Chapter 8 Geology and Water Quality

8.1 Introduction

1 This chapter describes the regional and site-specific physical environment, as well as the characteristics of the proposed Neart na Gaoithe offshore wind farm and cable route. The physical environment encompasses the bathymetry, geology and water/sediment quality. Specifically, this chapter includes:

- The bathymetry of the seabed in the region and within the proposed offshore wind farm and cable route;
- A description of the geology and geomorphology of the region and within the offshore site and cable route, including the nearby coast;
- Characteristics of the seabed sediments in the region and within the offshore site and cable route, identified by sidescan sonar, shallow seismic, vibrocores, seabed grab samples and video data;
- Details of notable features and potential obstructions on the seabed within the offshore site and cable route;
- An assessment of seabed mobility and sediment transport pathways within the region, offshore site and cable route, and nearby coast, based on previous studies, direct observations and an analysis of bedforms; and
- A description of the current sediment and water quality, including the water quality status of nearby bathing waters, shellfish waters and water bodies designated under the Scotland River Basin Management Plan (Scotland RBMP).

8.2 Guidance and Legislation

8.2.1 Bathymetry

2 There is no specific guidance for undertaking an assessment of bathymetry for wind farm developments; however, in accordance with the Marine Guidance Note (MGN) 371, 'Offshore Renewable Energy Installations (OREIs) - Guidance on UK Navigational Practice, Safety and Emergency Response Issues' (MCA, 2008) the swath bathymetry data have been collected to comply with the International Hydrographic Organisation (IHO) Order 1 standard multibeam bathymetry requirements (IHO, 2008).

8.2.2 Geology

3 There is no specific guidance and legislation for undertaking an assessment of the geology for wind farm developments. There are, however, key considerations that have been incorporated into this assessment methodology, including:

- Consultation with Scottish Natural Heritage (SNH);
- The need to review and incorporate geophysical, geotechnical and benthic ecology survey results into the baseline to inform the assessment. This will also enable the design of appropriate construction techniques to minimise any adverse effects; and
- The need to predict the physical effects that will result from the construction and operation of the wind farm. These include effects (e.g., scouring) that may result from the proposed development; all potential physical effects will be incorporated into the methodology for assessment.

8.2.3 Water Quality

4 Directive 2000/60/EC establishes a framework for community action in the field of water policy (Water Framework Directive) and requires all member states to achieve good ecological and chemical status of their water bodies (including coastal waters up to 1 nautical mile (NM) offshore) by 2015. The Water Framework Directive is implemented by the Water Environment and Water Services (Scotland) Act 2003 in Scotland.

5 The Water Framework Directive requires member states to establish river basin districts and to create a river basin management plan for each district. The Scotland RBMP was produced as a requirement of the Water Framework Directive. The competent authorities for the Scotland River Basin District are Scottish Ministers and Scottish Environment Protection Agency (SEPA). The Scotland RBMP divides Scottish surface waters into over 3,000 water bodies, each of which is classified according to its status. In 2008, 65% of these water bodies were of good status or better.

6 Directive 2006/7/EC concerning the management of bathing water quality (Bathing Water Directive) contains provisions aimed at preserving, protecting and improving the quality of the environment and protecting human health. The Bathing Water Directive requires member states to identify all bathing waters, define the length of the bathing season and to monitor bathing waters during the specified season.

7 The Bathing Water Directive is transposed into domestic law by the Bathing Water (Scotland) Regulations 2008. Under the Bathing Water (Scotland) Regulations 2008 the Scottish Government can designate an area of surface water as a bathing water if:

- They expect a large number of people to bathe there, with regard to past trends and infrastructure or facilities provided, or other measures taken to promote bathing; and
- Permanent advice against bathing there has not been introduced.

8 Under the Bathing Water (Scotland) Regulations 2008 bathing waters must meet water quality standards in order to protect the health of bathers. Further details of the monitoring standards are given in Section 8.9.

9 Directive 2006/113/EC on the quality required of shellfish waters (Shellfish Waters Directive) sets quality standards for water in which shellfish live and grow in order to contribute to the high quality of edible shellfish products. The Shellfish Waters Directive requires monitoring of shellfish waters to ensure that specified quality standards are met. This is transposed into Scottish law by the Surface Waters (Shellfish) (Classification) (Scotland) Regulations 1997. The parameters and the specified levels set out in the legislation are given in Appendix 8.1: Shellfish and Bathing Water Quality Information. The Shellfish Waters Directive is due to be repealed by the Water Framework Directive in 2013; the new legislation must provide at least the same level of protection for shellfish waters.

10 In addition to the Shellfish Waters Directive, Regulation 854/2004/EC laying down specific rules for the organisation of official controls on products of animal origin intended for human consumption (Hygiene Regulation) defines controls for the classification of shellfish harvesting areas. The Hygiene Regulation has direct effect and is therefore applicable in domestic law without the need for any transposing legislation.

11 Directive 2008/56/EC establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive) aims to achieve good environmental status in the marine environment by 2020. It requires member states to develop and implement national strategies to manage their seas in order to achieve or maintain good environmental status.

12 The United Kingdom (UK) is a signatory to the International Convention for the Prevention of Pollution from Ships (MARPOL Convention). Regardless of where they sail, ships flagged under signatory countries must adhere to the requirements of the Convention. Regulations included in the Convention are aimed at preventing and minimising accidental pollution from ships as well as pollution from vessels carrying out routine operations.

13 In the absence of quantified UK sediment quality standards, sediment contaminant concentrations are generally compared to two other guidelines: the Cefas guideline action levels for the disposal of dredged material, and the Canadian Interim Sediment Quality Guidelines (ISQG) for the protection of aquatic life, to give a general indication of the level of contamination (WRC Swindon, 1999; PLA, 2012).

14 The Canadian ISQGs have also been used in the assessment of sediment quality given that they have been recommended by the Habitats Directive Water Quality Technical Advisory Group (WQTAG) in order to protect Natura 2000 sites (Environment Agency, 2004).

8.3 Data Sources

15 Data used to inform the physical chapter are derived from two principle sources:

- Desk study (Section 8.3.1); and
- Site specific surveys (Section 8.3.2).

8.3.1 Desk Study

16 Physical environmental data were available for different areas, at various resolutions, and covering different time periods. Data drawn from the desk study were used to:

- Provide a wider regional physical context for the current assessment; and
- To identify data gaps to inform the site specific surveys.

17 A number of resources were used to gain knowledge of the area including:

- Maps and charts;
- Technical reports;
- Journals; and
- Online databases and resources.

18 The relevant sources used in the current desk study are presented in Tables 8.1 and 8.2.

Water Quality	
Reports	Digital Data
Scottish Environment Protection Agency (SEPA, 2011a, 2011b) **Scotland River Basin Management Plan (SEPA, 2009)**	International Council for the Exploration of the Sea (ICES, 2009) Scottish Government (2011a)

Table 8.1: List of key water quality studies and data sources for the Firth of Forth region

Bathymetry	
Maps and Charts	Digital Data.
Admiralty Chart 190 (UK Hydrographic Office (UKHO))	SeaZone Hydrospatial Data.
Geology	
Reports and Journals	Online.
British Geological Survey (BGS) (1986a) - Sea Bed Sediments	BGS National Geosciences Data Collections (NGDC).
BGS (1986b) - Solid Geology	
BGS (1987) - Quaternary	
Robertson and Miller (1997)	
Gatliff *et al.* (1994)	DECC Strategic Environmental Assessment 5. BGS Borehole information.
Ramsey and Brampton (2000a)	
Bates *et al.* (2003)	
Golledge and Stoker (2006)	
Water Quality	
Reports	Digital Data.
Scottish Environment Protection Agency (SEPA, 2011a, 2011b) **Scotland River Basin Management Plan (SEPA, 2009)**	ICES, 2009; and Scottish Government (2011a).

Table 8.2: List of key bathymetric and geological studies and data sources for the Firth of Forth region

8.3.2 Survey Methodology

19 Two main offshore baseline surveys (geophysical and benthic ecology) were conducted to obtain site-specific information on the distribution and extent of bathymetric and geological (surface and subsurface) characteristics and features within the development area.

8.3.2.1 Geophysical Survey

20 A geophysical survey of the proposed offshore wind farm and two potential export cable routes was conducted in the summer of 2009 (EMU, 2009). The survey comprised the acquisition of swath bathymetry, sidescan sonar, sub-bottom profiling, acoustic ground discrimination system (AGDS) and magnetometer data. For the purposes of this chapter, only the bathymetric, sidescan sonar and seismic systems are discussed as they form the main basis for the physical interpretation of the bathymetry and geology of the proposed offshore wind farm and cable route. A brief summary of each instrument type and survey is provided below.

Bathymetry

21 The specification of the survey was to determine accurate water depths and full seabed coverage across the offshore site and cable route. Data were collected to IHO Order 1 standards (IHO, 2008). Two separate multibeam echosounders were used during the survey and were chosen on the basis of their suitability to the variable water depths within the offshore site and cable route.

Sidescan Sonar

22 The specification of the survey was to identify textural characteristics of seabed sediments and any potential hazards to wind farm construction and development based on acoustic reflectivity of the seabed. Full coverage seabed data were collected across the offshore site and cable route.

Seismic

23 The objectives of the survey were to accurately evaluate the characteristics and thicknesses of the sub-surface geology of the offshore site and cable route, providing critical information for foundation design and cable installation. Two separate seismic systems were used: an ultra-high resolution digital transmitter pinger and a high resolution boomer mounted on a catamaran with an 8-element hydrophone streamer. Survey lines were spaced at 100 m, with 1000 m cross lines, across the offshore site and cable route.

24 Post-processing and interpretation were carried out using Coda Octopus Geosurvey 4.3.0 using a combination of band-pass filters. Geological horizons were identified, digitally picked, exported to a database and subsequently imported into a Geographical Information System (GIS) for contouring and quality control.

8.3.2.2 Geotechnical Survey

25 A survey comprising of vibrocore, cone penetrometer test (CPT) and boreholes was undertaken in 2010. Good correlation was generally found between the geophysical survey results (EMU, 2009) and the geotechnical survey measurements (Gardline, 2010).

8.3.2.3 Benthic Ecology Surveys

26 The benthic ecology survey (see Appendix 14.1: Benthic Ecology Characterisation Survey) included the collection and analysis of seabed grab samples and underwater photographs and video – these data were used to refine the (geological) seabed characterisation of the proposed wind farm and cable route presented in this Chapter. The benthic ecology survey is discussed in Chapter 14: Benthic Ecology and the report is presented in Appendix 14.1: Benthic Ecology Characterisation Survey.

27 For contaminant sampling, a 0.04 m^2 Shipek grab was used to return an undisturbed sediment sample. Samples were then transferred into 50 ml bottles and submitted to a United Kingdom Accreditation Service (UKAS) accredited laboratory for contaminants analysis. The suite of analyses included:

- Metals (As, Cd, Cr, Cu, Pb, Hg, Ni, Zn);
- Poly aromatic hydrocarbons (United States Environment Protection Agency, USEPA 16);
- Poly chlorinated biphenyl's (ICES 7); and
- Organotins (dibutyltin, tributyltin).

8.3.3 Engagement and Commitments

28 There are a number of requirements and commitments made on behalf of the developer as well as recommendations provided in the form of advice through documents such as the Scoping Opinion (see Chapter 7: Engagement and Commitments). In addition to general requirements from statutory consultees and regulators, strategic and site level requirements specific to geology and bathymetry are detailed in Table 8.3 along with cross references to discussion points within this chapter or wider Environmental Statement (ES).

