passing from deep water to shallower water interact with the seabed, thereby changing the wave height.

Time of year	Mean significant wave height (H_s)
Annual	1.5m
Spring	1.5m
Summer	1.0m
Autumn	1.6m
Winter	1.9m

Table 9.12: Significant wave height summary in the Inner Sound (BERR, 2008)

9.47 Secondly, maps provided by the BODC (BODC, 1998) present the significant wave height (H_s) exceeded for different percentages of the year in UK waters, and support the data shown in Table 9.12.

9.48 Localised modelling of the offshore wave climate was also conducted offshore of Gills Bay (HR Wallingford, 1990) which calculated significant heights for a range of extreme wave conditions up to a 1 in 100 year return period. The largest wave conditions were found to occur from the north-west, with a significant wave height of 14.6m for a 12 hour duration event (SNH, 2000).

9.49 More recently, a basic wave model covering the Inner Sound was developed, driven by long-term wave statistics at the east and west model boundaries, to better understand the extreme wave heights in the area (DHI, 2009b). A selection of results from the modelling study is presented in Figure 9.8. They show the maximum wave trough height (H_T), which is the distance between the lowest water level reached during a storm and the still water level. H_T was estimated conservatively (DHI, 2009b), so is likely to be an overestimate, but can be converted to maximum wave height using H_{max}=2H_T. The findings of the wave modelling study are summarised for the Project area in Table 9.13, but it should be recalled these values are the result of a fairly coarse study, and will be superseded by the extreme wave modelling study being undertaken at the time of writing.

Description	Modelled H_{max} in Project area
1 in 100 yr storm	18m
1 in 1 yr storm	13m

Table 9.13: Summary of wave model extreme wave heights

9.50 Maps provided by BODC (BODC, 1998) illustrate the most common (modal) wave period around UK waters. Periods of 6s are common to the west and north of the Orkney Islands, while shorter periods of 4s are more typical of the Pentland Firth and east of the Orkney Islands (Marine Scotland, 2009).

9.51 However, these modal periods do not indicate the contribution from long-period swell waves. The dominant direction for swell waves is from the west (i.e. propagating from the North Atlantic), so they will have the greatest impact in those areas most exposed to the west. Swell wave periods of 10-16s are typical, and significantly longer periods of up to 40s have been measured. Swell wave climates tend to exhibit more regular periods and directions, and a narrower range of wave heights, than locally generated wind waves (Marine Scotland, 2009).

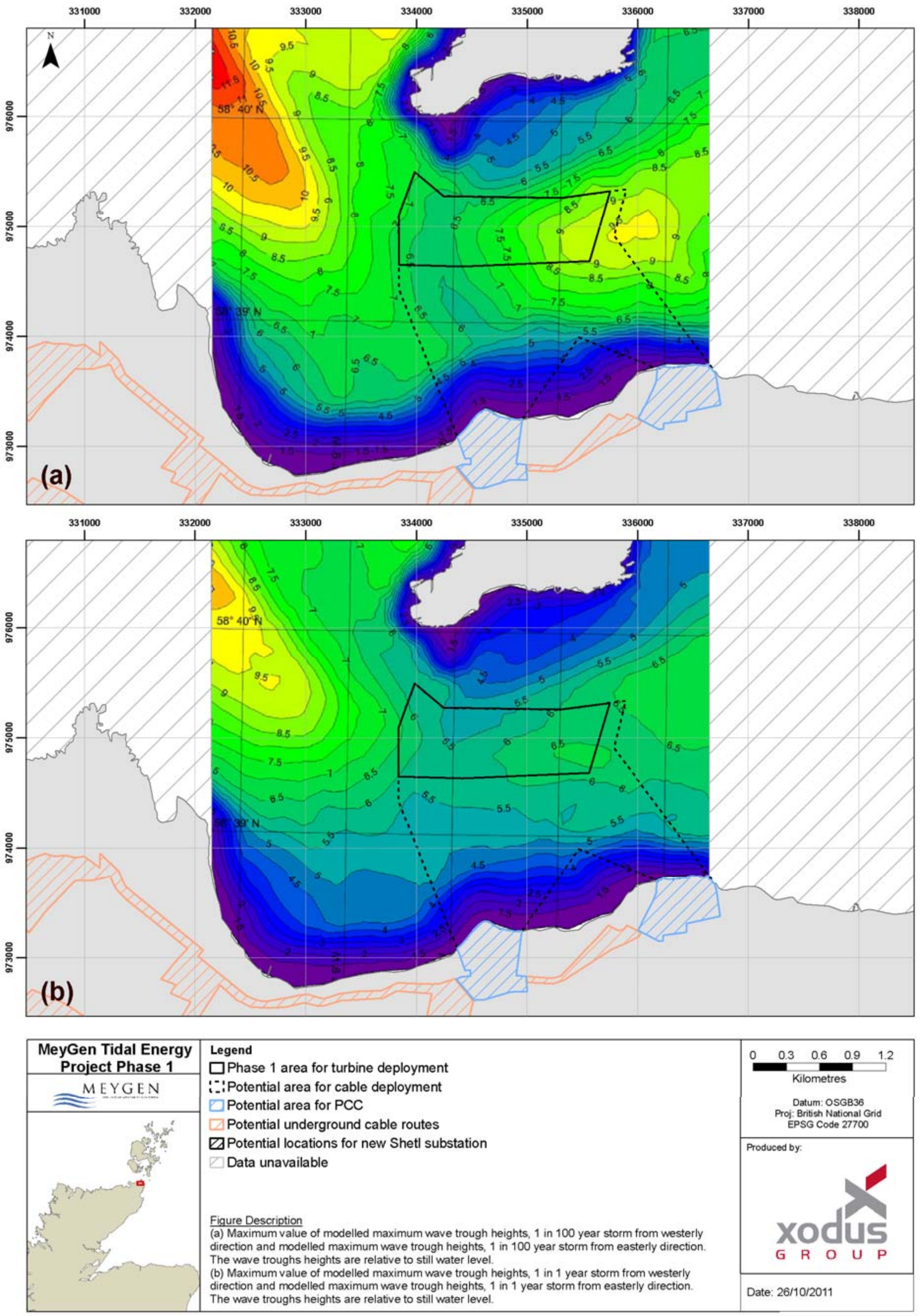


Figure 9.8: Wave modelling results

Extreme wave summary

9.52 Having reviewed data from all available sources and applying judgement based on general physical principles, the following preliminary wave criteria have been established for the MeyGen Agreement for Lease (AfL) area, as shown in Table 9.14. The extreme wave is specified as being from the east in Table 9.14 because the contours in Figure 9.8 show the extreme waves which impact on the Project area as coming most dominantly from the east.

Description	Estimated H_{max}	Estimated T_p
1 in 100 year wave from east	13.5m	14.5s
1 in 10 year wave from east	12.5m	13.0s
1 in 1 year wave from east	11.5m	11.5s

Table 9.14: Derived extreme wave heights for Agreement for Lease area

9.53 An additional analysis has been carried out to derive wave occurrence data for the turbine deployment area (Table 9.15).

Wave height H	Wave period T (at water depth 28m)	Percentage occurrence in 12 months
0.6m	3.3s	65.2%
1.4m	5.0s	20.4%
2.2m	6.3s	8.47%
3.1m	7.6s	3.59%
4.0m	8.9s	1.45%
4.8m	10.0s	0.578%
6.6m	12.7s	0.290%
9.2m	16. 8s	0.0363%
12.7m	22.4s	0.000926%

Table 9.15: Derived wave height, period and frequency statistics

Wave depth of influence

9.54 Wave orbital motions are the oscillatory currents associated with the passage of waves. These cause forwards and backwards movement associated with the passage of crest and trough respectively. Waves typically do not cause a net transport of water but can cause strong instantaneous loads on submerged structures. Wave orbital motions are aligned in the direction of wave propagation.

9.55 The strength of these currents is primarily dependent on the height and length of the wave and the depth of the water. Typically, higher and longer waves will induce orbital motions at greater depths within the water column. The strength of the motion for a given wave diminishes with depth. There are a three established criteria relating the water depth to wavelength, to establish the depth of wave influence (OU, 2008).

9.56 Assuming L=wavelength and d=water depth:

1. $d < L/20$ Shallow water – wave will have significant interaction with bed.
2. $L/20 < d < L/2$ Intermediate water – wave will have some interaction with bed.
3. $d > L/2$ Deep water – wave will not interact with bed in any way.

9.57 The wavelength of a water wave is generally larger for waves of longer wave period, and becomes shorter as the water depth decreases. These two effects are expressed by the following dispersion equation, which allows the wavelength to be calculated from the wave period (where g = 9.81 m s^{-2}, and T is the wave period), following the method of Soulsby (1997).

$$\left(\frac{2\pi}{T}\right)^2 = g\frac{2\pi}{L}\tanh\left(\frac{2\pi d}{L}\right)$$

9.58 Taking the wave criteria which have been established above, estimates have been made of the depth of influence of waves of differing periods in Table 9.16. The lower value T_s = 4s is a typical wave period for the Pentland Firth, while the higher value T_s = 40s is more representative of less frequent long-period swell wave. This is intended to summarise the best and worst case conditions for depth of influence of typical and extreme waves.

Wave period	Water depth throughout lease area (m)		
	d_{max} = 48m	d_{av} = 38m	d_{min} = 28m
$T_{s,min}$=4s	Calculated *L*=25m, therefore water is considered "deep" ([48 > 13], i.e. no wave interaction with the bed).	Calculated *L*=25, therefore water is considered "deep" ([38 > 13], i.e. no wave interaction with the bed).	Calculated *L*=25 therefore water is considered "deep" ([28 > 13], i.e. no wave interaction with the bed).
$T_{s,max}$=20s	Calculated *L*=399m, therefore water is considered "intermediate" ([20 < 48 < 199], i.e. wave will have some interaction with bed).	Calculated *L*=361m, therefore water is considered "intermediate" ([18 < 38 < 181], i.e. wave will have some interaction with bed).	Calculated *L*=316m, therefore water is considered "intermediate" ([16 < 38 < 158], i.e. wave will have some interaction with bed).
$T_{s,max}$=40s	Calculated *L*=850m, therefore water is considered "intermediate" ([43 < 48 < 425], i.e. wave will have some interaction with bed).	Calculated *L*=760m, therefore water is considered "intermediate" ([38 < 38 < 380], i.e. wave will have some interaction with bed).	Calculated *L*=655m, therefore water is considered "shallow" ([28 < 33], i.e. wave will have significant interaction with bed).

Table 9.16: Summary of depth of influence of waves of differing period

9.59 The cells coloured yellow in Table 9.16 show that most waves typical to the Pentland Firth will not cause any oscillatory motion at the seabed, because the water is deeper than the depth of influence of these short-period waves. The cells coloured blue shows that longer period waves will cause some oscillatory motion at the seabed, while the cell coloured grey shows that in the shallowest sites in the Project area, very long period waves will cause significant interaction. However, these waves will occur very infrequently (see Table 9.15).

9.5.6 Wind

9.60 On average, the northern and western parts of Scotland are the windiest in the UK, being fully exposed to the Atlantic and closest to the passage of areas of low pressure. The frequency and depth of these depressions is greatest in the winter half of the year, especially from December to February, and this is when mean speeds and gusts are strongest (Met Office, 2011).

Measured winds

9.61 A Met Mast is maintained on the Island of Stroma by the Environmental Research Institute (ERI), which records wind speed and direction. The location of the station is shown on Figure 9.2. Wind speed and direction data has been analysed from October 2010 and October 2011, and is shown in Figure 9.9.

9.62 At Stroma in the summer months, the average wind speed is in the region of 5ms^{-1}, while peak gusts of up to 27ms^{-1} were measured. In the winter months, the average wind speed is closer to 8ms^{-1}, while peak speeds of up to 36ms^{-1} were measured. The prevailing winds are from the south and west, as shown in Figure 9.9. Between October 2010 and October 2011, the average wind speed was 6.9ms^{-1}, and calm winds were recorded for 0.1% of the time.