Source	Comment	Cross reference
Blue Seas - Green Energy: A Sectoral Marine Plan for Offshore Wind Energy in Scottish Territorial Waters. Part A: The Plan (Marine Scotland, 2011)	Assessment of the effects on water quality, including shellfish waters, hydrodynamic and water quality modelling is required at the project level.	Refer to Section 8.6.3: Impact Assessment - Water Quality.
Marine Scotland	Specific impacts during construction, operation and decommissioning should be reduced through the selection and use of appropriate methods to reduce pollution risks. For example, through the use of best practice marine construction procedures for prevention and control of spillages and discharges of harmful substances (such as antifouling agents, sacrificial anodes, biocides, grouts etc.) to the marine environment. Also applicable to sediment mobilisation, associated turbidity and their secondary impacts, to avoid unacceptable impacts on marine and benthic fauna.	Refer to Section 8.7: Mitigation and Residual Impacts - prevention and control of spillages and discharges of harmful substances.
	Assessment work is recommended to reduce current uncertainty regarding impacts on coastal processes. Sediment dynamic modelling will be required at the project level.	Refer to Chapter 9: Physical Processes and Appendix 9.1: Physical Processes Technical Report.
	Project design should seek to optimise the location and arrangement of structures and their arrangement to mitigate any issues of erosion or deposition and resulting impacts on sensitive receptors.	Noted. Refer to Section 8.6.1: Impact Assessment – Coastline.
Scoping Opinion (SNH advice)	Advise that the scope of regional work proposed should also consider impacts of rock armouring for cable protection with regard to sediment mobility.	Refer to Chapter 9: Physical Processes and Appendix 9.1: Physical Processes Technical Report.
	An experienced coastal geomorphologist is used to assess cable route and landing site (the route of the cable through the 'wave base' needs careful consideration).	Refer to Section 8.6.1: Impact Assessment – Coastline.
Scoping Opinion (SEPA Advice)	Consultation with SEPA required for water quality issues (e.g., under Electricity Act 1989, Water Environment (Controlled Activities) (Scotland) Regulations 2005 (now the Water Environment (Controlled Activities) (Scotland) Regulations 2011)).	Refer to Section 8.3.1: Desk Study.
	Baseline assessments should consider the natural variability in background parameters with regards to normal and extreme conditions, e.g., suspended solids.	Refer to Chapter 9: Physical Processes and Appendix 9.1: Physical Processes Technical Report.
	ES should demonstrate Water Framework Directive objectives are not compromised: developments must be designed wherever possible to avoid engineering activities in the water environment (burns, rivers, lochs, reservoirs, wetlands and groundwater). A flood risk assessment is required if developments are likely to exacerbate flood risk (consult SEPA).	Refer to onshore ES and Section 8.6.3: Impact Assessment - Water Quality.
	ES should show areas of seabed affected by cabling/shore development including intertidal zone. Also consider existing coastal developments (e.g., use concept of system capacity to measure impacts to morphological conditions). Cumulative regional impacts need assessing.	Refer to Chapter 9: Physical Processes and Appendix 9.1: Physical Processes Technical Report. Refer to Chapter 14: Benthic Ecology.
	Guidance documents to be consulted: 'A Review of the Sources and Scope of Data on Characteristics of Scottish Waters. An Assessment of the Adequacy of the Data and Identification of Gaps in Knowledge' (Robertson and Davies, 2009) and 'A Framework for Marine and Estuarine Model Specification in the UK' (Foundation for Water Research, 1993).	Refer to Section 8.3: Data Sources and Chapter 9: Physical Processes and Appendix 9.1: Physical Processes Technical Report.
Scoping Opinion (Royal Society for the Protection of Birds (RSPB))	Increased disturbance due to construction work and changes in the pattern of sediment transportation and deposition need to be addressed.	Refer to Chapter 9: Physical Processes and Appendix 9.1: Physical Processes Technical Report, and Section 8.6: Impact Assessment.
Advice to Forth and Tay Offshore Wind Developer Group (FTOWDG) (SNH)	Advise that the scope of regional work proposed should also consider impacts of rock armouring for cable protection with regard to sediment mobility.	Refer to Chapter 9: Physical Processes and Appendix 9.1: Physical Processes Technical Report, and Section 8.6: Impact Assessment.

Table 8.3: Strategic and site level commitments and requirements – physical environment

8.4 Impact Assessment Methodology

29 The assessment followed in this chapter mirrors that described in Chapter 6: The Approach to Environmental Impact Assessment. Since there are no sandbanks or significant bedforms (receptors) in the vicinity of the offshore site or the cable route, these receptors have been screened out of the assessment as there are no impacts. The receptors considered in the impact assessment are the coastline and water quality.

8.4.1 Rochdale Envelope

30 The impacts assessed in this chapter were based on the outputs of the hydrodynamic modelling undertaken as part of this Environmental Impact Assessment (EIA) (see Chapter 9: Physical Processes). As described in Chapter 9: Physical Processes, the parameters used for the models represent a realistic 'high-impact' scenario, based on the information available at the time of assessment (May 2011) and therefore differ from the finalised Rochdale Envelope (refer to Chapter 5: Project Description). A comparison of the modelled and Rochdale Envelope parameters is given in Chapter 9: Physical Processes. The modelled parameters are in line with the finalised Rochdale Envelope, and the predicted impacts reflect a reasonable 'high impact' scenario.

8.5 Baseline Description

8.5.1 Introduction

31 This section presents baseline information on the regional and site-specific physical characteristics of the proposed offshore Neart na Gaoithe wind farm site and cable route. The results are based on a combination of desk-based and site-specific marine surveys (as discussed in Section 8.3). Specific information in this section, divided into regional, offshore site and cable route, includes:

- The bathymetry and general morphology of the seabed;
- Textural characteristics and distribution of the seabed sediments;
- Details of notable features and potential development obstructions on the seabed;
- An assessment of seabed mobility and sediment transport pathways;
- A description of the subsurface geology;
- A characterisation of the nearby coast with respect to its geology, sediment transport and coastal protection measures; and
- Water/sediment quality is discussed in Section 8.6.3 and Appendix 8.1: Shellfish and Bathing Water Quality Information.

8.5.2 Bathymetry

8.5.2.1 Regional Bathymetry

32 In general, the bathymetry of the central North Sea (which extends from approximately Newcastle to Aberdeen) is relatively uniform, with localised bathymetric deeps and topographic highs, which are mostly present outwith the region (refer to Figure 8.1 and Figure 8.2). A number of depressions are present in the region, including Farn Deeps (approximately 100 km to the southeast), the Witch Ground Basin (approximately 180 km to the north) and Devils Hole (160 km to the east), where water depths can exceed 150 m. There is also a series of relatively large bathymetric highs or banks, including the Marr Bank, located offshore and north of the offshore site (refer to Figure 8.1); Aberdeen Bank, located in the north and East Bank in the south.

33 The geophysical survey used Chart Datum (CD) as the reference point. In the Firth of Forth area, CD is approximately the same as lowest astronomical tide (LAT), the reference datum used throughout this ES.

34 The seabed directly opposite Fife Ness headland has the steepest gradients within the Firth of Forth region, reaching depths of 40 m within 8 km of the coast. The offshore site (the area within the purple boundary in Figure 8.1), where depths are in the region of 40-57 m, is located between two slightly elevated regions. The bathymetrically high region to the east of the proposed offshore wind farm is known as the Wee Bankie (refer to Figures 8.1 and 8.2). Water depths south of the offshore site are greater, reaching up to 70 m depths. The coastal and nearshore gradients from Thorntonloch to Fife Ness are relatively consistent, with the 20 m depth contour located 2-3 km from the coast. A series of elongated ridges, which cross the proposed cable route, are also located in the south of the region. These are described in more detail in Section 8.5.2.3.

8.5.2.2 Offshore Site

35 In general, the seabed of the offshore site (the area within the purple line boundary shown on Figure 8.1) can be broadly described as hummocky (refer to Figure 8.2). Multibeam bathymetry data indicate that depths within the proposed offshore wind farm range from approximately 40 to 58 m below LAT, with a mean of 50.6 m. The shallowest water is located in the southern half of the proposed wind farm site, along a linear ridge, orientated northwest to southeast, which rises approximately 2 m above the surrounding seabed to 40.5 m. The deepest water (57.5 m below LAT) occurs in the west of the site, close to the boundary, within a channel orientated northwest-southeast. To the southwest of this, the seabed shelves into deeper water (60.4 m) outside of the wind farm site, within a north-south trending trough.

36 Over 25 high relief 'mounds' have been identified within the survey area, most of which are located within the proposed wind farm boundary. These moderately rounded seabed features are approximately 1.0 km in diameter and are often up to 6 m shallower than the surrounding seabed; these are predominantly located in water depths of 40 to 48 m (refer to Figure 8.2). The surfaces of these features are irregular, mostly due to the presence of boulders and localised scour. They become less prevalent in the north of the offshore site.

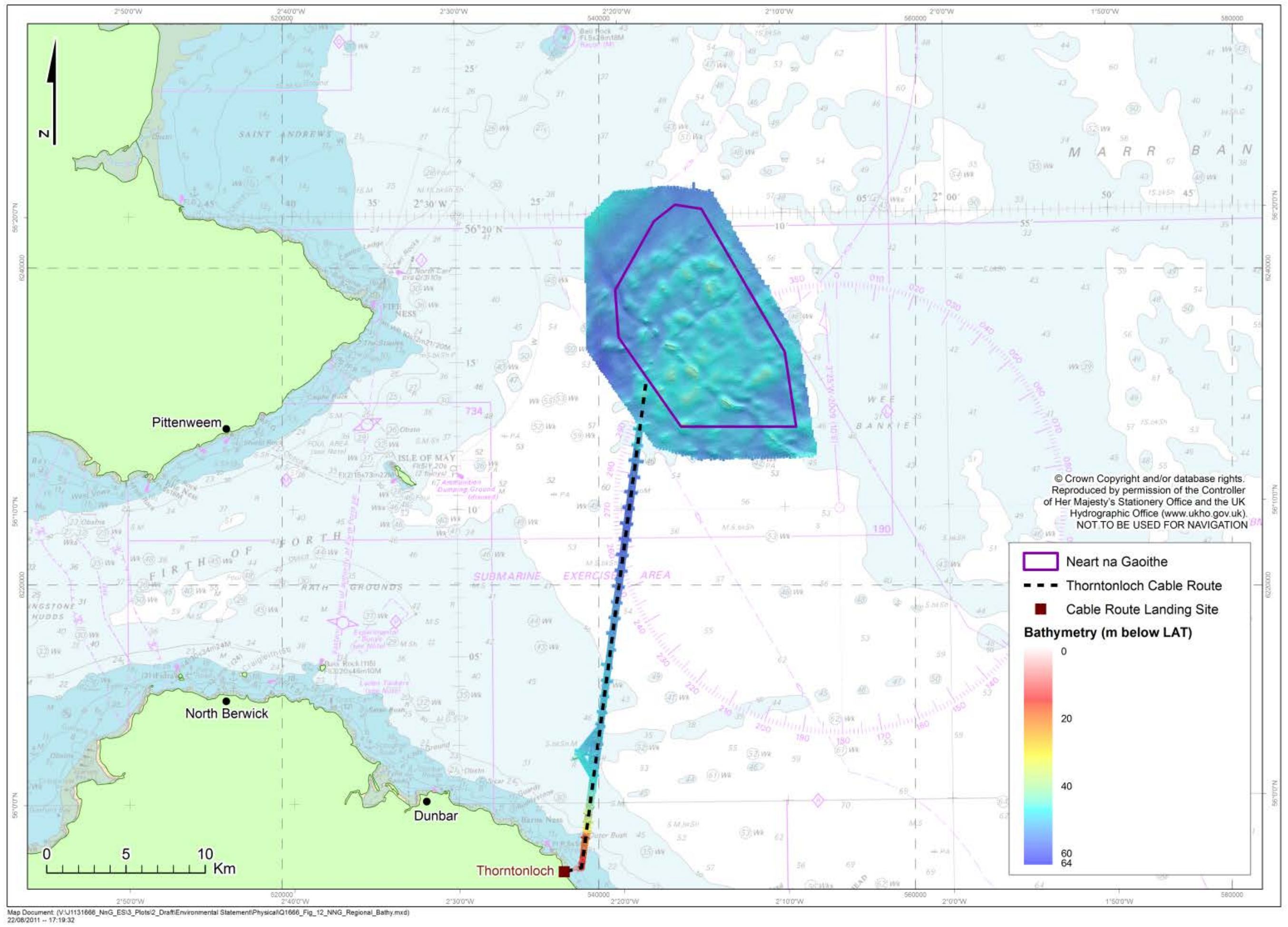

Figure 8.1: Regional bathymetry of proposed wind farm site and cable route. Source: UKHO Admiralty Chart 190