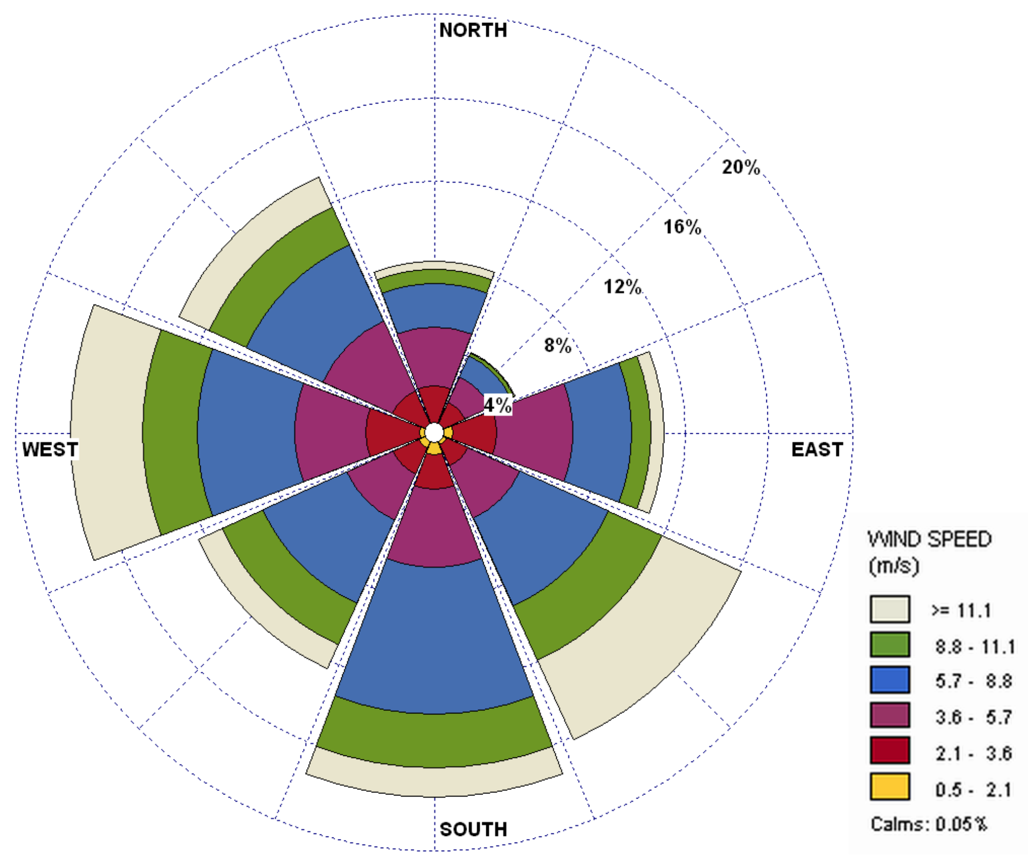


Figure 9.9: Wind rose from the Stroma met mast

Modelled winds

9.63 Maps showing modelled wind speeds throughout UK waters were produced by BERR (BERR, 2008) for the offshore wind industry, using wind data based on hourly model hindcast values over 7 years. The maps show wind speed at a reference height of 100m, which is useful for estimating wind resource, but needs modifying to represent wind speeds at lower heights. This modelled mean wind speed at 100m within the Inner Sound is summarised in Table 9.17 below, but the data is presented for general context to try and illustrate the scale of seasonal variations, rather than to give comparative absolute values.

Time of year	Modelled mean wind speed at 100 m
Annual	8.1m s^{-1}
Spring	8.1m s^{-1}
Autumn	8.7m s^{-1}
Winter	9.4m s^{-1}

Table 9.17: Summary of mean wind speed (BERR, 2008)

9.5.7 Seabed description

Overview

9.64 The British Geological Society (BGS) report that the geology of the Inner Sound is composed largely of exposed Devonian Old Red Sandstone bedrock (RPS, 2009). The 2009 geophysical survey confirmed this, while providing further detail that the majority of the seabed is comprised of current scoured bedrock with patches of sand, megarippled sand and sandbanks with coarse gravel in isolated patches both directly south and southwest of Stroma (iXSurvey, 2009).

Survey summary

9.65 A number of recent surveys have been carried out which can provide insight into the detailed geology and bedform structures of the site. They are summarised as follows:

- Video tows and associated still images taken by Marine Scotland in 2009 and 2010, which provide good general background on the benthic fauna and bed type (Moore, 2009; Moore, 2010);
- A geophysical site survey was undertaken in the Inner Sound in September 2009. A detailed report was produced to accompany the collected data, providing images and interpretation on the side scan sonar and sub-bottom profile records. The salient findings of that report have been summarised in the following text and in Figure 9.12. Further details can be found in iXSurvey (2009); and
- MeyGen commissioned a benthic and seabed sediment survey of the AfL area which was undertaken in 2011. It included collecting sediment grab samples, suspended sediment samples and bedload samples. The quantitative results from this survey are summarised in Table 9.18, Table 9.19 and Table 9.20.

Seabed description

9.66 Within the Inner Sound survey area 70% (7.8km^2) of the seabed is current scoured bedrock exhibiting a sawtooth profile, comprising folded and tilted sedimentary sandstone, flagstone and siltstone. Subrock, defined as rockhead at or near the seabed surface but intermittently covered in thin sediment, forms a further 13% (1.4km^2) of the survey area. A further 10% (1.1km^2) is made of isolated mega-rippled sand or sandbanks with coarse gravel forming 7% (0.8km^2) of the remaining sediments (iXSurvey, 2009). The distribution of these features is shown in Figure 9.12.

9.67 Deep fissures within the bedrock are found throughout the site, most notably in the central and western parts of the survey area. These fissures are up to 10m deep, and they are at their most extensive towards the centre of the survey area south of Mell Head (see Figure 9.12).

9.68 Areas of shell sand accumulation are present in the north-eastern regions of the survey area as well as a localised area in the north-west. These sand bodies rest upon underlying bedrock which is otherwise exposed at the seabed in the remainder of the site. These regions commonly exhibit mega-ripples, of lengths up to 20m and heights of between 0.2 and 0.5m.

9.69 In the far north-east of the survey area two discrete sand waves occur within a large sand bank, with wavelengths up to 140m and heights of 10m. The maximum thickness observed at this sandbank was approximately 15.5m. Likewise in the lee of Mell Head on the Island of Stroma sediments have accumulated to form an extensive sand bank, as shown in Figure 9.10 below.

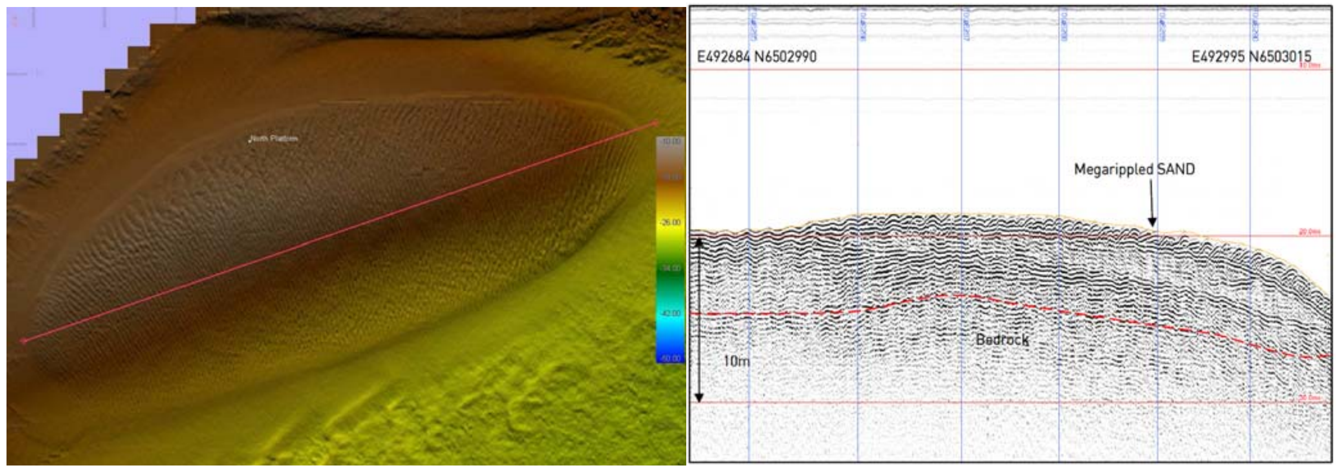


Figure 9.10: Images showing sandbank south of Mell Head (iXSurvey, 2009)

9.70 Deposits of coarse gravel are present in the north-western, north-eastern and eastern parts of the survey area. These deposits directly overlay bedrock and vary in thickness from a veneer, to 5m deep ridges in the far east of the survey area, as shown in Figure 9.11.

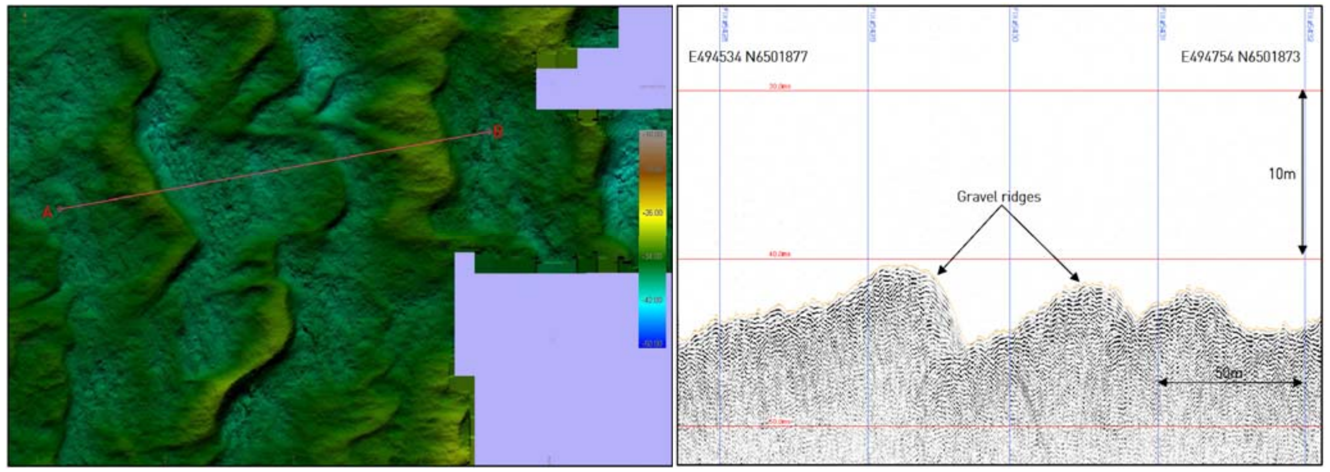


Figure 9.11: Images showing gravel waves to the east of the Project area site (iXSurvey, 2009)