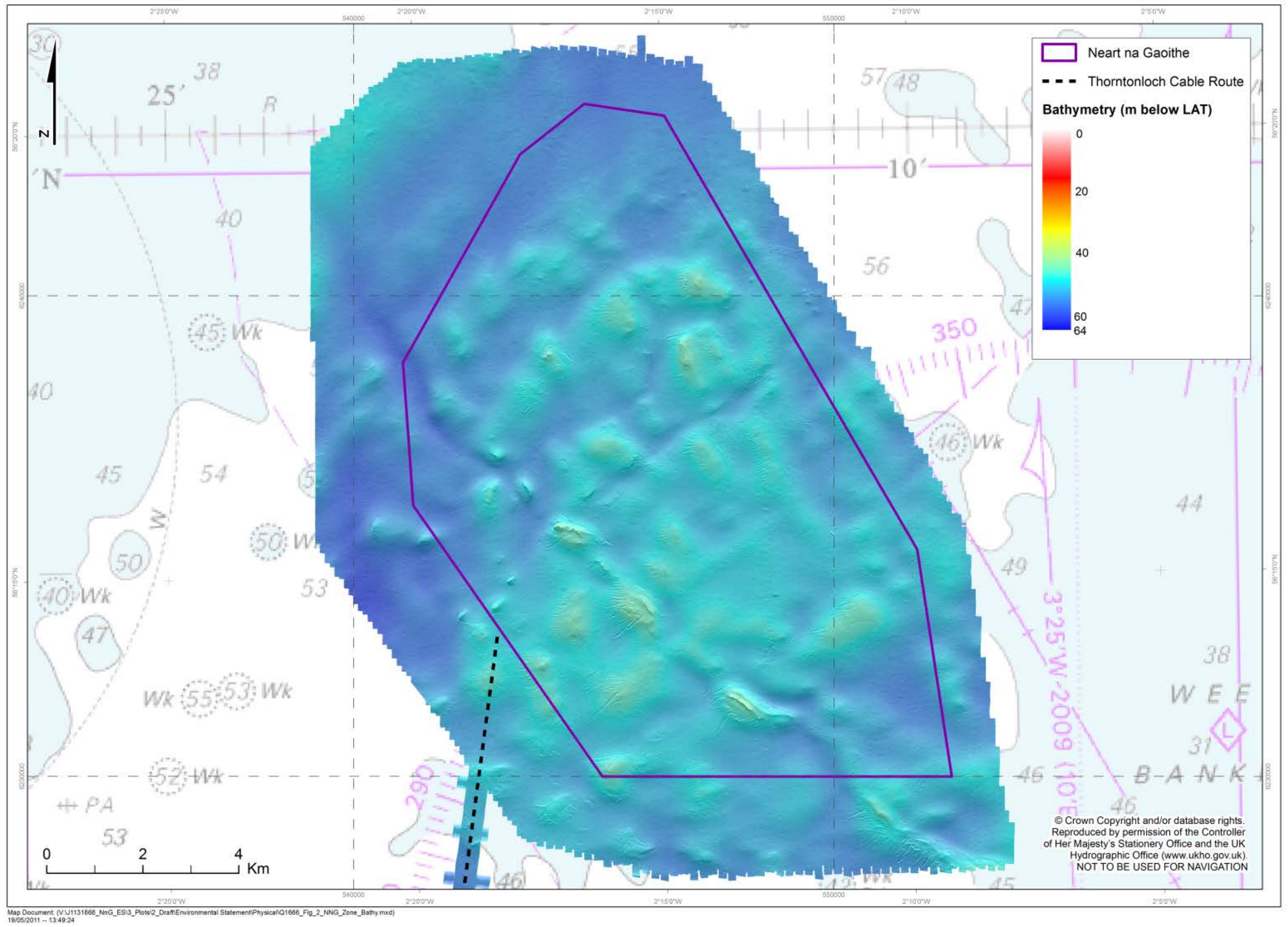

Figure 8.2: High resolution swath bathymetry of proposed Neart na Gaoithe wind farm and vicinity. Source: EMU, 2009

8.5.2.3 Cable Route

37 Surveyed depths along the proposed Thorntonloch cable route range from 12 to 58 m below LAT (refer to Figure 8.3). The shallowest depths are located at the coastal landing site. The nearshore section of the cable route, from 0 to 2.2 km (0 km marking the start of the surveyed cable route and increasing towards the main site), is also highly irregular due to the presence of exposed folded bedrock that comprises the seabed here (refer to Figure 8.4). Northward of the sloping shoreface, between 2.2 and 7.2 km the seabed gradient decreases and is generally flat and featureless, especially where soft-sediment makes up the seabed surface.

38 Linear ridges, comprising east-west outcropping igneous dykes, are notable from 7.2 km to 8.5 km in 45 m to 50 m depths. These relict volcanic features rise up to 3 m above the surrounding seabed. From 8.5 km to 25.7 km the seabed deepens gradually from approximately 50 m to 60 m. From approximately 25 km northward along the Thorntonloch cable route to the offshore site, the bathymetry shallows to 46 m below LAT.

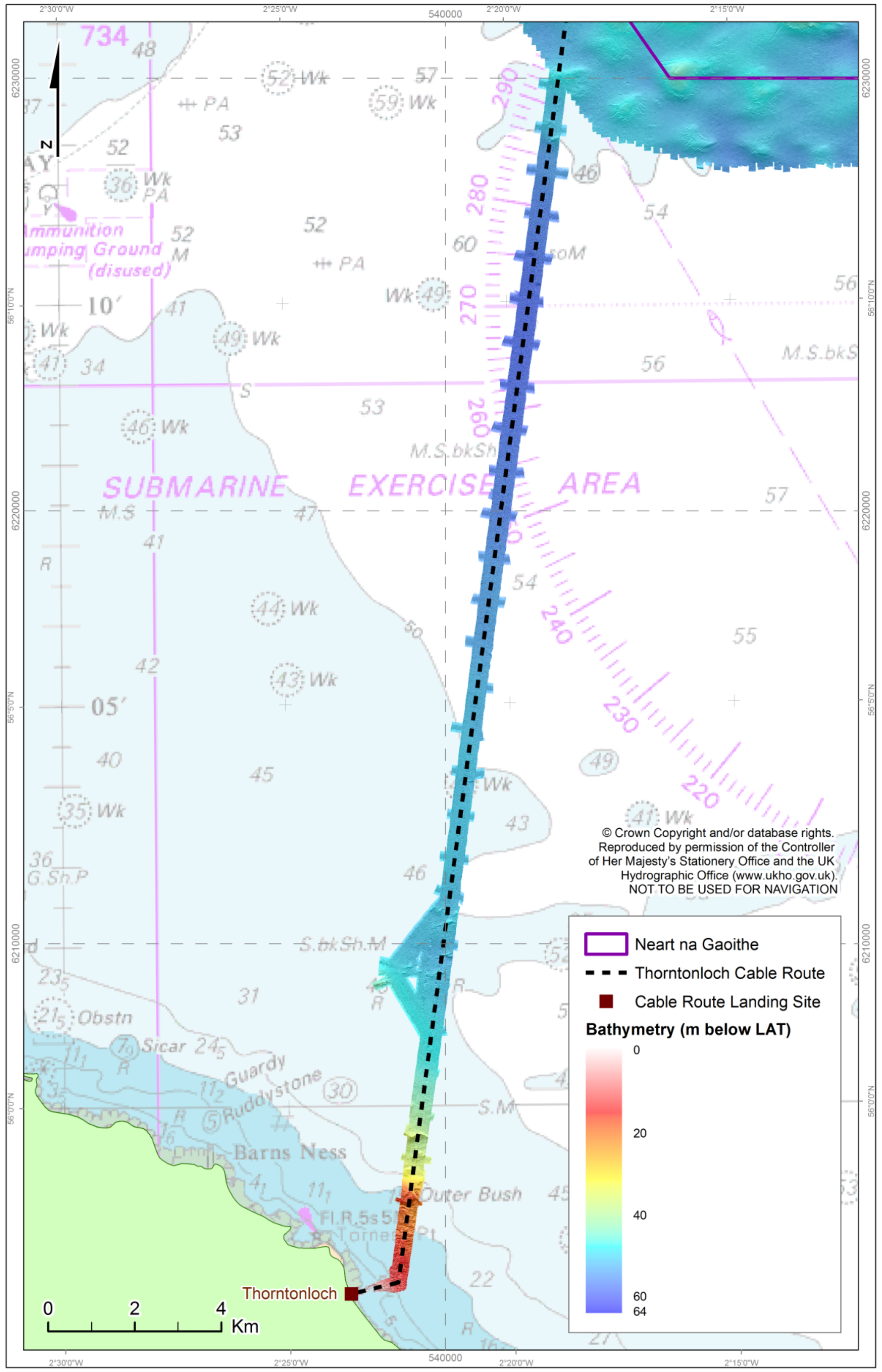

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Figure 8.3: Bathymetry along proposed Thorntonloch cable route. Source: EMU, 2009