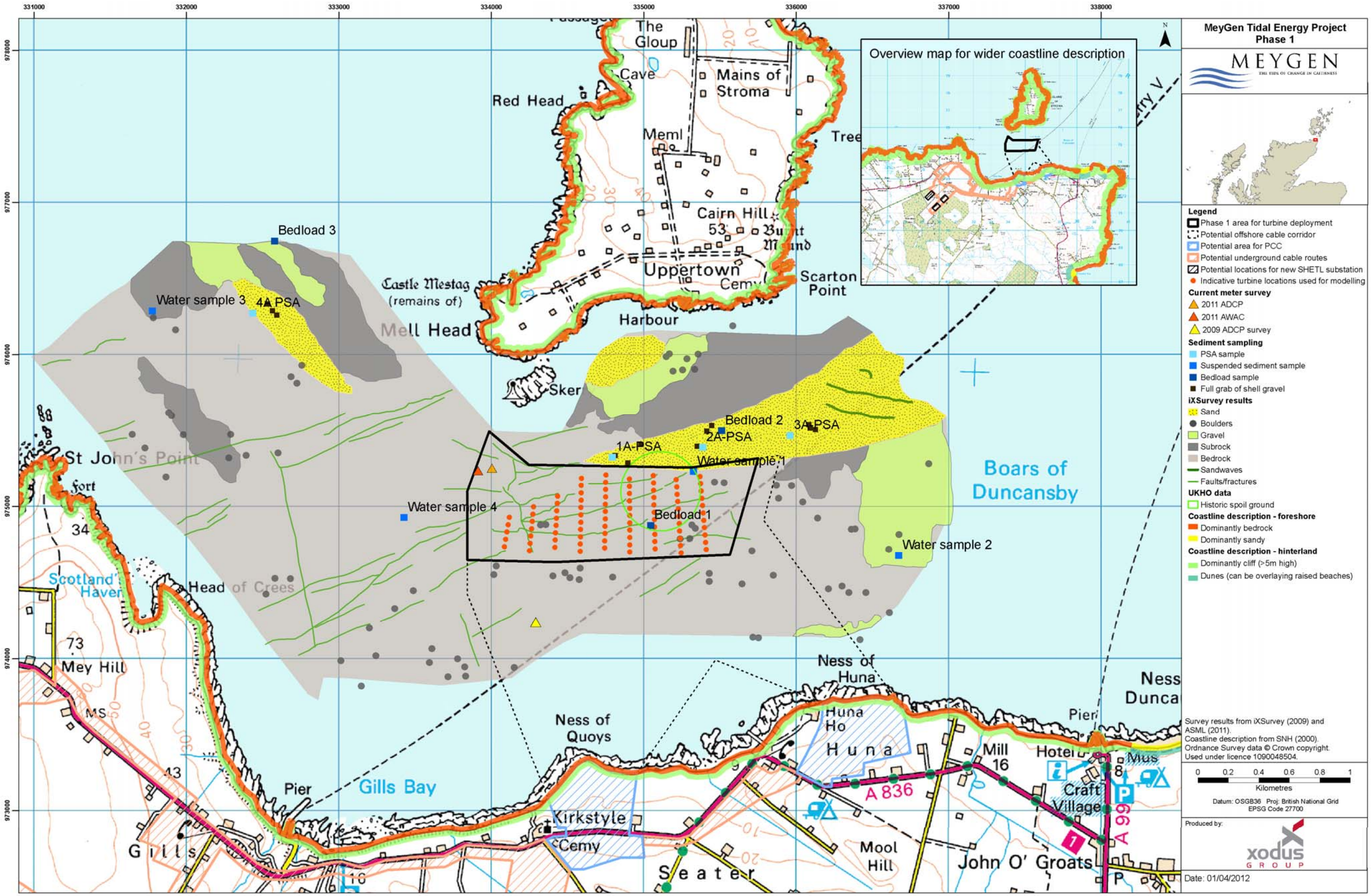
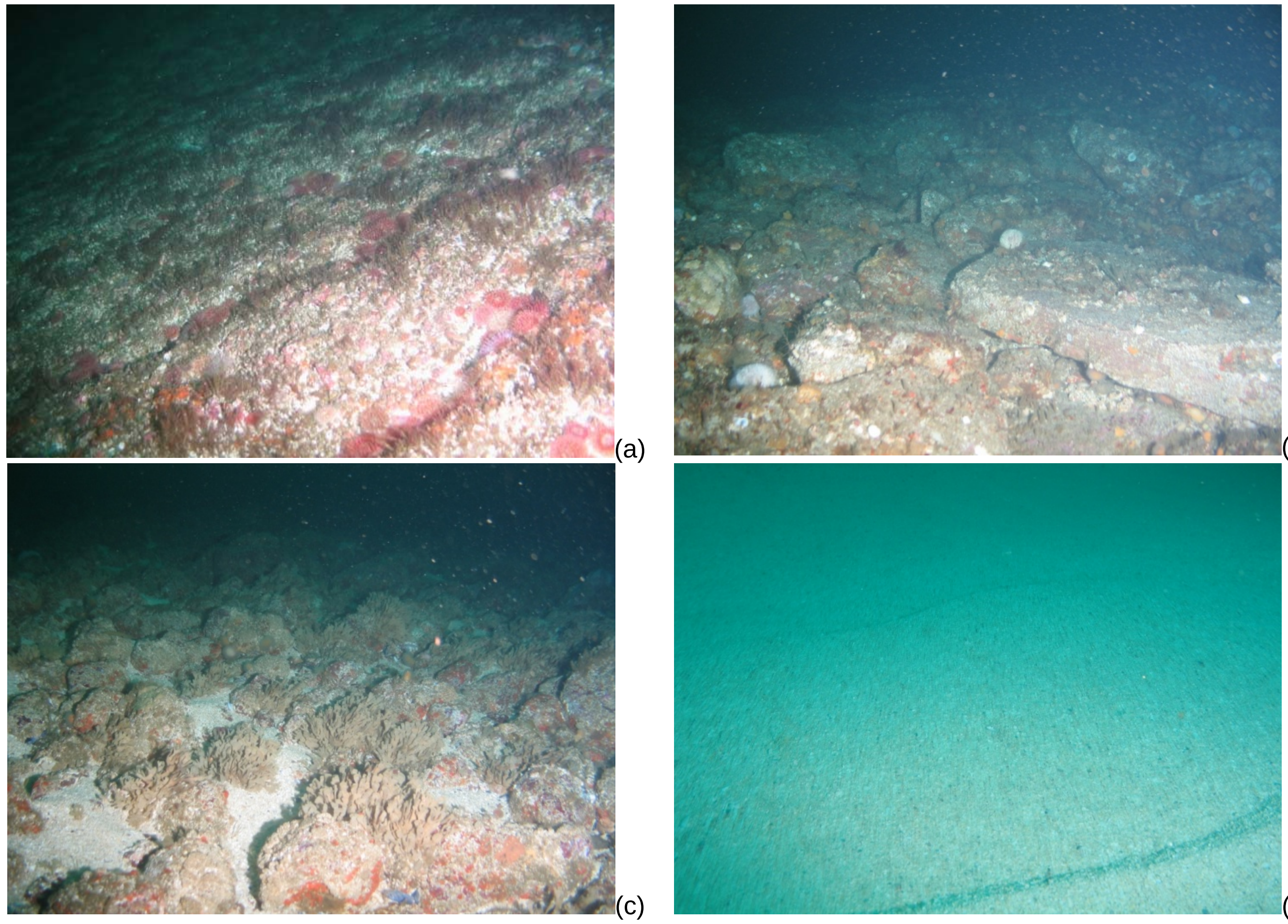


Figure 9.12: Summary of seabed morphology and sampling locations

9.71 The benthic survey included a drop-down video and photographic survey to map the substrata and the epibenthic biotopes, and a selection of images useful for visualising the seabed are shown in Figure 9.13 (ASML, 2011).



(a) (b) (c) (d)

Figure 9.13: Photos of the seabed showing (a) bedrock platform, (b) broken bedrock and boulders, (c) small boulders and cobble and (d) the shell sand bank (ASML, 2011)

Seabed processes and sediment transport

9.72 The Project area is generally devoid of superficial sediments, with the exception of the north-eastern and north-western regions of the site. Where found, sediments range from a coarse gravel veneer to larger mobile accumulations of coarse shell sand. A series of grab samples were taken from the large sediment wedge towards the north-east of the site, and the far west of the survey area as shown in Figure 9.12. These samples were found to consist of very clean shell gravel with little or no organic matter and a particle size distribution dominated by shell granules and very coarse shell sand (ASML, 2011). The results of the particle size analysis undertaken at each site is summarised below in Table 9.18.

Sediment type	Size	Phi	1A-PSA (W sand wedge)	2A-PSA (M sand wedge)	3A-PSA (E sand wedge)	4A-PSA (W sand bank)
			See Figure 9.12			
Medium pebble (gravel)	>8mm	< -3	5.3 %	0%	0%	8.4%
Small pebble (gravel)	4-8mm	-2 to -3	21.52 %	2.46%	8.82%	20.93%
Granule (very fine gravel)	2-4mm	-1 to -2	50.66 %	36.8%	44.03%	45.26%
Sand (very coarse)	1-2mm	0 to -1	22.47 %	56.07%	43.8%	24.77%
Sand (coarse)	500-999µm	1 to 0	0.02 %	4.59%	3.31%	0.61%
Sand (medium)	250-499µm	2 to 1	0.01 %	0.04%	0.02%	0.02%
Sand (fine)	125-249µm	3 to 2	0.01 %	0.01%	0.01%	0.01%
Sand (very fine)	63-125µm	4 to 3	0 %	0.01 %	0.01%	0.01%
Silt & Clay	<63µm	>4	0 %	0.01 %	0%	0%
d50 (estimated)	-	-	4.8mm	2.7mm	3.2mm	4.8mm

Table 9.18: PSA grades for samples throughout Project area (ASML, 2011)

9.73 At higher current speeds, and in coarser sediments, somewhat larger bed forms known as megaripples are produced. The shape of bedform crests are related to flow conditions. Where flows are relatively slow and/or the water is deep, bed forms are linear with long straight crests. At higher current speeds or in shallower water, the crests become progressively more indented until eventually they are broken up into short, curved sections. Fluctuating flows can lead to the superposition of smaller bedforms on larger ones.

9.74 The sand waves and ripples in the Inner Sound are thought to be current-induced. Firstly, because the water depth at the site makes it unlikely waves typical of the region would have any influence at the seabed (Table 9.16). Secondly, the ripples seem to be asymmetric on plan view, which is usually evidence of current-induced ripples (wave-induced ripples tending to be symmetrical on plan view) (OU, 2008).

9.75 This conclusion is strengthened by the findings of the bedload sampling. This survey element was carried out during neap tides, in conditions of relatively low current speeds for the Inner Sound, at various times throughout the tidal cycle. Depth-averaged currents at a nearby moored current meter (shown on Figure 9.12) did not exceed 2ms^{-1} throughout the neap period, whereas spring currents can exceed 4.5ms^{-1}. Weather conditions were benign during the survey, measuring light breezes at most, which means local wind driven waves would have been low at this time.

9.76 A number of bedload samples were collected during benign current conditions above three different types of seabed feature as summarised in Table 9.19, including: the large sand wedge south of Stroma, subrock with a veneer or sediment, and scoured bedrock. As would be expected under normal to low flow conditions, there is very little bedload transport recorded in the samples above bedrock and subrock. Above the sandbank however, there is a measureable flux of sand grains travelling across the sandbank (28$gm^{-1}s^{-1}$). Given the currents at the bed are likely to be in the region of 1ms^{-1}, this movement of particles supports the theory the sediment features are formed by currents, and are therefore a stable feature within the Sound, rather than temporary storm induced structures.

9.77 Gravel waves are found where the currents are very strong, typically 1.5ms^{-1}, so the gravel waves in the east of the Sound are also thought to be current-induced (Pugh, 1996).

9.78 Finally, to confirm the generally stable nature of the sediment features within the Inner Sound, a comparison was made between the geophysical survey carried out in 2009, anecdotal evidence of a previous survey carried out in 2008, and the Admiralty Chart bathymetry which was collected in 1984. The comparison indicated that the large sand body in the north-east of the site had not migrated to any significant degree (iXSurvey, 2009). A large storm event might cause a short term disturbance of the sediment distribution, but the large scale characteristics of the Sound including the high current scouring and the relatively reduced currents in the lee of Mell Head, are likely to redistribute the sediments bedforms to their pre-storm state (Easton, 2011).

Variable	Bedload 1 (bedrock)	Bedload 2 (sand wedge)	Bedload 3 (gravel bank)
	See Figure 9.12		
Date and time of sample	25/07/2011 16:28	25/07/11 16:52	27/07/11 13:49
Depth averaged current speed at AWAC	1.7ms^{-1}	1.7ms^{-1}	1.9ms^{-1}
Approximate current speed 1m above bed	1.1ms^{-1}	1.1ms^{-1}	1.1ms^{-1}
Depth-averaged current direction at AWAC	124^{o}N (flood)	124^{o}N (flood)	268^{o}N (ebb)

Sample time relative to high water (HW)	HW-2	HW-2.5	HW-7 (or LW+1)
Current description	Approaching peak flood	Approaching peak flood	Leaving peak ebb
Mass of particles with diameter <63µm	0.0685g	0.0134g	0.0257g
Mass of particles with diameter >63µm	2.3619g	713.3778g	3.9887g
Bedload transport ($gm^{-1}s^{-1}$)	$0.25gm^{-1}s^{-1}$	$28.20gm^{-1}s^{-1}$	$0.30gm^{-1}s^{-1}$

Table 9.19: Bedload concentrations measured in the lease area (ASML, 2011)

9.5.8 Coastline

9.79 Much of the coastal section around the Project area is marked by cliffs between 5 to 10m high, with a platform of nearly flat-lying slabs exposed in the littoral zone at the cliff foot, as summarised in Figure 9.12. The cliff sections are usually vertical to sub-vertical, with a sloping vegetated bank section at the top, and include good exposure of the local bedrock.

9.80 Beyond the eastern end of the Project area on the mainland are the sheer cliffs at Duncansby Head, which are cut in Old Red Sandstone and rise up to 70m in height. Natural coastal erosion at these cliffs has produced stacks, sea arches and caves. Similar cliffs are seen to the west of the site at Dunnet Head, which reach over 90m in height.

9.81 In areas where cliff exposures are absent, the back wall of the beach is formed by a usually steep, vegetated bank of between 2 and 15m in height. These areas tend to have more beach development, composed largely of cobbles and boulders up to 2m in length.

9.82 Despite the Caithness coast having some of the most abundant sand dune systems in the UK, there are no identified coastal sand dunes flanking the Project site. The shoreline is relatively uniform, with minor indentations caused by local erosion along the lines of joints, faults or dykes (Barne *et al*, 1996).