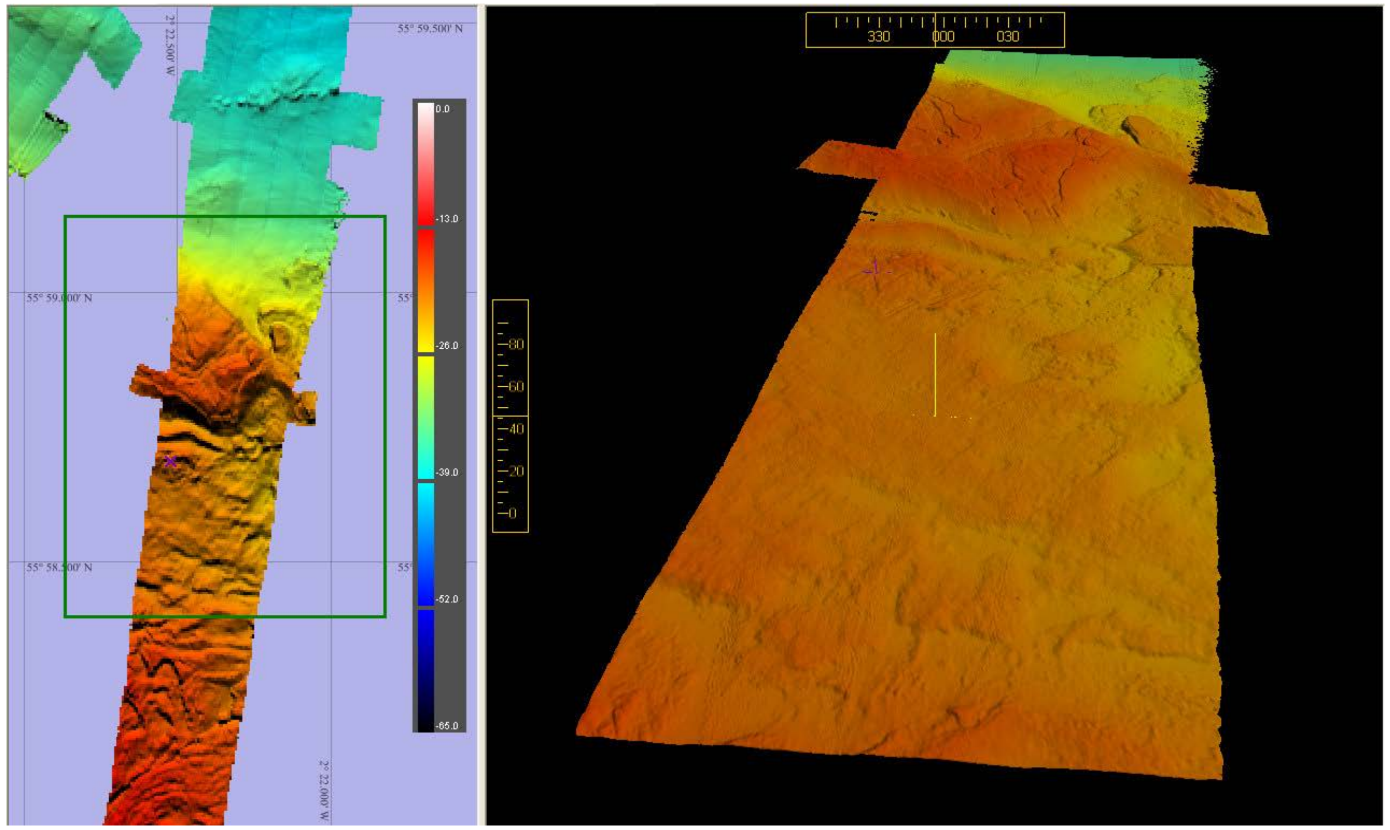

Figure 8.4: Nearshore swath bathymetry data illustrating the outcropping folded bedrock near the proposed Thorntonloch cable route landing site. Source: EMU, 2009

8.5.3 Seabed Sediments and Characterisation

8.5.3.1 Regional

39 A regional seabed sediment map (refer to Figure 8.5), based on SeaZone data, indicates that the seabed comprises a wide range of sediment types, including sand, muddy sand (especially near estuary mouths and deeps) and gravelly sand (particularly along bathymetric highs). Rock is prevalent along the coast and along the localised igneous dykes in the south, offshore of Dunbar and within the Firth of Forth.

40 Large bedforms, for example large sandwaves, are not common in the area and, where present, they are typically either megaripples or sinuous to linear sand waves (BGS, 1986a)

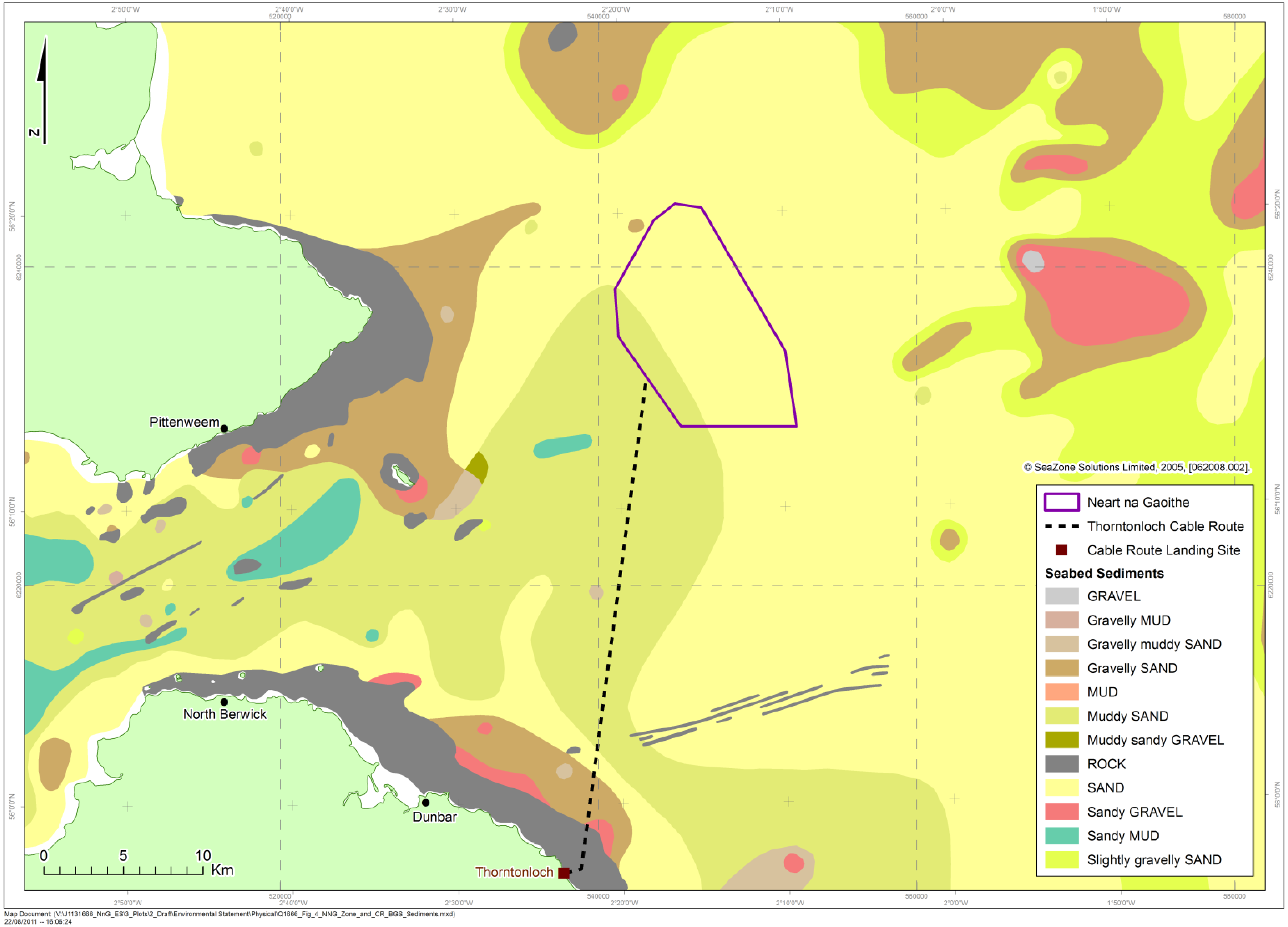

Figure 8.5: Regional seabed sediment distribution of proposed wind farm and cable route. Source: EMU, 2009

8.5.3.2 Offshore Site

41 A characterisation of seabed sediments and dominant morphological features in the vicinity of, and within, the proposed Neart na Gaoithe wind farm has been generated by analysing several marine datasets, described in Section 8.3.

42 Figure 8.6 shows the spatial distribution and textural characteristics of the seabed grab samples within the offshore site, overlain on a high-resolution sidescan sonar mosaic (EMU, 2009). In general, the seabed of the proposed wind farm comprises three main sedimentary types: muddy sand, fine to very fine sand and gravelly sand (refer to Figure 8.7). Other smaller and localised areas of the seabed include muddy sandy gravel, slightly gravelly sand and sandy gravel. Representative seabed sediment photographs are shown in Figure 8.8.

43 Additional seabed types which are identifiable within the offshore site include muddy sand and (exposed underlying) rock. Other seabed features include areas of boulders, which are often present on and around the high-relief Wee Bankie mounds. Although boulders were not captured via grab sampling (due to their size), they were identified in sidescan sonar and seabed video transects (Appendix 14.1: Benthic Ecological Characterisation Survey). No major bedforms were identified within the bathymetry or sidescan data.

44 In general, the coarse sandy gravels and gravelly sands are directly associated with the Wee Bankie Formation, occurring as acoustically dark areas in the sidescan sonar and as areas of higher relief in the bathymetry (refer to Figure 8.2 and Figure 8.6). In contrast, the muddy sand and sandy areas of seabed are typically flat and featureless. Some localised areas of bedrock have also been identified in the sidescan and seismic data; these are mostly located in the north and west of the site (refer to Figure 8.9).

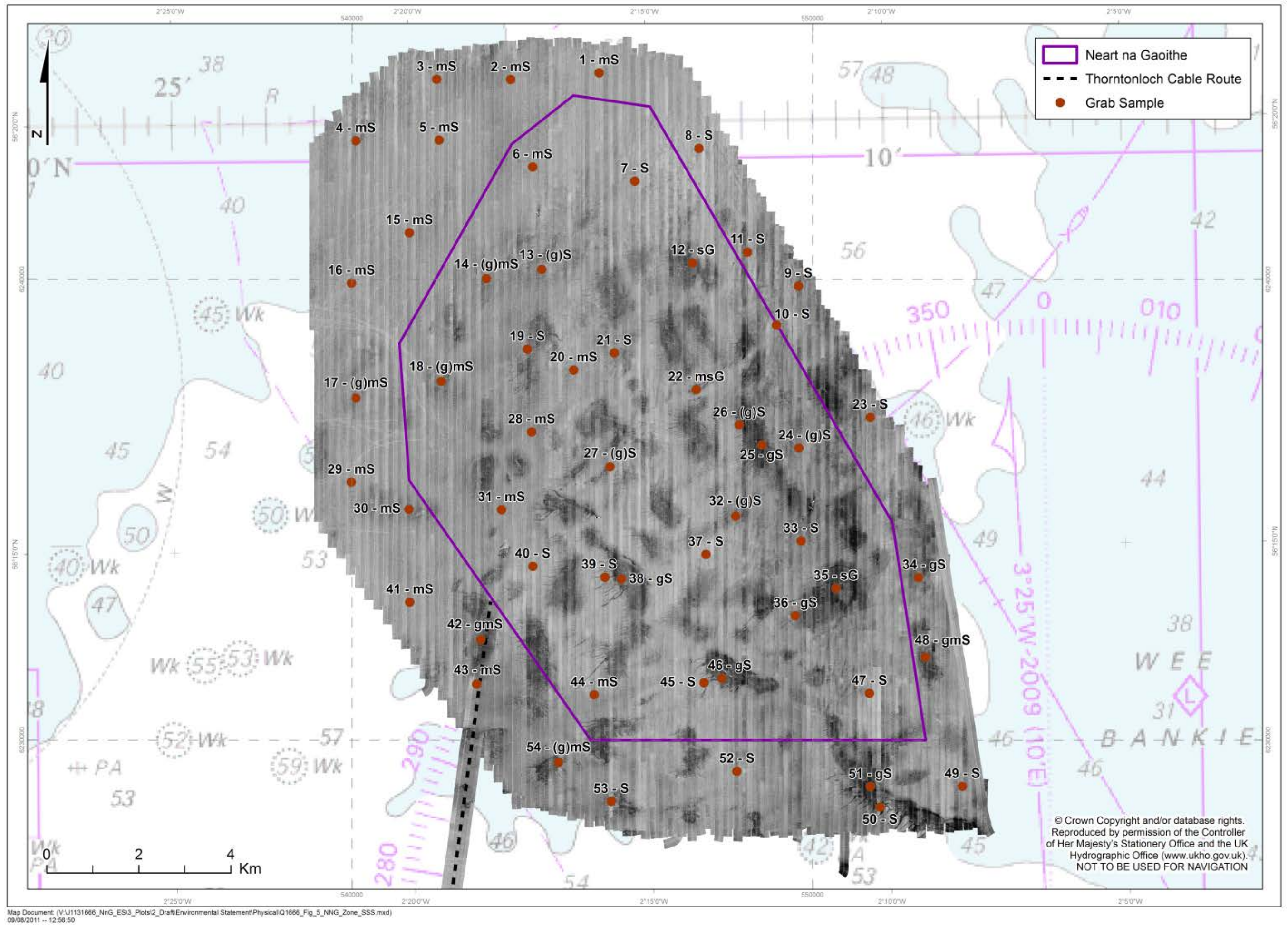

Figure 8.6: Distribution and classification of surface sediment samples (based on BGS modified Folk, 1954) overlain on sidescan sonar mosaic from 2009. Sources: Sidescan sonar mosaic (EMU, 2009); Grab sample data (Appendix 14.1: Benthic Ecological Characterisation Survey)