9.83 At the eastern end of the coast particularly between the Bay of Sannick and Gills Bay, beach areas have developed in between breaks in the rock platform and rock reefs which outcrop in the intertidal zone. Beach sediments here are sparse with thin sand beaches formed in gaps between the intertidal rock platforms. The beach material is predominantly derived from shell material. At present shell material still provides a very slow feed of sediment to these beach areas. There is little sand offshore of the regions, as any glacial deposits have been swept off the seabed by the strong tidal currents; hence there has not been a suitable supply of beach material from offshore glacial deposits to allow larger beaches to form along this coastline (SNH, 2000b).

9.84 The beaches around the Project area are relatively stable with respect to long term processes. Storm erosion will periodically occur but sediment will remain within the beach system (SNH, 2000b).

9.85 For further details on coastline description, see Section 17 and the report of Flett Brown (2009).

9.5.9 Water quality

9.86 The marine and inshore water quality in Scotland is considered to be generally good. The nearest bathing water sites to the proposed development are Dunnet and Thurso, both of which are classified as having excellent water quality (SEPA, 2011).

9.87 Fish farming can cause elevated concentrations of certain compounds and organic enrichment in seawater and seabed sediments. However, there are no shellfish or aquaculture sites near the Inner Sound (Xodus, 2011).

9.88 Suspended sediment samples were taken at a mid-depth in the water column above four different types of seabed feature, including the large sand wedge south of Stroma, the gravel bank at the east of the site, subrock with a veneer or sediment, and scoured bedrock, as summarised in Table 9.20. Despite each sample being collected at a different state of the tide and above a different seabed feature, all the samples show consistent absence of any significant suspended sediment concentration, the maximum being $14mgl^{-1}$. To put the results in context, the limit of detection of the sampling equipment is $1mgl^{-1}$. The particles in suspension are likely to be very fine, since the concentrations are consistent across the survey area, and do not settle out as the current speed decreases.

Variable	Water sample 1 (SS) (sand wedge)	Water sample 2 (SS) (gravel bank)	Water sample 3 (SS) (subrock)	Water sample 4 (SS) (bedrock)
	See Figure 9.12			
Latitude (WGS84) (deg)	58.6601 °	58.6553 °	58.669 °	58.6570 °
Longitude (WGS84) (deg)	-3.1164 °	-3.0931 °	-3.1779 °	-3.14907 °
Date and time	25/07/11 17:20	26/0711 08:29	26/07/11 15:10	27/07/11 12:10
Depth averaged current speed from AWAC	$1.5ms^{-1}$	$0.5ms^{-1}$	$0.3ms^{-1}$	$2.0ms^{-1}$
Approximate current speed at 1m above bed	$1.1ms^{-1}$	$0.2ms^{-1}$	$0.2ms^{-1}$	$1.ms^{-1}$
Depth-averaged current direction from AWAC	126°N (flood)	144°N (flood turning to ebb)	206°N (ebb turning flood)	270°N (ebb)
Sample time relative to high water (HW)	HW-1.5	HW+1	HW-5	HW+4
Current description	Peak flood speed	Approaching slack water	Slack water	Approaching peak flood
Water depth of sample (to CD)	35m	32m	34m	31m
Approximate depth sample taken at	17m	16m	17m	16m
Suspended Sediment Concentration	$10mgl^{-1}$	$14mgl^{-1}$	$11mgl^{-1}$	$12mgl^{-1}$

Table 9.20: Suspended sediment concentrations measured in the Project area (ASML, 2011)

9.89 The disused Gills Bay disposal site is located within the area of the proposed MeyGen development (see Figure 9.12). The site was once used for the disposal of dredge spoil, predominantly sandy material, following maintenance/capital dredging at the nearby ports of Scrabster and Gills Bay. The high current velocities and scoured rock topography of the region suggests that the spoil is likely to have dispersed rapidly (RPS, 2009), and the 2009 geophysical survey confirmed that there were no identified deposits relating to the disposal site (iXSurvey, 2009).

9.90 Munitions contamination within the proposed development is considered unlikely. The study area does coincide with the WWII Northern Mine Barrage area between the northern coast of Scotland and the Orkneys / Faeroes. The entire area was comprehensively swept for mines at the end of the war. However, as some mines were fitted with a clock, which after a pre-determined time caused a scuttling charge to be detonated and sink the mine, the possibility that some mines which scuttled themselves are still on the seabed in the region where the barrage coincides with the study area cannot be entirely discounted (Xodus, 2011).

9.91 The Dounreay nuclear site, located approximately 40km to the west by sea from the proposed MeyGen development, was responsible for the release of an unknown quantity of nuclear particles between the 1950s and 1970s. These particles have been identified in seabed sediments as far away as Dunnet Beach, approximately 15km to the west of the Inner Sound.

9.92 The main source of information on environmental radioactivity is the series of reports on Radioactivity in Food and the Environment (RIFE) published by the various UK Environment Agencies. The most recent report (RIFE, 2010) shows typical levels of gross alpha activity of the order of 100-600 $Bqkg^{-1}$ and gross beta activity of 400-1500$Bqkg^{-1}$ in UK coastal sediments. These compare to the results in the Inner Sound grab samples summarised in Table 9.18 of <55$Bqkg^{-1}$ (gross alpha) and <100$Bqkg^{-1}$ (gross beta). It can be seen that the results presented are well below typical national figures, due to the high level of shell in the sediment (Davidson, pers. com. Centre for Radiation, Chemical and Environmental Hazards, Health Protection Agency, Monitoring Services Manager).

9.93 The gamma spectrometry indicates the levels of caesium-137 are below 0.1$Bqkg^{-1}$. From this result, combined with the low gross alpha and gross beta results, it can be concluded that there is no evidence of contamination in any of these samples from artificial radioactivity (Davidson, pers. com. Centre for

Radiation, Chemical and Environmental Hazards, Health Protection Agency, Monitoring Services Manager).

9.6 Impacts during Construction and Installation

9.94 The impact assessment is based on the worst-case construction and installation options. For seabed morphology, this is the drilled monopile TSS for 86 turbines, and 86 HDD bores.

9.6.1 Impact 9.1: Change in bed morphology from drill cuttings discharge

Pile drilling

9.95 Mono-pile drilling operations will generate rock cuttings and these will be discharged from the drilling rig into the marine environment. Drilling operations will take approximately 4 hours per pile and a total of 30 hours to complete the preparations for each TSS. Seawater (with no additives) will be used as the drilling fluid to lubricate the drill bit and aid in the removal of cuttings from the hole. A compressor will be used to pump air into the drilled holes in order to lift the cuttings clear as required. This compressor will use a lubricant which will be discharged to sea along with any cuttings to a maximum 17,200m^3 for all 86 turbines installed over a 3 year period.

HDD drilling

9.96 The cables to shore will be routed through bores directionally drilled through the cliffs onshore. Assuming a worst case scenario of 29, 600mm bores, 700m in length. These will generate approximately 195m^3 of drill cuttings per bore; a total volume of 5,655m^3 for 29 bores. These will be collected from the bore at the drilling site onshore. As drilling is occurring from the onshore end, there may be some loss of cuttings to the marine environment upon breakthrough to the seabed. In the worst case scenario, the final 10m of the bore will be lost into the marine environment; a total of 82m^3 for all 29 bores.

9.97 The consequence of both HDD and monopole drilling operations is that the largest and heaviest particles will settle relatively quickly to the seabed in the close vicinity of the drilling centre, while the finer particles will be swiftly transported and dispersed by the highly energetic currents and waves in the Inner Sound. It is likely any particles with a settling velocity greater than the resupension and lift forces exerted by the tidal currents will be transported away under storm conditions. Drill cuttings' modelling has not been carried out as part of this EIA, because the environment is known to be so dispersive.

9.98 Under calm weather conditions, the prevailing current flow and the distance to shore means it is very unlikely the cuttings will be washed ashore. There will also be a length of time between each pile being drilled which will allow for dispersion time between each discharge event.

9.99 The dynamic environment (resulting from intense wave action and tidal activity) into which the operational discharge will be released means that drill cuttings will be dispersed into the wider marine area; the Pentland Firth is one of highest energy coastal environments in the UK. The lack of sediment across the Project installation area and the likely cable corridors indicates a dynamic environment on which solids are unlikely to accumulate. Indeed, anecdotal evidence that spoil has been dispersed from the disposal site in the centre of the site further confirms this. Natural turbulent conditions should ensure any deposition on the seabed is quickly dispersed and does not accumulate into large deposits. Naturally occurring material (including rock and other debris) is constantly moved around by tide and wave action ordinarily and, as such, the addition of rock debris is unlikely to be an unusual event. The bedload information collected by ASML (2011) and presented in Section 9.5.7 confirms the presence of such material under normal conditions.

9.100 Evidence from shallow waters of the southern North Sea, where wave and tidal movements greatly influence the marine environment, suggests that erosion rates are greater than natural sedimentation rates and that cuttings piles are dispersed (e.g. Kjeilen *et al.*, 1999).

9.101 In summary, drill cuttings piles will disperse rapidly, any short-term increases in suspended sediment concentration or scattered rock fragments on the seabed is not considered a significant impact to the physical environment or local sediment dynamics. The increased debris levels are only likely to be present for a short period of time before dispersion and transport processes return concentrations to their baseline condition. The main channel of the Inner Sound is known to be scoured bedrock, exhibiting deep fissures and cracks which have been generated through natural processes. This indicates that the spoil from any piling activities will also be dissipated.

9.102 The sensitivity of the receptor to the discharge of drill cuttings and fluid is assessed as negligible as the environment is considered to be highly tolerable of change. The impact will be of short term duration and due the dynamic environment dispersing any discharges relatively rapidly any changes will be imperceptible in comparison to the baseline conditions. Therefore, the magnitude of the impact is also considered to be negligible.

Impact Significance

Sensitivity of receptor	Magnitude of impact	Consequence	Significance
Negligible	Negligible	Negligible	Not Significant

MITIGATION IN RELATION TO IMPACT 9.1
▪ No mitigation measures proposed as no significant impact predicted.

9.6.2 Impact 9.2: Displacement of sediment resulting in alteration or loss of bedform and morphology

9.103 Sediment and existing bedforms may be disturbed during any of the following construction activities:

- Monopile or pin pile drilling for the TSS;
- HDD bore breakthrough; and
- Cable laying.

9.104 There is very little sediment in the Project area (see Figure 9.12), the seabed is largely current scoured bedrock, so there are not expected to be any indirect effects through sediment resuspension from piling activities. The nearest bedform to the turbine array is the large sand wedge which borders the north-eastern edge of the Project area, formed where the current speeds decrease significantly away from the main channel through the Sound. In their present nominal location, some turbines will be less than 50m from this sand wedge. Grab samples taken from nearby regions of the sand wedge found coarse sediments ranging from very coarse sand to small pebbles (on the Wentworth, 1922 scale). Any sediment displaced as a result of piling is likely to rapidly return to the seabed and settle within meters of the disturbance.

9.105 The HDD bores will not be emerging near any known bedforms, so there is not expected to be any impact from that process.

9.106 There is the potential for the installed cables to alter any seabed bedforms on the site via alteration of near bed hydrodynamic and sedimentary processes. However, the cable corridor is largely composed of exposed bedrock and nearer shore, kelp forests. The only known sedimentary feature near the cable corridor is a small (0.03km^2) patch of gravel approximately 500m north of the Ness of Huna. The coarse grain size of this gravel (4-8mm) means that any sediment displaced as a result of the cable laying process is likely to rapidly return to the seabed and settle within meters of the disturbance. To provide additional cable stability, MeyGen intend to lay the cable as much as possible within the natural fissures and crevices in the site bedrock. A consequence of this is that the cable will present the smallest possible ridge obstruction to near-bed hydrodynamics and bed processes, thereby reducing potential impacts.

9.107 The sensitivity of the receptor to the displacement of sediment resulting in alteration or loss of bedform and morphology is assessed as negligible as the environment is considered to be highly tolerable of change. The impact will be of short term duration and due to the dynamic environment little sediment will be present in the Project area that will be displaced. Any changes will be imperceptible in comparison to the baseline conditions. Therefore, the magnitude of the impact is also considered to be negligible.

Impact significance

Sensitivity of receptor	Magnitude of impact	Consequence	Significance
Negligible	Negligible	Negligible	Not Significant

MITIGATION IN RELATION TO IMPACT 9.2
▪ No mitigation measures proposed as no significant impact predicted.

9.6.3 Impact 9.3: Change in water quality

9.108 Suspended sediment concentrations may increase or bedforms may be disturbed and resuspended into the water column increasing suspended sediment concentrations, as described in Impact 9.1 and Impact 9.2, during any of the following construction activities:

- Pin pile or monopile drilling for the TSS;
- HDD bore breakthrough; and
- Cable laying.

9.109 The large tidal resource of the area means that any increases in suspended sediment will be quickly dispersed into the wider marine area, as described in Impact 9.1 and Impact 9.2.

9.110 The environment is considered to be tolerable of changes to water quality due to its dynamic nature. As a result the sensitivity of the receptor is assessed as low. The impact will be of short term duration during construction and while it will be a detectable change the change would be temporary and would cease on completion of construction activities. Therefore, the magnitude of the impact is considered to be minor.

Impact significance

Sensitivity of receptor	Magnitude of impact	Consequence	Significance
Low	Minor	Minor	Not Significant - however will require some management to ensure remains within acceptable levels

MITIGATION IN RELATION TO IMPACT 9.3
▪ Although no significant impact has been identified, mitigation measures have been provided on a precautionary approach to ensure this remains the case. ▪ Minimise as far as practicable the depth and diameter of the turbine foundation piles (without compromising technical performance); ▪ Minimise as far as practicable the volume of drill cuttings released into the marine environment during breakthrough of HDD bores, by implementing a closed loop recycling system to return drill cuttings and fluid from the HDD to shore.

9.7 Impacts during Operations and Maintenance

9.111 The impact assessment is based on the potential ‘maximum’ operation and maintenance parameters. For the physical environment, this is 86 turbines.

9.7.1 Impact 9.4: Change in hydrodynamics

9.112 Once the turbines are fully installed and operating, the hydrodynamic modelling study shows that there would be a flow separation around the tidal array. Current speeds will marginally increase to the north and south of the array, while through the array itself speeds will decrease.

9.113 The plots in Figure 9.14(a)-(c) show under calm conditions (a) mean current speed before array installation, (b) mean current speed after 86 turbines installed, (in which the flow separation around the array is clear), (c) the difference between the mean currents before and after array installation. The small region of blue running through the middle of the Sound shows how the modelled mean flows in this region are reduced by between 0 and 0.4ms^{-1} after the installation of the array, while the yellow patches to the north and south indicate that the mean flow is expected to increase here by between 0.1 and 0.2ms^{-1}.

9.114 The plots in Figure 9.14(d)-(f) show under calm conditions (d) max current speed before array installed, (e) max current speed after 86 turbines installed (in which the flow separation around the array is clear), (f) the difference between the max currents before and after array installation. The large region of blue running through the middle of the Sound shows how the maximum modelled flows in this region are reduced by between 0 and 1ms^{-1} after the installation of the array, while the yellow patches to the north and south indicate that the maximum flow is expected to increase here by between 0.1 and 0.8ms^{-1}.

9.115 The same patterns can be observed in Figure 9.15(a)-(f) which shows the mean and max currents from a worst case easterly storm, and Figure 9.16(a)-(f) which shows the mean currents from a worst case westerly storm. The conclusions are much the same as for the calm condition, except that as would be expected, the extent and magnitude or the differences are greater under storm conditions.

9.116 It is worth recalling (from Section 9.4.4) that the model is depth-averaged, so the predicted current speed increases and decreases presented here are likely to be conservative for surface currents, since the model does not consider the vertical flow fields and the fact that there will be a minimum of eight meters of clear water above the turbines.

9.117 In conclusion, the hydrodynamic model runs “with turbines” do not show an overall increase or decrease in current speeds through the Inner Sound, rather a relocation of the regions of higher and lower speed. It is important to make this point, because although the high flow channels may be displaced once the array is installed, the overall flow extremes should not change significantly.

9.118 The environment is considered to be tolerable of changes in hydrodynamics and the sensitivity of the receptor is assessed as negligible. There would be a material change to the hydrodynamics of the environment. However, the change would not be substantial as the overall hydrodynamic environment is not altered and the there is no overall significant increase or decrease in current speeds through the Inner Sound. Therefore the magnitude of the impact is considered to be moderate.

Impact significance

Sensitivity of receptor	Magnitude of impact	Consequence	Significance
Negligible	Moderate	Negligible	Not Significant

MITIGATION IN RELATION TO IMPACT 9.4
▪ No mitigation measures proposed as no significant impact predicted.

9.7.2 Impact 9.5: Change in wave height

9.119 It is possible that the once the turbines are operating, they will effect the wave regimes within and around the Project site.

9.120 The introduction of the array is not predicted to have a significant effect of the overall significant wave height (H_s) in and around the Project site. The wave modelling study predicts that H_s will marginally increase to the north and south of the array, while over the array itself H_s is predicted to decrease.

9.121 The plots in Figure 9.17(a)-(c) show for a two day continuous storm coming from the west: (a) max H_s before array installed, (b) max H_s after 86 turbines installed, (c) the difference between max H_s before and after array installation. The large region of blue to the west of the array in (c) shows that during a westerly storm, the presence of the full 86 turbine array is predicted to relocate part of the wave field, leading to an apparent decrease in incoming wave heights by between 0 and 2m, due to wave-current interaction. Equally, a region of higher waves is predicted to be relocated to the eastern side of the array, because the array is expected to reduce current speed downstream of the turbines, and while the currents are propagating with the waves the waves tend to become flattened, so a reduction in the ambient current speed will reduce this flattening effect causing the wave height to increase.

9.122 The plots in Figure 9.17(d)-(f) show for a two day continuous storm coming from the east: (a) max H_s before array installed, (b) max H_s after 86 turbines installed, (c) the difference between max H_s before and after array installation. The same redistribution of H_s is seen as described above.

9.123 It is worth noting that the storm conditions modelled here are extremely conservative, that is 14 days of continuous strong wind, waves and currents, which will give an extreme worst case storm result. Some of the wave heights output from the modelling study are comparable to heights which are expected for less than 0.05% of the year in the Inner Sound (Table 9.15), which shows the infrequency of these expected events.

9.124 In terms of overall impact, the conclusions of the wave modelling are very similar to those from the hydrodynamic modelling. There is no overall increase in max H_s throughout the Sound, the region of max H_s just moves north and south of the array, without changing much in magnitude. It is important to make this point, because although the location of max H_s may change once the array is installed, the overall wave extremes should be largely unaffected. Similarly, any such changes in the wave regime would only be noticeable over the short period for which the storm event occurred.

9.125 The environment is considered to be highly tolerable of changes in wave height and the sensitivity of the receptor is assessed as negligible. The modelling demonstrates there would be a material change to the wave heights in the area but the change would not be substantial as there is no overall increase or decrease in wave heights within the Inner Sound. Therefore the magnitude of the impact is considered to be moderate.

Impact significance

Sensitivity of receptor	Magnitude of impact	Consequence	Significance
Negligible	Moderate	Negligible	Not Significant

MITIGATION IN RELATION TO IMPACT 9.5
▪ No mitigation measures proposed as no significant impact predicted.

9.7.3 Impact 9.6: Change in sediment dynamics

9.126 It is possible that the once the turbines are operating, they will effect the hydrodynamic and wave regimes enough to change the sediment dynamics of the Project site.

9.127 The morphology modelling study predicted that there will be no significant impacts to the sediment dynamics and bedforms following the installation of the tidal array. There is a natural movement of sediments as would be expected in a site exposed to strong tidal currents, but the array is not predicted to affect these processes significantly. A study exists which concludes that most of the bedforms in the Inner Sound change shape between flood and ebb tide, so some movement is normal (Easton, 2011).

9.128 The plots in Figure 9.18(a)-(c) show under calm conditions (a) erosion/sedimentation before array installed, (b) erosion/sedimentation after 86 turbines installed, (c) the difference between the erosion/sedimentation before and after array installation. The interpretation of Figure 9.18(a) is that even under calm conditions and with no turbines, the bedforms show evidence of movement, but not in a way which is significant. The pattern of red and yellow patches is characteristic of sand simply shifting backwards and forwards under the flooding and ebbing tide, but there is no evidence of bedform migration or net sediment transport.

9.129 The key plot here is Figure 9.18(c), which shows that under calm conditions, the addition of the array is predicted to make little or no difference to the existing bedform structures. The large characteristic sand wedge bordering the north-eastern extent of the Project area does not migrate, there are just small (±0.2-0.5m) differences in bed height, which are normal for a dynamic sediment bedform up to 15m deep in places.

9.130 The plots in Figure 9.18(d)-(f) show under calm conditions (a) mean bedload transport before array installed, (b) mean bedload transport after 86 turbines installed, (c) the difference between the mean bedload transport before and after array installation. The interpretation of Figure 9.18(d) is that even under calm conditions and with no turbines, bedload transport is predicted to occur, as the bedload sampling indicated (see Section 9.4.7 and DHI, 2011). The orange, yellow and green patch just north of the Project area shows that, as would be expected, sand enters suspension above the sand bank. However, it is not transported away from the bedform, it is simply shifted backwards and forwards under the flooding and ebbing tide. There is no evidence of net bedload transport away from the existing bedforms.

9.131 The same patterns can be observed in Figure 9.19(a)-(f) which shows the bed change and bedload transport from a worst case easterly storm, and Figure 9.20(a)-(f) which shows the bed change and bedload transport from a worst case westerly storm. The conclusions are much the same as for the calm condition, except that as would be expected, the extent and magnitude of the differences are greater under storm conditions. Any sediment displaced during storm activity is expected to return to its equilibrium state after a few days, as also found in an independent modelling study (Easton, 2011).

9.132 In conclusion, the erosion/deposition and bedload transport results do not show any significant impacts on the existing sediment dynamics. Sediment movement is normal under storm conditions.

9.133 The environment is considered to be highly tolerable of changes in sediment dynamics due to a lack of net sediment transport in the Project area. Therefore, the sensitivity of the receptor is assessed as negligible. The modelling demonstrates there would be little change to the sediment dynamics regime and any changes would be non-material changes. As a result the magnitude of the impact is considered to be minor.

Impact significance

Sensitivity of receptor	Magnitude of impact	Consequence	Significance
Negligible	Minor	Negligible	Not Significant

MITIGATION IN RELATION TO IMPACT 9.6
▪ No mitigation measures proposed as no significant impact predicted.

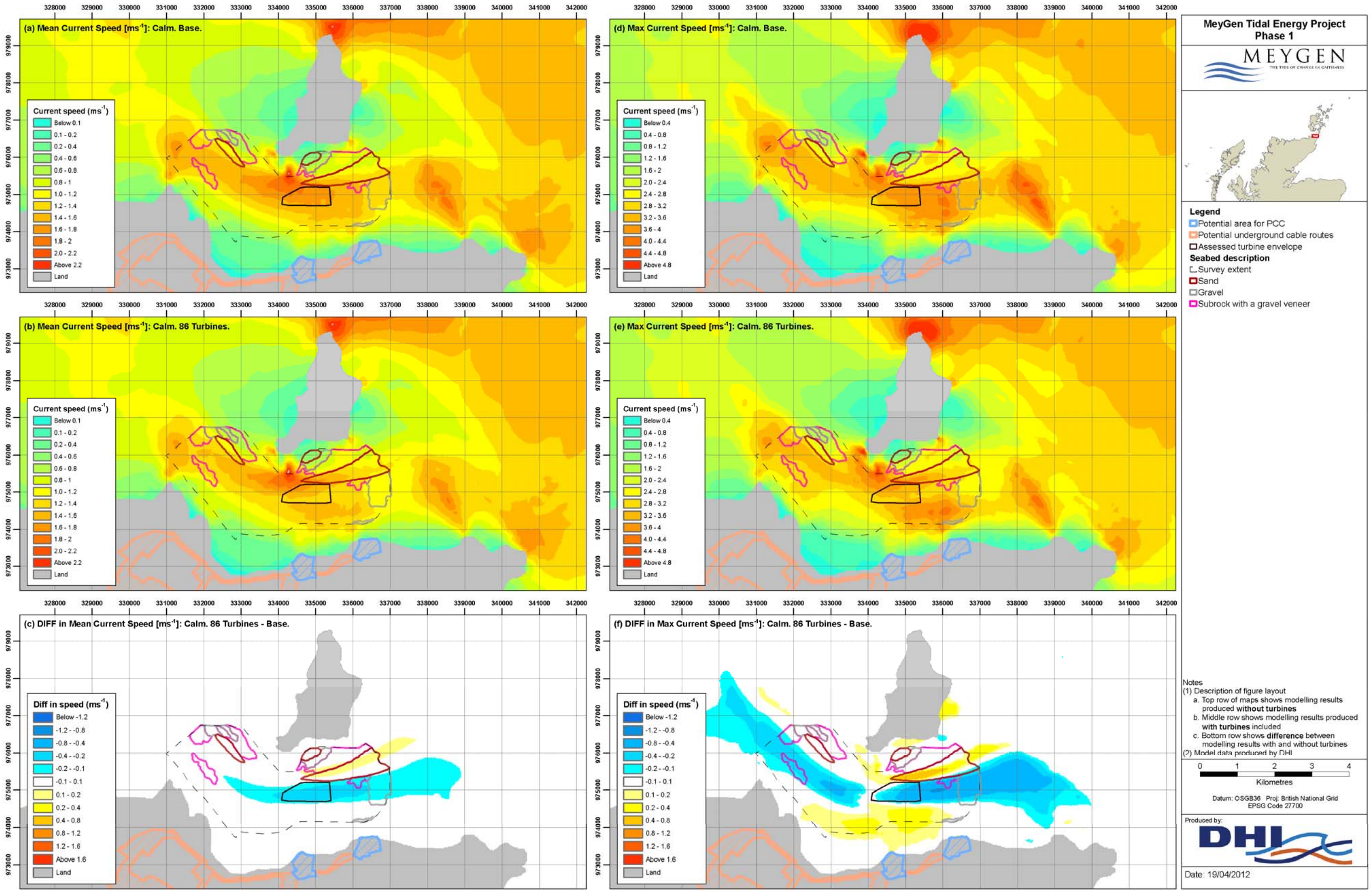


Figure 9.14: Modelling results showing difference in current speeds after the addition of the 86 turbines, calm scenario, (a), (b) and (c) mean current speed, (d), (e) and (f), max current speed