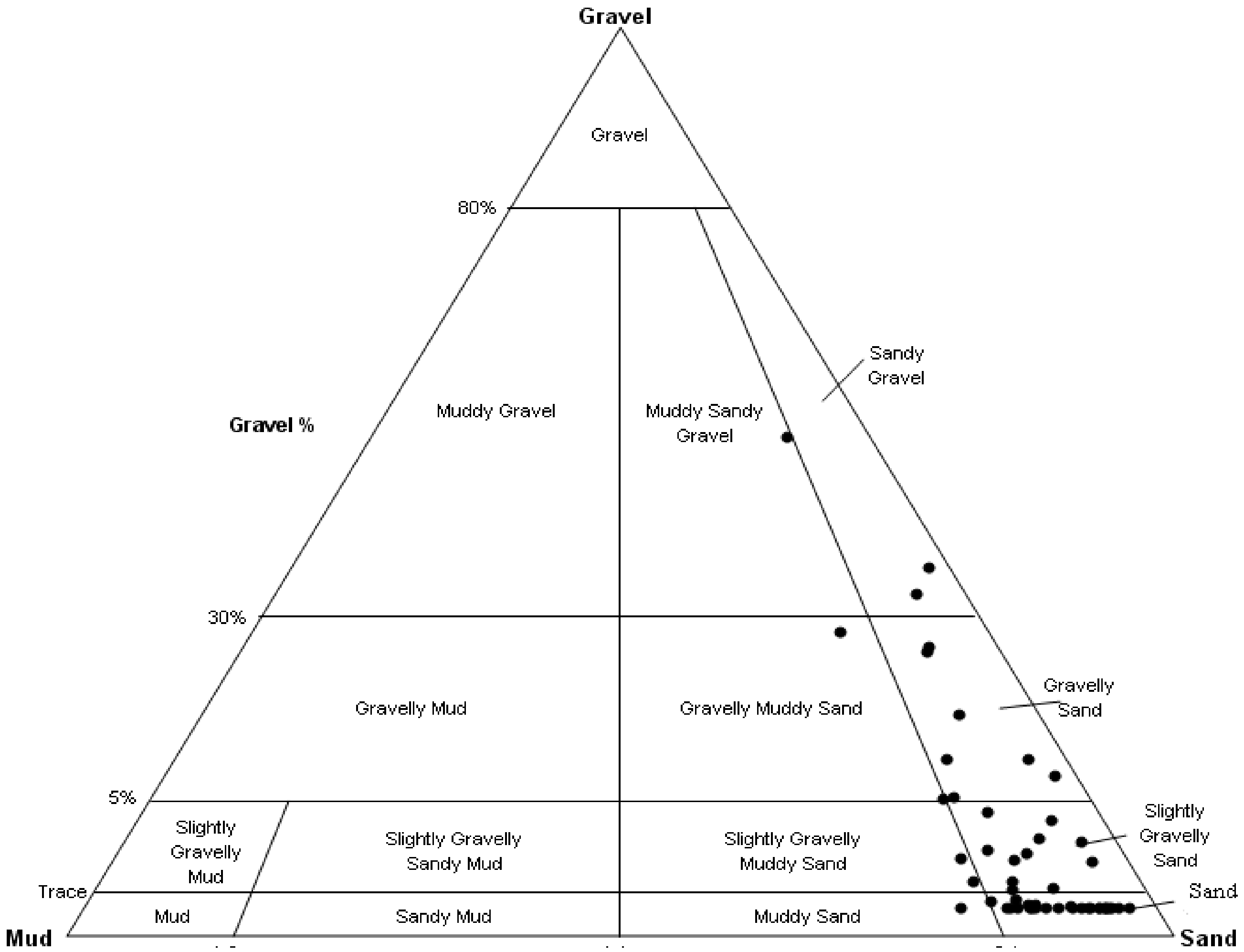

Figure 8.7: Textural (gravel-sand-mud) distribution of 54 seabed samples from the proposed offshore site. Classification is based on BGS modified Folk (1954). Source: Appendix 14.1: Benthic Ecological Characterisation Survey

Figure 8.8: Representative seabed sediment photographs. (Left) – Sandy gravel and boulders from areas of Wee Bankie, sample no. 35; (Middle) - fine to very fine sand, sample no. 33; and (Right) - Muddy sand, sample no. 31. Note: the difference between fine/very fine sand and muddy sand is difficult to distinguish visually. Source: Appendix 14.1: Benthic Ecological Characterisation Survey

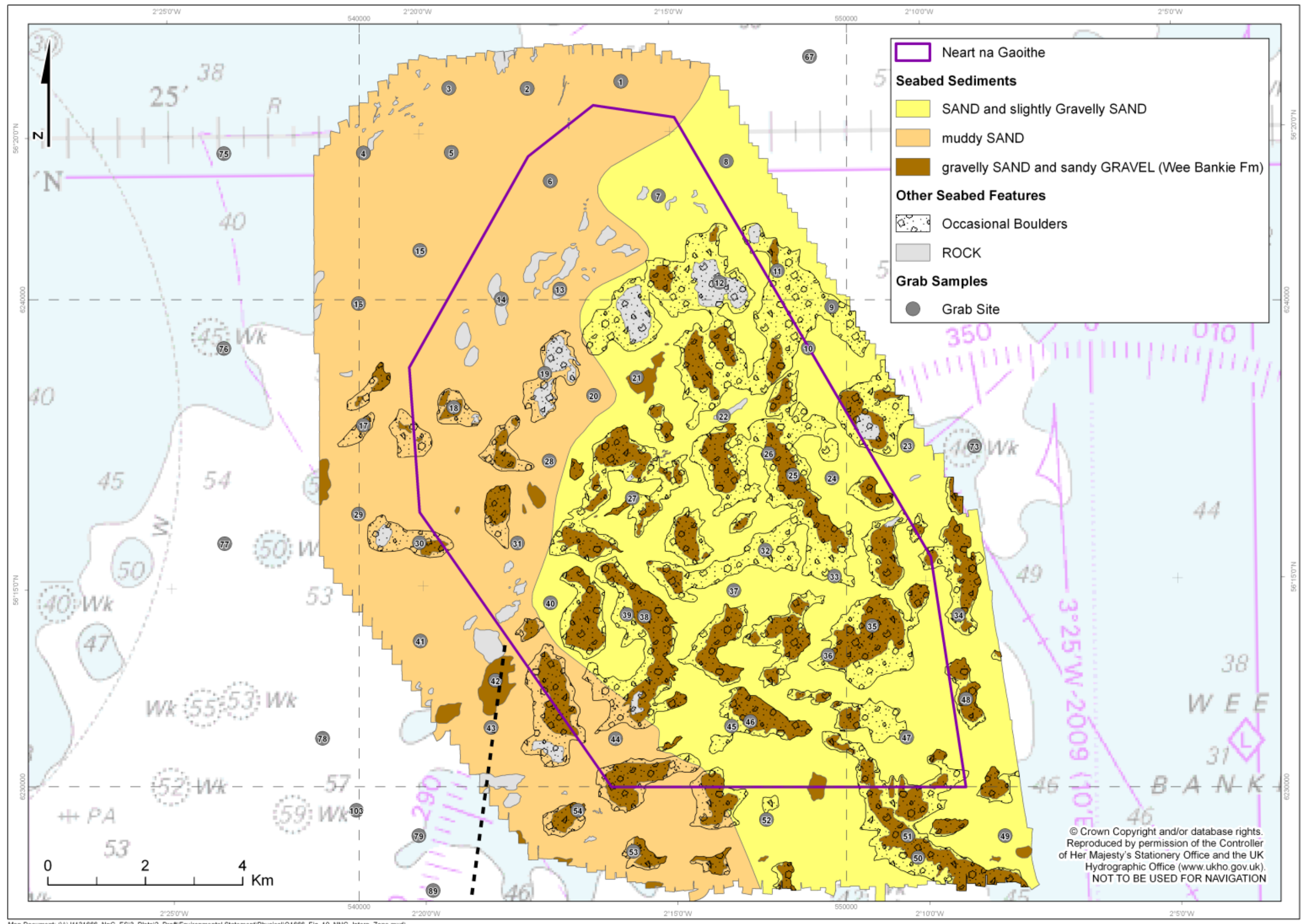

Figure 8.9: Interpreted seabed characterisation based on sidescan sonar, swath bathymetry and grab sample data Source: Appendix 14.1: Benthic Ecological Characterisation Survey and EMU, 2009

8.5.3.3 Cable Route

45 Figure 8.10 shows the spatial distribution and textural characteristics of the 12 cable route seabed grab samples overlain on a high-resolution sidescan sonar mosaic (EMU, 2009). In general, the surface of the cable route can be divided into two dominant types: muddy sand (refer to Figure 8.11, ratio of gravel, sand and mud composition), and rock outcrops (refer to Figure 8.10). One sample (no. 96), comprising muddy sandy gravel, was located near rock outcrops associated with the igneous dykes.

46 The majority of the proposed cable route, from the wind farm boundary and extending towards the coast, comprises muddy sand (refer to Figure 8.10). This is abruptly interrupted by the exposure of a series of igneous dykes (identified where additional sidescan sonar data have been collected) which traverse the cable route. The sediments overlying the dykes either form a thin veneer or are entirely absent. Landward of the dykes, the surface sediment type reverts to muddy sand before thinning out and transitioning to bedrock, which extends all the way to the coast.

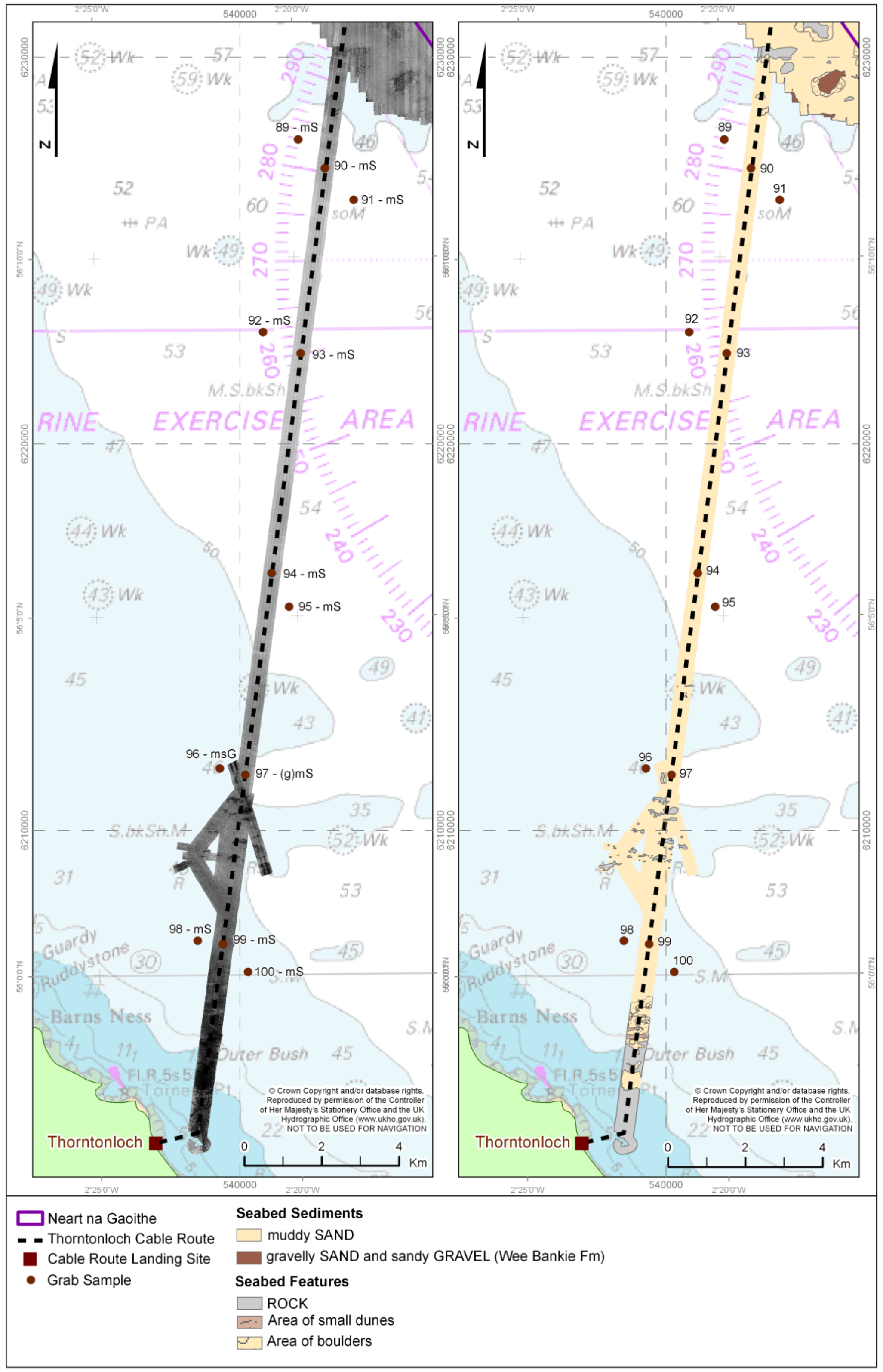

Figure 8.10: Sidescan sonar mosaic overlain with seabed grab samples (left) and seabed characterisation (right) of proposed cable route. Source: EMU, 2009 and Appendix 14.1: Benthic Ecological Characterisation Survey

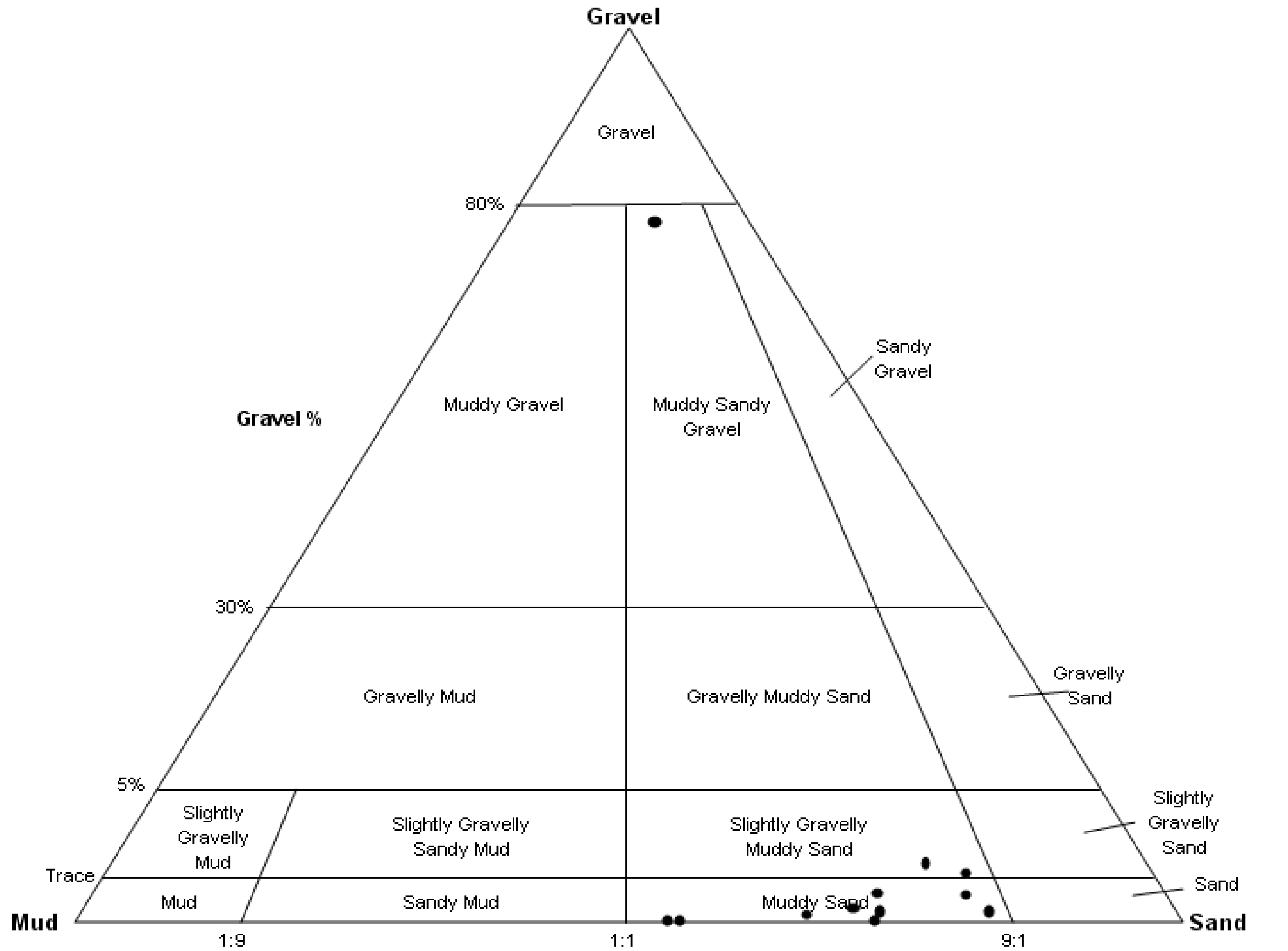

Figure 8.11: Gravel-sand-mud triplot illustrating the muddy sandy surface of the 12 grab samples collected along proposed cable route. Rock outcrops are not included within this classification. Source: Appendix 14.1: Benthic Ecological Characterisation Survey

8.5.4 Sediment Transport

8.5.4.1 Regional Sediment Transport

47 Sediment transport is limited across much of the central and eastern North Sea, due to lower tidal current speeds in deep (greater than 30 m) water; sediment mobility is only predicted to take place in these regions under storm conditions (Gatliff *et al*., 1994). This is confirmed by a lack of significant bedforms in the region. Most of the large-scale bedform fields are found near Aberdeen Bank, approximately 115 km to the northeast, and East Bank Ridges, approximately 200 km to the southeast, where a series of relict[1] tidal sand ridges, orientated southwest to northeast, have been identified (Gatliff *et al*., 1994). No clear asymmetry or associated superimposed sand dunes are evident on the sand ridges, suggesting these large-scale bedforms are likely to be moribund (Kenyon and Cooper, 2005), except possibly under high-energy storm conditions.

48 The predominant drivers of sediment transport in the region are tidal currents, especially along the coast and within the sheltered estuaries. Occasionally, wave-driven storm events are capable of suspending and eroding sediments up to medium-size sand in the open shelf opposite the estuaries (BGS, 1986a). Localised changes in seabed currents are also affected by morphological features of submarine banks (Owens, 1981).

[1]Relict features are those that have been formed under previous conditions; they are therefore no longer dynamic.

49 Sediment transport directions are typically parallel to the coast and towards the north (refer to Figure 8.12), in line with regional tidal currents (Kenyon and Cooper, 2005; Gatliff *et al.*, 1994; BGS, 1986a). Some sediment transport takes place from the northeast into the Firth of Forth, with some localised east to west wave-induced transport along the north coast of the Firth of Forth (HR Wallingford, 1998; Gatliff *et al.*, 1994). Two bedload parting zones, where coarse sands and gravels comprise much of the seabed, have been identified: one directly offshore of Fife Ness (approximately half way to the proposed Neart na Gaoithe wind farm, and the other offshore of St Abbs Head (refer to Figure 8.12)).

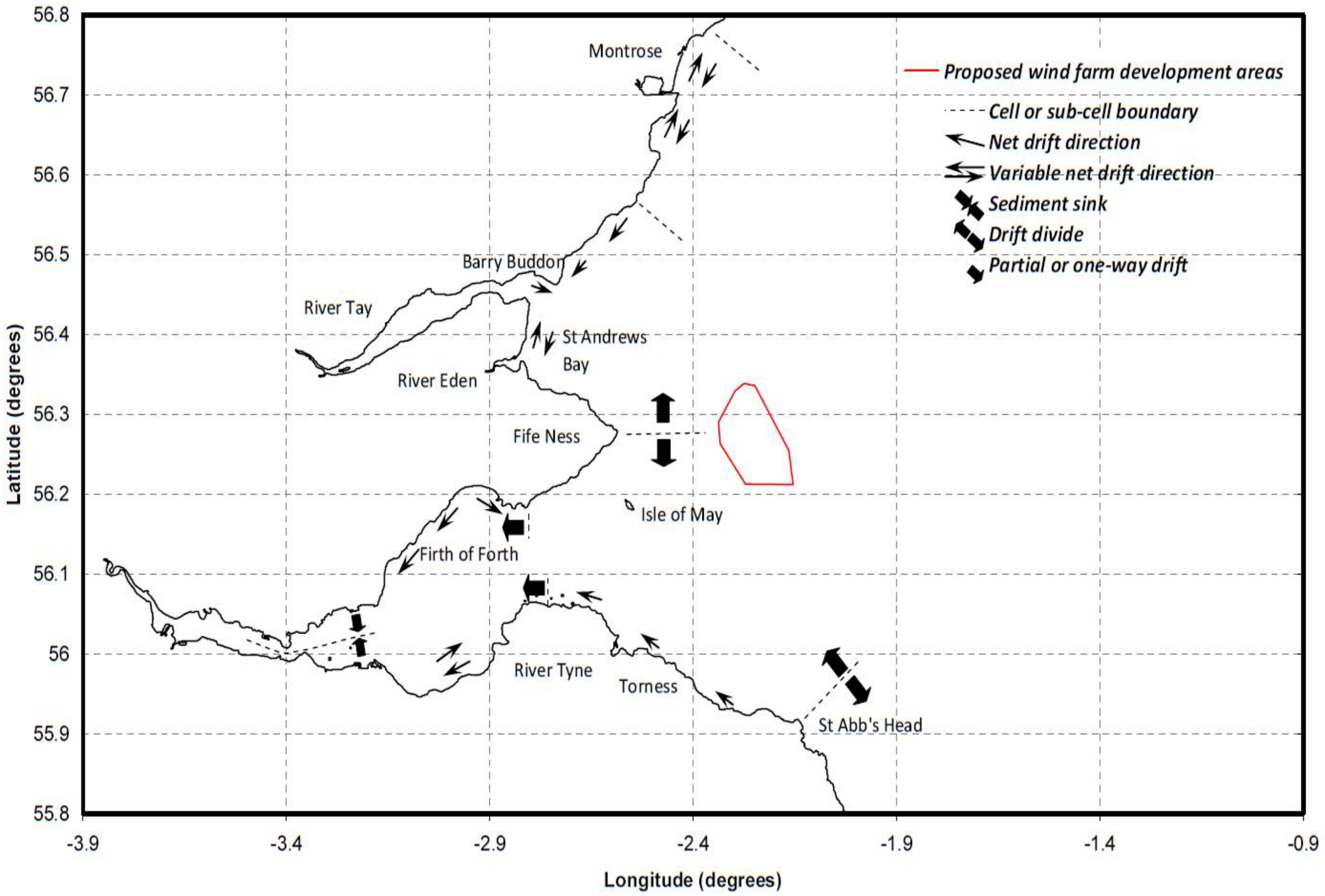

Figure 8.12: Schematic of coastal sediment transport pathways. Source: HR Wallingford, 1998

8.5.4.2 Offshore Site

50 An examination of high-resolution bathymetric and sidescan sonar data within the proposed wind farm area (EMU, 2009) identified no significant bedforms, suggesting sediment transport is not active in the area. Furthermore, analysis of other potential indicators of sediment transport, such as scour around wrecks, did not identify any preferential sediment transport directions. This indicates that sediment transport pathways are not present within the offshore site, probably due to the relatively low tidal current speeds operating on the seabed and a lack of significant quantities of sandy sediments.