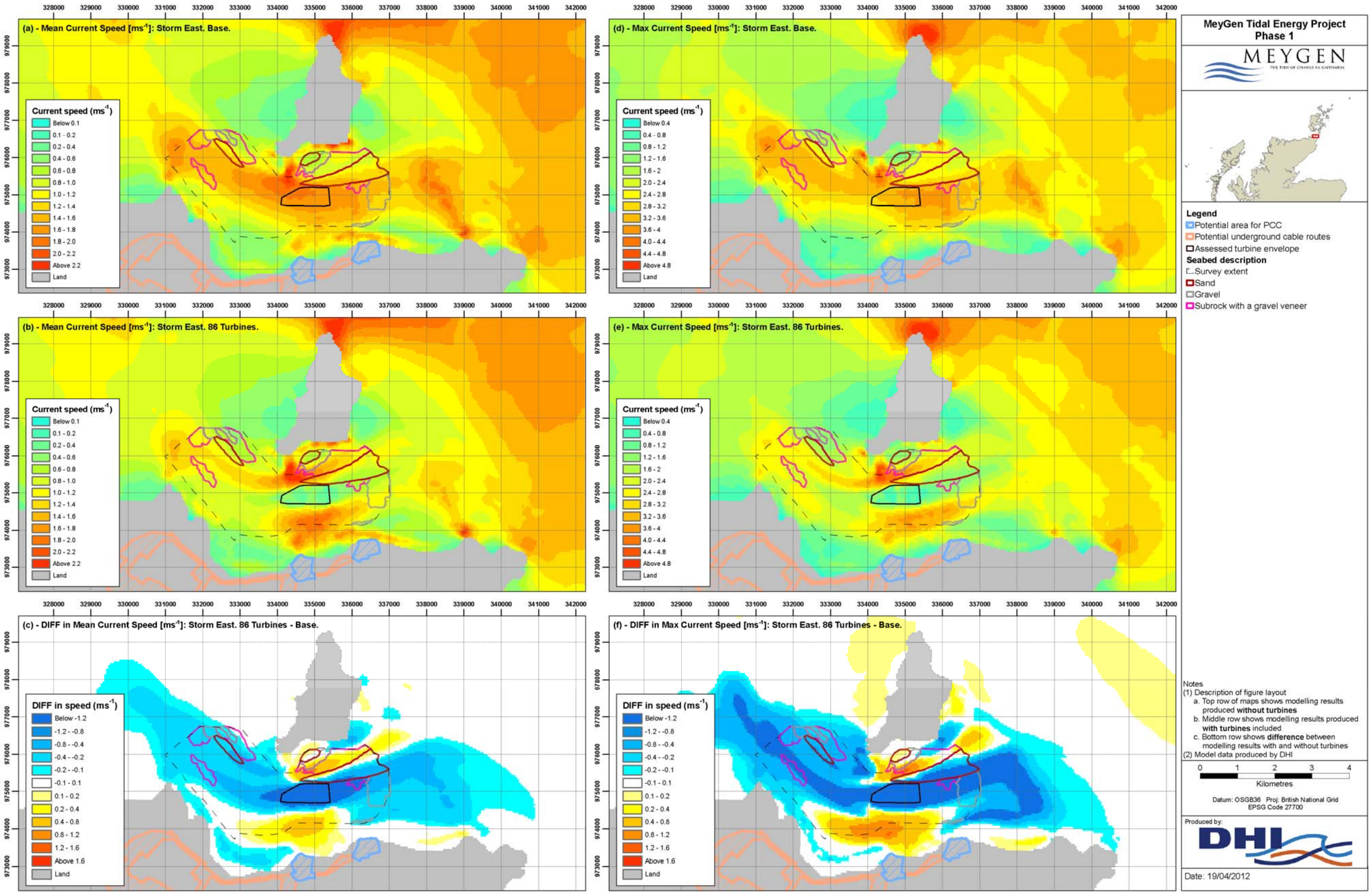


Figure 9.15: Modelling results showing difference in current speeds after the addition of the 86 turbines, easterly storm scenario, (a), (b) and (c) mean current speed, (d), (e) and (f) max current speed

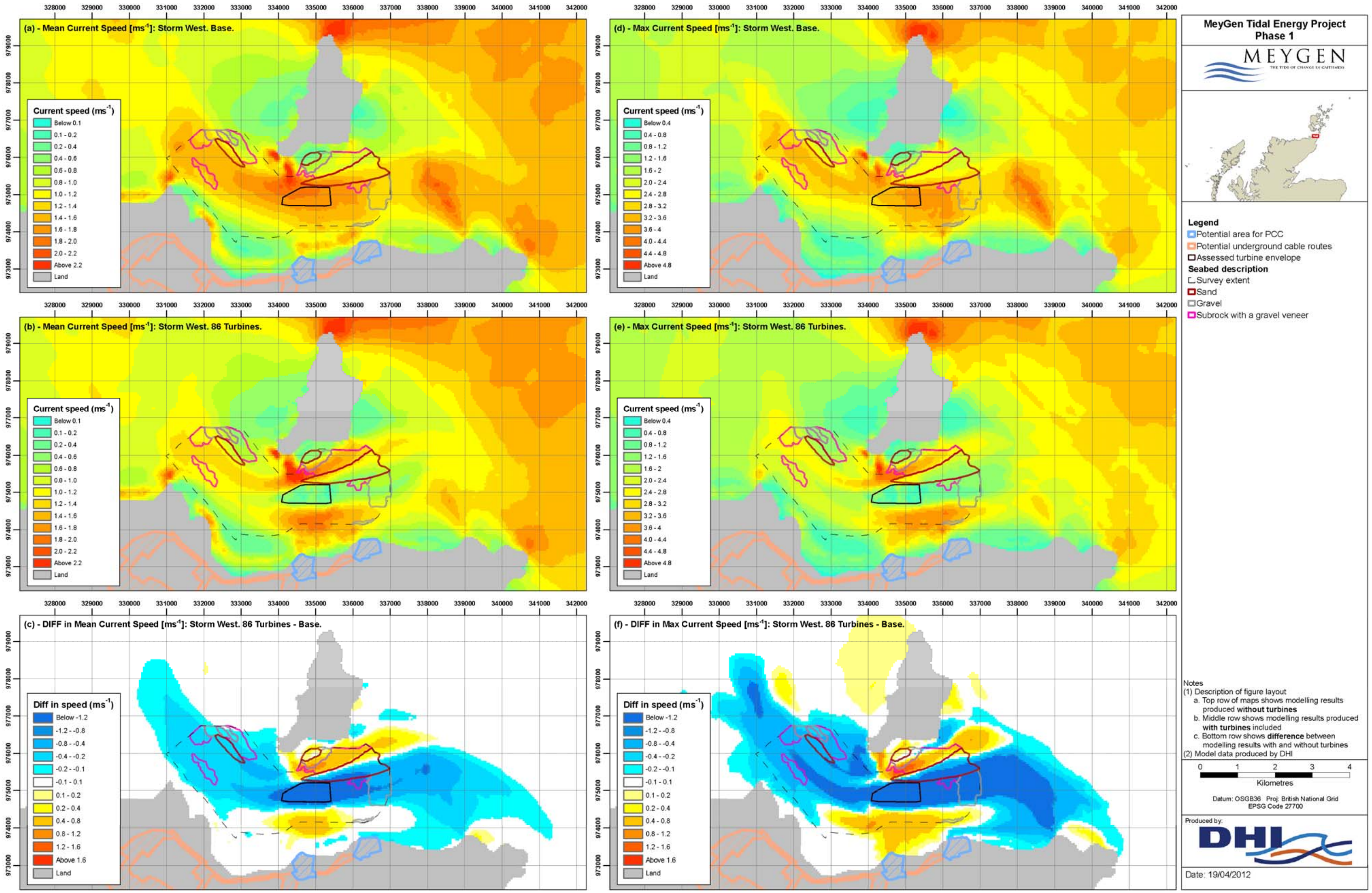


Figure 9.16: Modelling results showing difference in current speeds after the addition of the 86 turbines, westerly storm scenario, (a), (b) and (c) mean current speed, (d), (e) and (f) max current speed

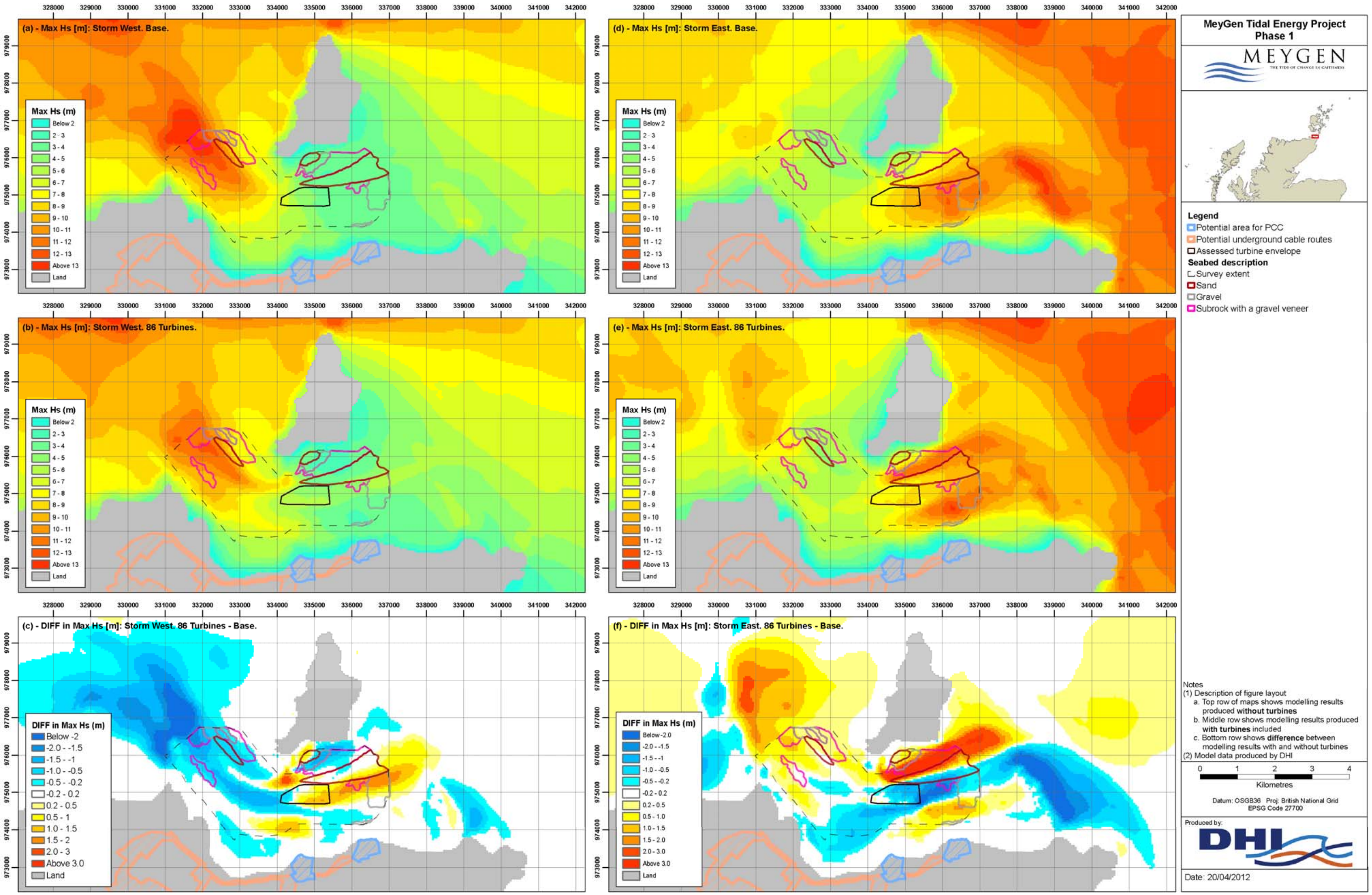


Figure 9.17: Modelling results showing difference in max wave height H_s after the addition of the 86 turbines, (a), (b) and (c) westerly storm scenario, (d), (e) and (f) easterly storm scenario

9.7.4 Impact 9.7: Erosion of the coastline

9.134 There are two sites of coastal importance near to the Project area, John o' Groats SSSI and GCR, and Duncansby Head SSSI and GCR. It is possible that the installation of the tidal array could change the hydrodynamics and waves at these designated sites, and increase coastal erosion.

9.135 The morphology modelling study predicted that there will be no significant impacts to the coastline following the installation of the tidal array.

9.136 The changes to the hydrodynamic and wave regime described previously (Impact 9.3 and Impact 9.4) largely occur in the channel area of the Inner Sound, and do not impact the coastline (see Figure 9.11 (c) & (f), Figure 9.12 (c) & (f) and Figure 9.13 (c) & (f)), therefore no changes at the coastline should be expected. The morphology results confirm this (see Figure 9.14 (c) & (f), Figure 9.15 (c) & (f) and Figure 9.16 (c) & (f)).

9.137 Both sites are undergoing natural coastal erosion due to the high energy environment they are exposed to. The installation of the array is not expected to increase or decrease the rate of erosion of these natural processes.

9.138 The John o' Groats SSSI and GCR, and Duncansby Head SSSI and GCR are of high environmental value and are therefore considered to be of high sensitivity. The modelling demonstrated that there would be no changes to the coastline once the tidal array is operational and the magnitude of the impact is considered to be negligible.

Impact significance

Sensitivity of receptor	Magnitude of impact	Consequence	Significance
High	Negligible	Minor	Not Significant

MITIGATION IN RELATION TO IMPACT 9.7
▪ No mitigation measures proposed as no significant impact predicted.

9.8 Impacts during Decommissioning

9.139 The potential impacts during decommissioning are expected to be, at worse of the same nature and magnitude as those during the installation and construction phase.

9.8.1 Impact 9.8: Displacement of sediment resulting in alteration or loss of bedforms and geomorphology

9.140 Sediment and existing bedforms may be disturbed during any of the following construction activities:

- Removing the TSS from seabed.
- Cable retrieval.

9.141 The impacts described here will be the same as those described in Impact 9.2.

9.142 There is no change anticipated to the status of the geomorphology of the sound both at the coast and on the seabed as a result of Decommissioning. The magnitude of impacts on geomorphological processes will be low with a possible short term localised disturbance to existing bedforms.

Impact significance

Sensitivity of receptor	Magnitude of impact	Consequence	Significance
Negligible	Negligible	Negligible	Not significant

MITIGATION IN RELATION TO IMPACT 9.8
▪ No mitigation measures proposed as no significant impact predicted.

9.9 Impacts to Designated Sites

9.143 Referring back to Section 9.5.1, the following designated sites were identified as being within 5km of the Project site:

- John o' Groats SSSI and GCR;
- Duncansby to Skirza Head GCR; and
- Duncansby Head SSSI.

9.144 All of the designated sites which were identified are coastal, so in keeping with the fact that no impacts are predicted at the coastline, none of the designated sites are predicted to be impacted.

9.10 Potential Environmental Variances

9.145 The impact assessment above has assessed the worst case Project options with regards to impacts to the physical environment and sediment dynamics. This section provides a brief overview of the potential variances between the worse case Project option assessed and alternative Project options.

9.146 Not considered worst case for the physical environment and sediment dynamics was the option of a pin pile TSS. The installation methods for pin pile TSS would have a lesser impact compared to the installation of the monopile TSS since it would produce less drill cuttings.

9.147 The modelling carried out for this study was undertaken to understand the implications of 86 turbines rated at 1MW. There is the potential that turbines of up to 2.4MW may be used to obtain the 86MW for the Project or a combination of different rated powers may be utilised. However, the modelling demonstrates that extracting 86MW of power from the tidal stream does not have a significant impact on the environment. Whether this 86MW consists of 36 devices of 2.4MW or a combination of devices will not significantly affect the results of the modelling. Therefore, it is unlikely that they will be any variation beyond the predictions presented in Section 9.7 (DHI, 2012). As a result the impact will remain not significant.

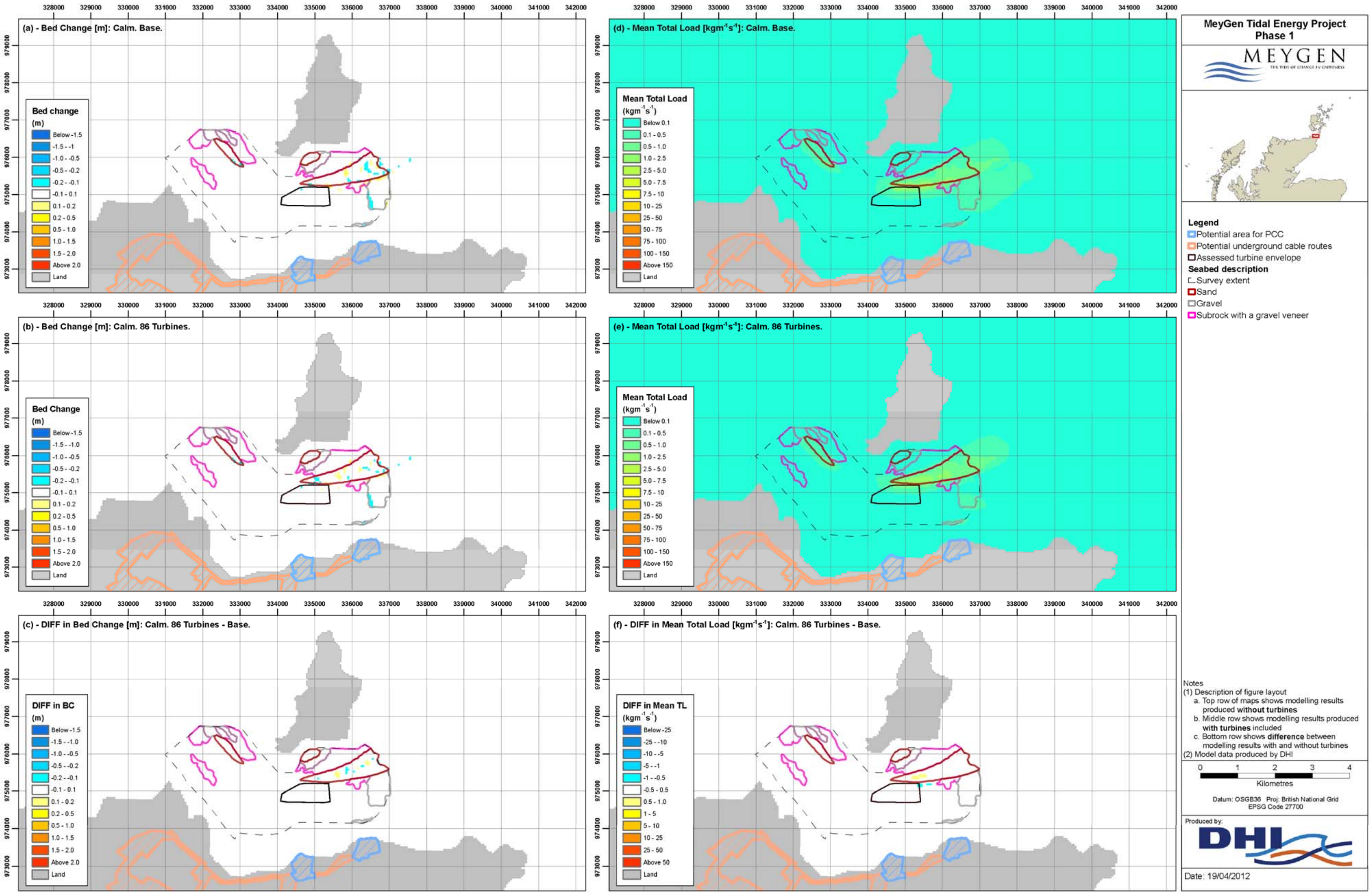


Figure 9.18: Modelling results showing difference in morphology after the addition of the 86 turbines, calm scenario, (a), (b) and (c) bed change, (d), (e) and (f) bedload

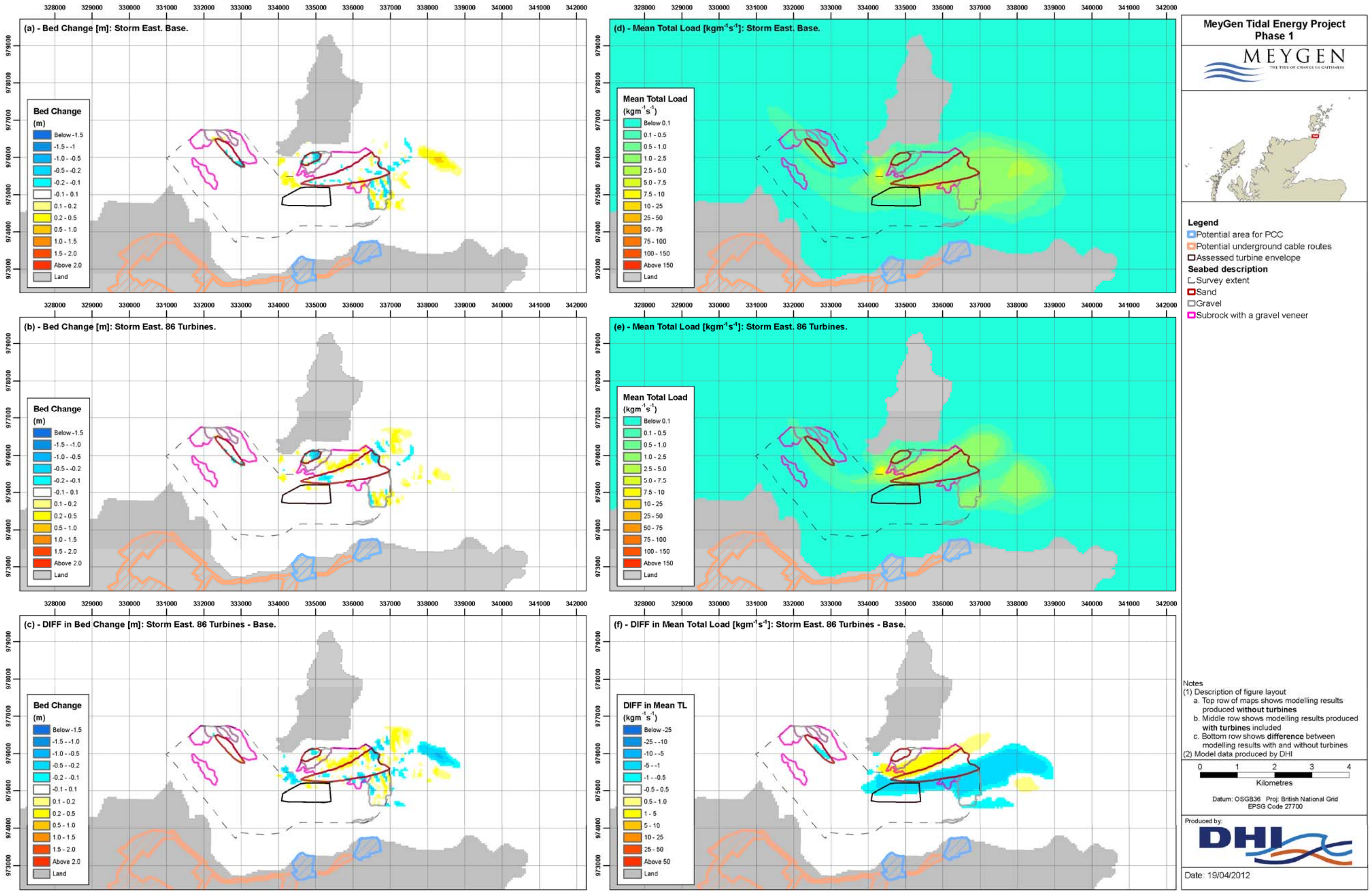


Figure 9.19: Modelling results showing difference in morphology after the addition of the 86 turbines, easterly storm scenario, (a), (b) and (c) bed change, (d), (e) and (f) bedload