8.5.4.3 Cable Route

51 The bathymetric and sidescan sonar data within the proposed cable route (EMU, 2009) also showed no evidence of significant bedforms which could indicate potential sediment transport pathways. Although some small and highly localised dunes were identified in the south, a clear indication of sediment transport was not identifiable. However, the orientation of the crests of the small dunes suggests a potential east-west aligned transport direction. Regional sediment transport studies suggest that sediment transport direction is northward and shore-parallel along this section of the Scottish coast (Kenyon and Cooper, 2005; HR Wallingford, 1998; BGS, 1986a).

8.5.5 Quaternary Geology

8.5.5.1 Regional

52 The Quaternary Period, encompassing approximately the last two million years, has strongly influenced the regional seabed morphology, mostly as a result of numerous and large-scale fluctuations in global sea-levels during glacial and inter-glacial periods. During this period, significant volumes of material were eroded from the mainland and continental shelf (DECC, 2004). These rocks and sediments were subsequently deposited on the shelf and re-distributed through wave and tidal-driven processes, resulting in the morphology and geological environment seen today.

53 The main regional Quaternary deposits around the Neart na Gaoithe wind farm site (from oldest to youngest) are: the Wee Bankie Formation, St Abbs Formation and the Forth Formation (which includes the Largo Bay Member and the more recent St Andrews Bay Member). The main geological characteristics and distribution of these units are described and shown in Table 8.4 and Figure 8.13, respectively.

54 The main geomorphologic unit in the vicinity of the proposed wind farm is the Wee Bankie Formation, a morainal till bank (comprising a wide variety of glacial muds, sands and gravels), which forms the Wee Bankie moraine ridge complex (Golledge and Stoker, 2006). This unit has been interpreted as forming the seaward extent of the most recent Ice Age (Devensian) till and is distinct from the gravelly sand Marr Bank Formation, which is located further offshore. The Wee Bankie Formation is often overlain by the more recent sediments of the Forth Formation (refer to Table 8.4).

Geochronology (not to scale)			Geological history	Site lithology	Unit
Period	Epoch	Series			
QUATERNARY	Holocene 10 Ka - present		**Forth Formation**: Deposition of sediments in marine, glaciomarine, fluviomarine and estuarine environments.	**St Andrews Bay Member**: Interbedded sands and clays in the west and pebbly muds and shelly sands in the east.	Soft-sediments
				Largo Bay Member: Muds and silts within Firth of Forth becoming coarser seawards.	
	Upper Pleistocene 110 – 10 Ka		**St Abbs Formation**: Deposition of sediments in a glaciomarine environment.	Soft to stiff, plastic, weakly laminated muds and silty muds with sporadic pebbles.	
			Wee Bankie Formation: Latter part of Devensian glaciation – deposition of basal/morainal till.	Stiff, variably matrix-dominated polymictric diamicton with some interbeds of sand, pebbly sand and silty clay with boulders.	Wee Bankie Formation

Table 8.4: Main Quaternary units present within the offshore site and cable route. Source: Gatliff *et al*., 1994

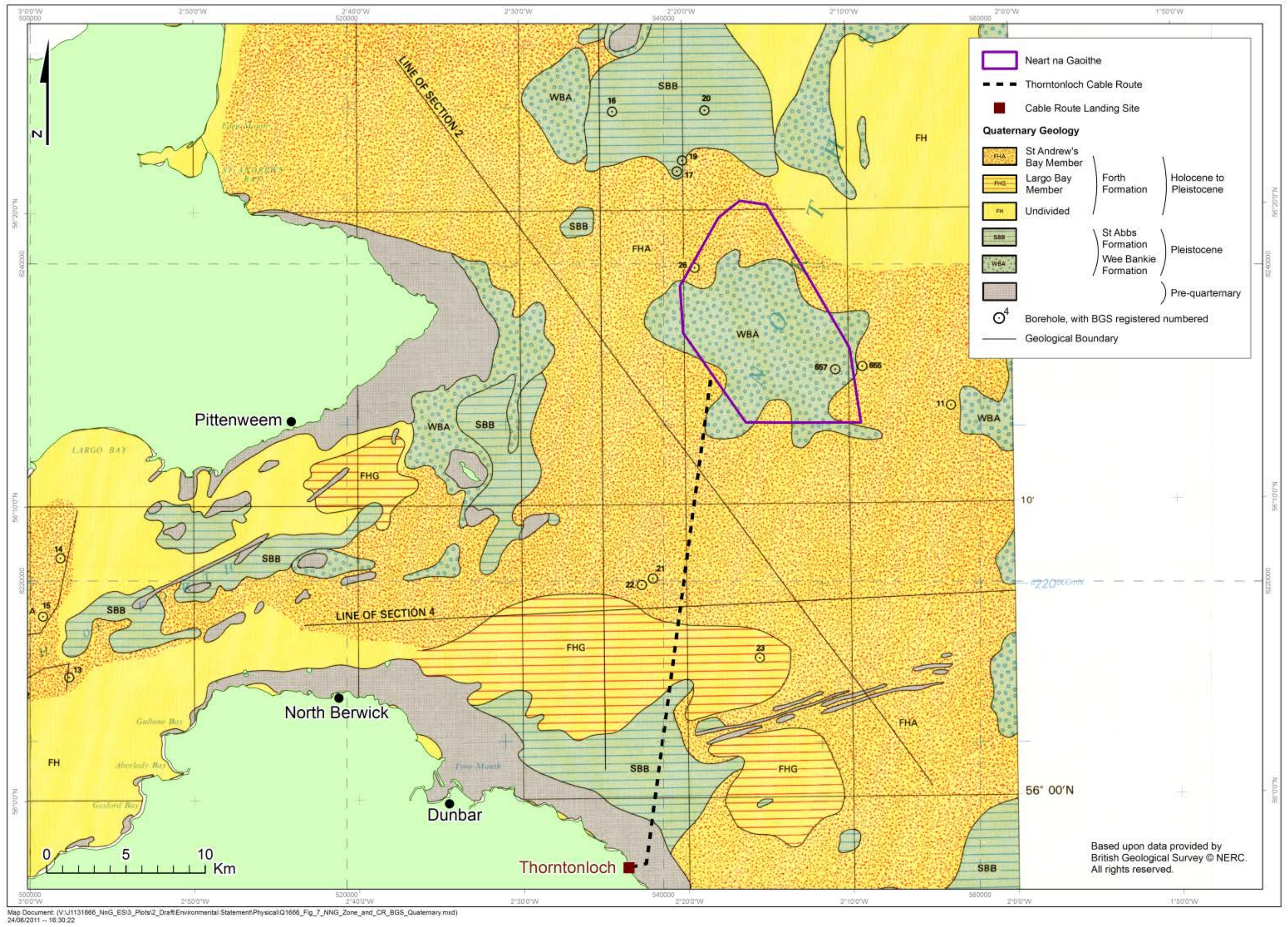

Figure 8.13: Regional Quaternary geology

8.5.5.2 *Offshore Site*

55 The Quaternary geology of the offshore site comprises both Pleistocene and Holocene deposits (refer to Table 8.4). The earliest Quaternary unit present is the Wee Bankie Formation, a morainal till with a highly irregular surface (Golledge & Stoker, 2006). The Forth Formation, which includes the younger St Andrews Bay Member, is of late Pleistocene to Holocene in age. The St Andrews Bay Member includes interbedded sands and clays in the west and shelly sands in the east (BGS, 1987).

56 The St Abbs Formation and Firth Formation have been grouped together as Quaternary 'soft-sediments'. Where the stiff Wee Bankie Formation has been added, this is referred to as Quaternary 'total sediment', which also represents the depth to the bedrock surface (refer to Figure 8.14). Soft-sediments across the offshore site range from 0 to 15 m in thickness with a mean of 3.4 m. In areas interpreted as zero (particularly in the centre and east of the offshore site), it is likely that a veneer of sediment (less than 0.3 m thick) is present that cannot be distinguished within the acoustic data.

57 Total Quaternary sediment thickness across the offshore site ranges from 0 to 70 m, with a mean of 12.9 m. In several areas, especially in the east and centre of the survey area, total Quaternary sediment thickness is approximately zero and therefore bedrock is present at or near the seabed. These areas correlate well with exposed bedrock in the sidescan sonar and Acoustic Ground Discrimination System (AGDS) data (EMU, 2009).

58 The interpreted Quaternary sediment thickness, based on seismic data, indicates the presence of two infilled valleys (palaeochannels) running across the proposed offshore wind farm (refer to Figure 8.14). Total Quaternary sediment thickness in these valleys is up to 73 m. The formation of these palaeochannels is probably related to glacial erosion during Pleistocene glaciations and sea level lowstands. They have subsequently been infilled with till and more recent sediments (Gardline, 2010). A seismic section across one of the palaeochannels, illustrating the relationship between the different Quaternary units, is shown in Figure 8.15.

59 Composite borehole results for a 37.58 m long borehole through the northeast/southwest trending valley (Gardline, 2010) indicate silty gravelly sand with occasional clay beds extending from the surface to 25 m below the seabed; this material is likely to represent the Quaternary soft-sediments. From 25 to 37.58 m below the seabed, extremely high strength sandy gravelly clay was identified; this stiffer material probably represents the Wee Bankie Formation (refer to Table 8.4). For detailed vibrocore, cone penetrometer test (CPT) and borehole log results, refer to Gardline (2010). Good correlation was generally found between the geophysical survey results (EMU, 2009) and the geotechnical survey measurements (Gardline, 2010).