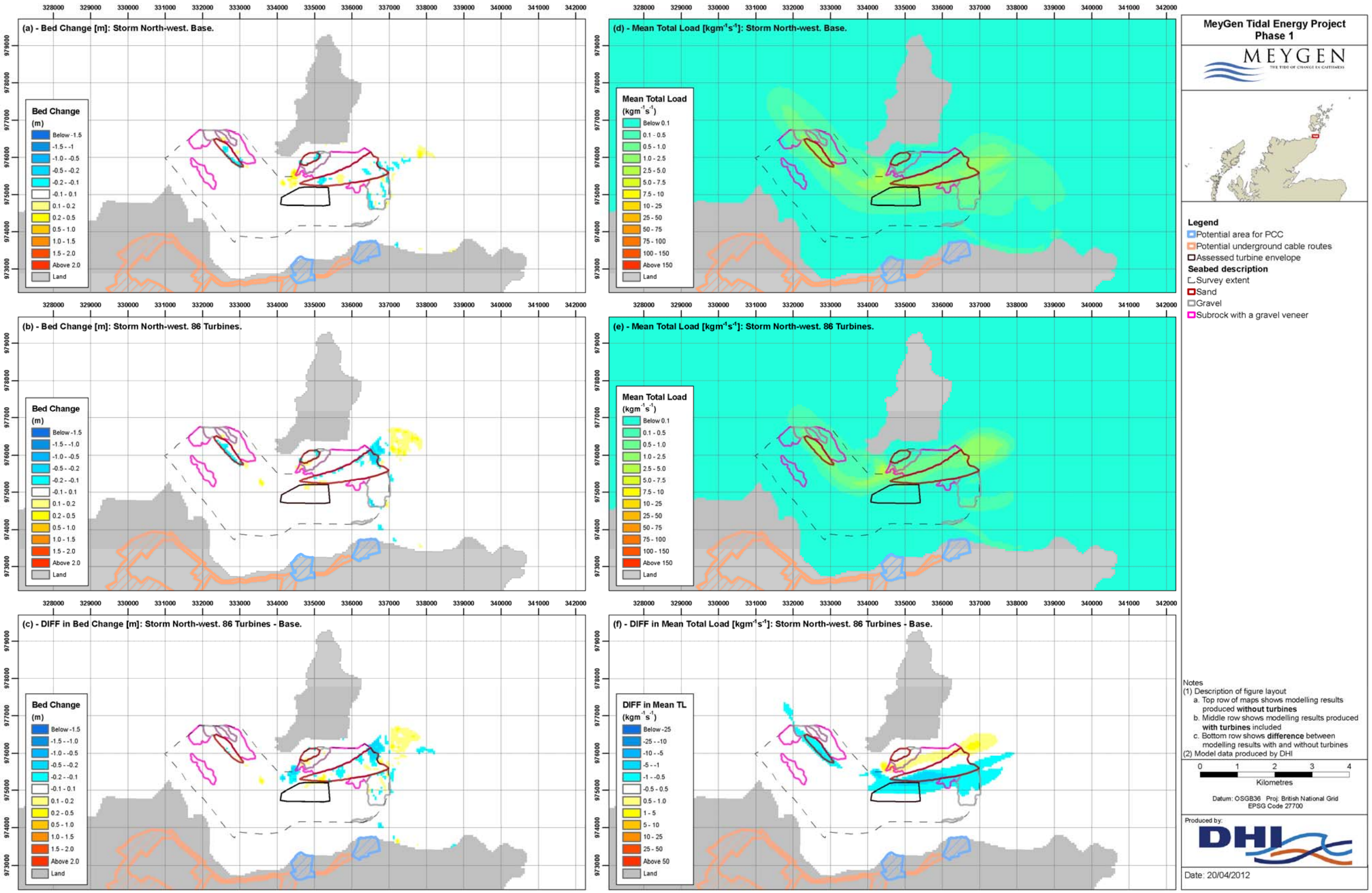


Figure 9.20: Modelling results showing difference in morphology after the addition of the 86 turbines, north-westerly storm scenario, (a), (b) and (c) bed change, (d), (e) and (f) bedload

9.11 Cumulative Impacts

9.11.1 Introduction

9.148 MeyGen has in consultation with Marine Scotland and The Highland Council identified a list of other projects (MeyGen, 2011) which together with the Project may result in potential cumulative impacts. The list of these projects including details of their status at the time of the EIA and a map showing their location is provided in Section 8; Table 8.3 and Figure 8.1 respectively.

9.149 Having considered the information presently available in the public domain on the projects for which there is a potential for cumulative impacts, Table 9.21 indicates those with the potential to result in cumulative impacts for the physical environment and sediment dynamics perspective. The consideration of which projects could result in potential cumulative impacts is based on the results of the project specific impact assessment together with the expert judgement of the specialist consultant.

Project title	Potential for cumulative impact	Project title	Potential for cumulative impact	Project title	Potential for cumulative impact
MeyGen Limited, MeyGen Tidal Energy Project, Phase 2	✓	SHETL, HVDC cable (onshore to an existing substation near Keith in Moray)	✗	OPL, Ocean Power Technologies (OPT) wave power ocean trial	✗
ScottishPower Renewables UK Limited, Ness of Duncansby Tidal Energy Project	✓	Brough Head Wave Farm Limited, Brough Head Wave Energy Project	✗	MORL, Moray Offshore Renewables Ltd (MORL) offshore windfarm	✗
Pelamis Wave Power, Farr Point Wave Energy Project	✗	SSE Renewables Developments (UK) Limited, Costa Head Wave Energy Project	✗	SSE and Talisman, Beatrice offshore Windfarm Demonstrator Project	✗
Sea Generation (Brough Ness) Limited, Brough Ness Tidal Energy Project	✗	EON Climate & Renewables UK Developments Limited, West Orkney North Wave Energy Project	✗	BOWL, Beatrice Offshore Windfarm Ltd (BOWL) offshore windfarm	✗
Cantick Head Tidal Development Limited, Cantick Head Tidal Energy Project	✗	EON Climate & Renewables UK Developments Limited, West Orkney South Wave Energy Project	✗	Northern Isles Salmon, Chalmers Hope salmon cage site	✗
SSE, Caithness HVDC Connection - Converter station	✗	ScottishPower Renewables UK Limited, Marwick Head Wave Energy Project	✗	Northern Isles Salmon, Pegal Bay salmon cage site	✗
SSE, Caithness HVDC Connection - Cable	✗	SSE Renewables Developments (UK) Limited, Westray South Tidal Energy Project	✗	Northern Isles Salmon, Lyrawa salmon cage site	✗
RWE npower renewables, Stroupster Windfarm	✗	EMEC, Wave Energy test site (Billia Croo, Orkney)	✗	Scottish Sea Farms, Bring Head salmon cage site	✗
SSE, Gills Bay 132 kV / 33 k V Substation Phase 1: substation and overhead cables (AC)	✗	EMEC, Tidal energy test site (Fall of Warness, Orkney)	✗	Northern Isles Salmon, Cava South salmon cage site	✗
SSE, Gills Bay 132 kV / 33 k V Substation Phase 2: HVDC converter station and new DC buried cable	✗	EMEC, Intermediate wave energy test site (St Mary's Bay, Orkney)	✗	Scottish Sea Farms, Toyness salmon cage site	✗
SHETL, HVDC cable (offshore Moray Firth)	✗	EMEC, Intermediate tidal energy test site (Head of Holland, Orkney)	✗	Northern Isles Salmon, West Fara salmon cage site	✗

Table 9.21: Summary of potential cumulative impacts

9.150 The following sections summarise the nature of the potential cumulative impacts for each potential project phase:

- Construction and installation;
- Operations and maintenance; and
- Decommissioning.

9.11.2 Potential cumulative impacts during construction and installation

9.151 Cumulative impacts arising from installation of multiple marine renewable projects at the same time as the proposed installation are not anticipated as the majority of impacts are expected to be localised (e.g. release of drill cuttings[1], modification of local bedforms). The Ness of Duncansby Tidal Energy project is the only project that may potentially be constructed at the same time as the MeyGen Tidal Energy Project, Phase 1 and would not act in combination to cause significant impacts.

9.11.3 Potential cumulative impacts during operation and maintenance

9.152 Of those projects listed in Table 9.21, only the MeyGen Tidal Energy Project, Phase 2 and the Ness of Duncansby Tidal Energy Project have the potential to lead to cumulative impacts on the physical environment. The Cantick Head and Brough Ness tidal projects are too far away to be impacted, and although the Farr Point wave project will remove wave energy from the area local to it, it is extremely unlikely that it will have an impact on the bulk of wave propagation from the north-east Atlantic

9.153 The erosion/deposition and bedload transport modelling does not show any changes which extend into the Ness of Duncansby site under either calm or storm conditions. Even if there were further sedimentary bedforms outside of the Project area which have not been modelled here, the changes to the hydrodynamics and waves are negligible and as a result it is extremely unlikely they would be modified.

9.154 The MeyGen Tidal Energy Project, Phase 2 may introduce a further 312MW into the Inner Sound. The exact turbine number, location and layout within the Agreement for Lease area is not yet defined and will incorporate lessons learned from technology advancements beyond Phase 1 of the Project. These factors will influence the potential, nature of and significance of any cumulative impacts. However, following the results of the Phase 1 modelling study, the additional 312MW will probably have a similar effect on the hydrodynamics and waves, but their area of influence will be greater. It is possible the flow separation seen in the Phase 1 results will extend closer to the coastline, so may cause increased current speeds at the coastline, but given that the chief coastal erosion mechanisms along that stretch of coast are driven by storms, these differences are unlikely to cause a significant difference. If the flow speeds continue to slow within the array following the introduction of the next phase of turbines, it is possible some sediment will begin to collect on the surface of what is currently scoured bedrock, but the sensitivity of the seafloor as a receptor is considered low, so this is not considered significant.

[1] Cumulative impacts from discharges of drill cuttings would only be a potential impact if other developers used piled foundations.

9.155 With regards to the Ness of Duncansby site, once the array is fully installed, the modelling results under calm conditions do not show any changes which extend into the Ness of Duncansby site. Under storm conditions, only small changes extend into the Ness of Duncansby site (very small changes in current speed, and decreases in wave height of up to 1.5m), which are thought to be negligible in storm conditions.

9.11.4 Potential cumulative impacts during decommissioning

9.156 Although it is possible that a number of the impacts that may occur during decommissioning (e.g. stirring up of existing sediment bedforms) could act cumulatively with other developments, it is highly unlikely that the Ness of Duncansby development (the only development other than MeyGen Phase 2 expected to offer the potential for cumulative impact) would be decommissioned at the same time as this development, or that of the MeyGen Phase 2 development (which would likely be decommissioned at the same time as the proposed development). Baseline conditions would quickly return following decommissioning.

9.11.5 Mitigation requirements for potential cumulative impacts

9.157 No mitigation is required over and above the Project specific mitigation.

9.12 Proposed Monitoring

9.158 MeyGen propose to deploy at least 1 ADCP with the initial turbines. Data collected will be used to validate the hydrodynamic modelling undertaken to inform the physical environment and sediment dynamics impact assessment. The sediment erosion/deposition and bedload transport results produced during this modelling study are directly dependant on the quality of the hydrodynamic and wave models, so by validating those underlying models, the morphology results will be partially validated by proxy.

9.13 Summary and Conclusions

9.159 An assessment has been carried out of the likely effects of the proposed Project on the physical environment and sediment morphology. The assessment has considered construction and installation, operations and maintenance, and decommissioning of the Project.

9.160 The potential effects on the physical environment and coastal processes that have been considered are:

- Change in bed morphology from drill cuttings;
- Displacement of sediment resulting in alteration or loss of bedform;
- Change in water quality;
- Change in hydrodynamic regime;
- Change in wave regime;
- Change in sediment dynamics; and
- Erosion of the coastline.

9.161 The mobility of the seabed is dependant on the local current and wave conditions, and the local sediment characteristics. The strong tidal currents are thought to be the main cause for the sedimentary features in the Inner Sound, the fast currents scouring any mobile sediment from the central channel, and tending to deposit it where the current speeds naturally decrease.

9.162 The installation of up to an 86 turbine array is not expected to disturb the hydrodynamics significantly enough to change any of the existing processes. The region of highest flow within the Inner Sound may be separated north and south of the tidal array and there will be a small net decrease of current speed over the array. Likewise, there may be local changes to the regions of higher waves, but they are likely to be negligible in the context of the existing high energy environment.

9.163 The study found that none of the scenarios are likely to have a significant impact on the physical environment or sediment morphology, so no mitigation is required.

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