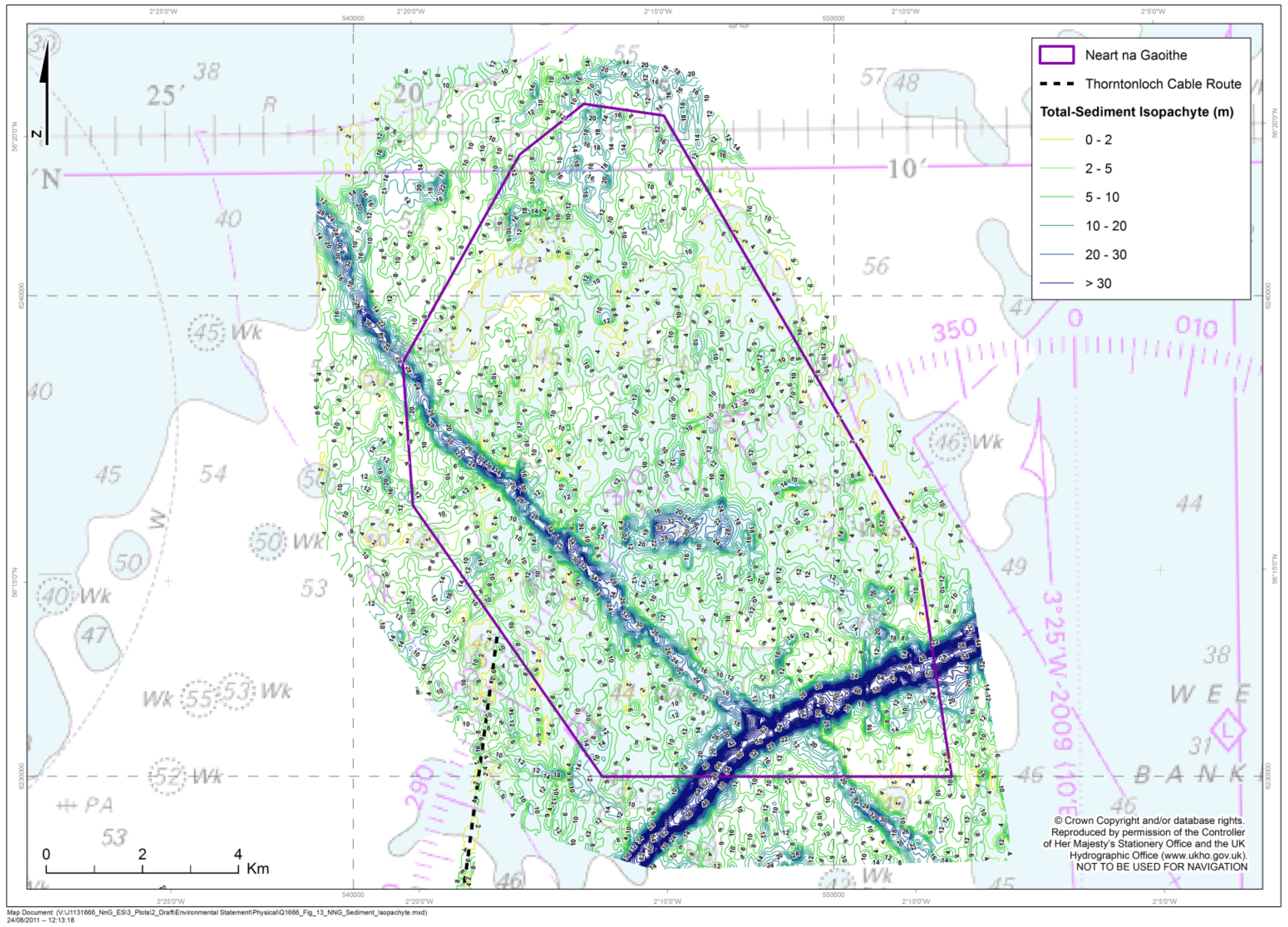

Figure 8.14: Total Quaternary sediment thickness (including Wee Bankie Formation) for Neart na Gaoithe. Source: EMU, 2009

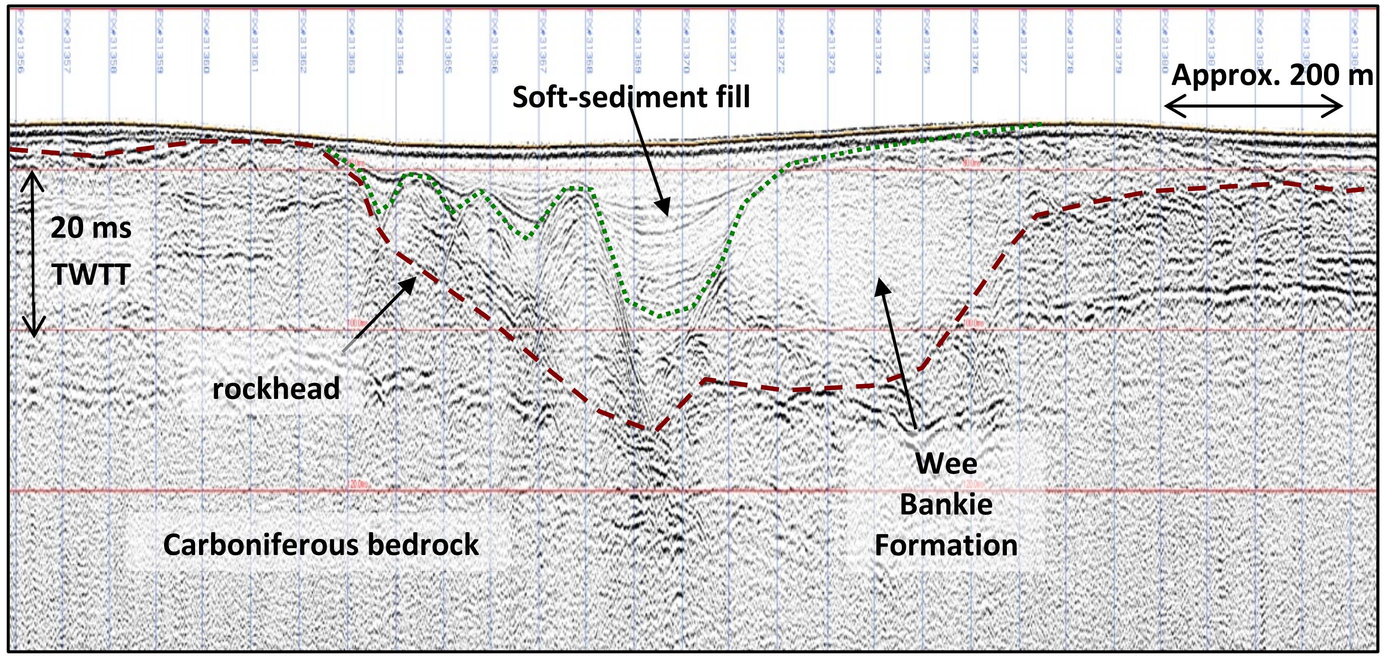

Figure 8.15: Seismic (boomer) data example showing infilled valley incised into underlying bedrock. The infill sediments include the Forth and St Abbs Formation, collectively termed soft sediments, and the older underlying Wee Bankie Formation. Source: EMU, 2009

8.5.5.3 Cable Route

60 The Quaternary formations along the proposed cable route generally become older towards the south. The northern (upper) half comprises the (Holocene to Pleistocene) St Andrews Bay and Largo Bay Members, transitioning into the older (Pleistocene) St Abbs Formation further south, approximately 10 km from the coastline (refer to Figure 8.13). The last section of the cable route, near its landing site at Thorntonloch, comprises outcropping pre-Quaternary rock. The Pleistocene sediments are glaciomarine in origin, comprising soft to stiff, plastic, weakly laminated muds with occasional pebbles.

61 Soft-sediments along the cable route range from 0 to 43 m in thickness (refer to Figure 8.16), averaging approximately 6 m (EMU, 2009). The thickness of soft-sediments along the cable route is shown in Table 8.5. The Wee Bankie Formation (which is not included within Table 8.5), is present over bedrock and lies within 1 m of the seabed between sections 26.9 km to 27.2 km and 28.1 to 28.4 km of the proposed cable route.

Approximate distance along cable route (km)	Soft sediment thickness (m)
0 – 2.5	Bedrock at surface
2.5 – 3.6	0 – 3
3.6 – 7.2	2 – 10
7.2 – 8.5	Up to 4, separated by outcropping or subcropping dykes
8.5 – 27.0	Up to 43
27.0 to end	0 – 8

Table 8.5: Soft-sediment thicknesses along the proposed export cable route. Source: EMU, 2009

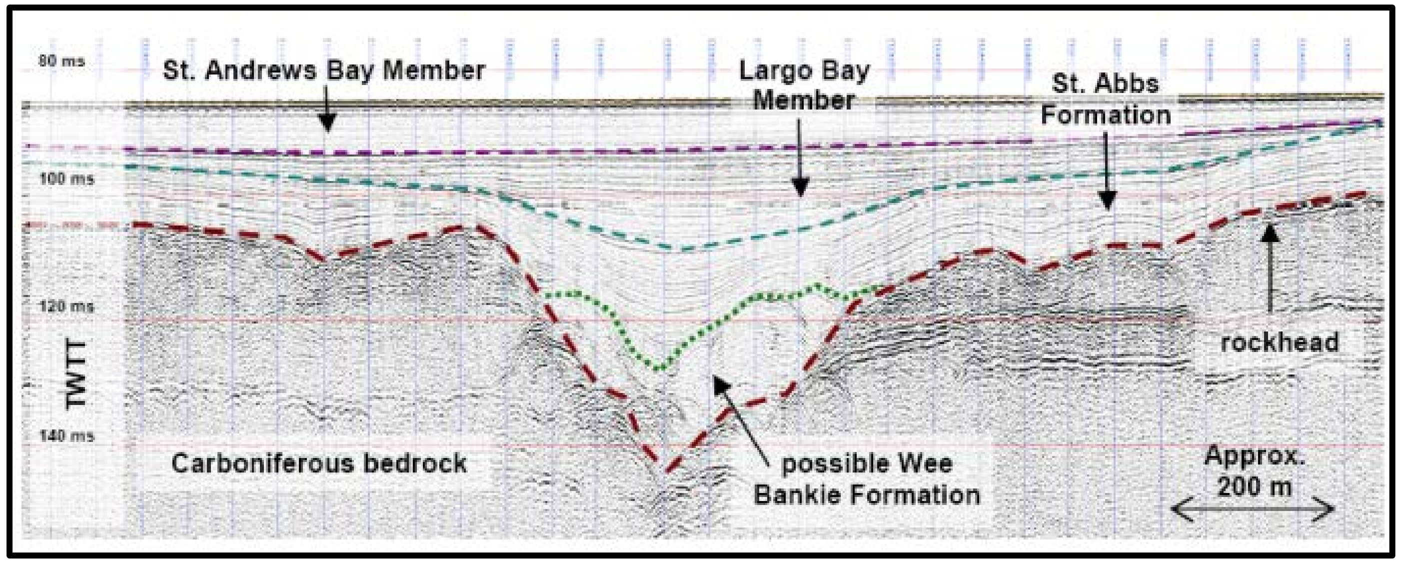

Figure 8.16: Seismic (boomer) data example from proposed cable route showing Quaternary sediments overlying bedrock. 20 ms in vertical scale represents approximately 16 m. Source: EMU, 2009

8.5.6 Solid Geology

8.5.6.1 Regional

62 The regional offshore solid geology, which encompasses all rocks prior to the Quaternary Period, is dominated by Carboniferous aged rocks and sediments (BGS, 1986b). These were deposited approximately 300-350 million years before present during marine transgressions associated with crustal extension, resulting in the widespread deposition of fluvio-deltaic and shallow marine sediments (Gatliff *et al.*,1994). Apart from the igneous dykes, no rocks older than Upper Devonian - Carboniferous age are present along the coast (Gatliff *et al.*, 1994). The Carboniferous (Solid) geology of the region (refer to Figure 8.17) can be broken down into the following main units, starting with the oldest:

- Calciferous Sandstone Measures - comprising mostly deltaic and highly variable fluvial sandstones and mudstones with thin coals;
- Lower Limestone group – deltaic grey mudstones and sandstones with some thin limestones and coals;
- Upper/Limestone Coal Group – Deltaic grey mudstones and sandstones, some coals and marine horizons;
- Passage Group – thick fluvial sandstones;
- Lower/Middle Coal Measures – Deltaic grey sandstones and mudstones with workable coals; and
- Upper Coal Measures – Fluvio-deltaic red sandstones and mudstones, rare coals.

63 Other geological units in the region include:

- Older (nearshore) Upper Devonian, mainly fluvial yellow and reddish-brown sandstones and more recent undivided Permian and Triassic rocks, located mainly offshore.

64 Significant geological features near the offshore site also include:

- The Firth of Forth Fault, a major southwest to northwest trending zone of disturbance up to 3 km wide located in the Firth of Forth;
- A major anticline located to the south of the offshore site; and
- A series of mainly east to west trending Permo-Carboniferous igneous dykes, also located to the south of the offshore site.

8.5.6.2 Offshore Site

65 The proposed Neart na Gaoithe offshore wind farm lies within the southwest-northeast trending Forth Approaches Basin (Gatliff *et al.*, 1994). This pre-Permian structural basin is bounded to the north by the Strathmore Syncline and to the south by the Southern Upland Fault. The solid geology mostly comprises Carboniferous limestones in the east of the proposed wind farm and sandstones in the west (refer to Figure 8.17). Overlying Permian mudstones, and to a lesser extent gypsum, encroach into the north and east of the area (refer to Figure 8.18).

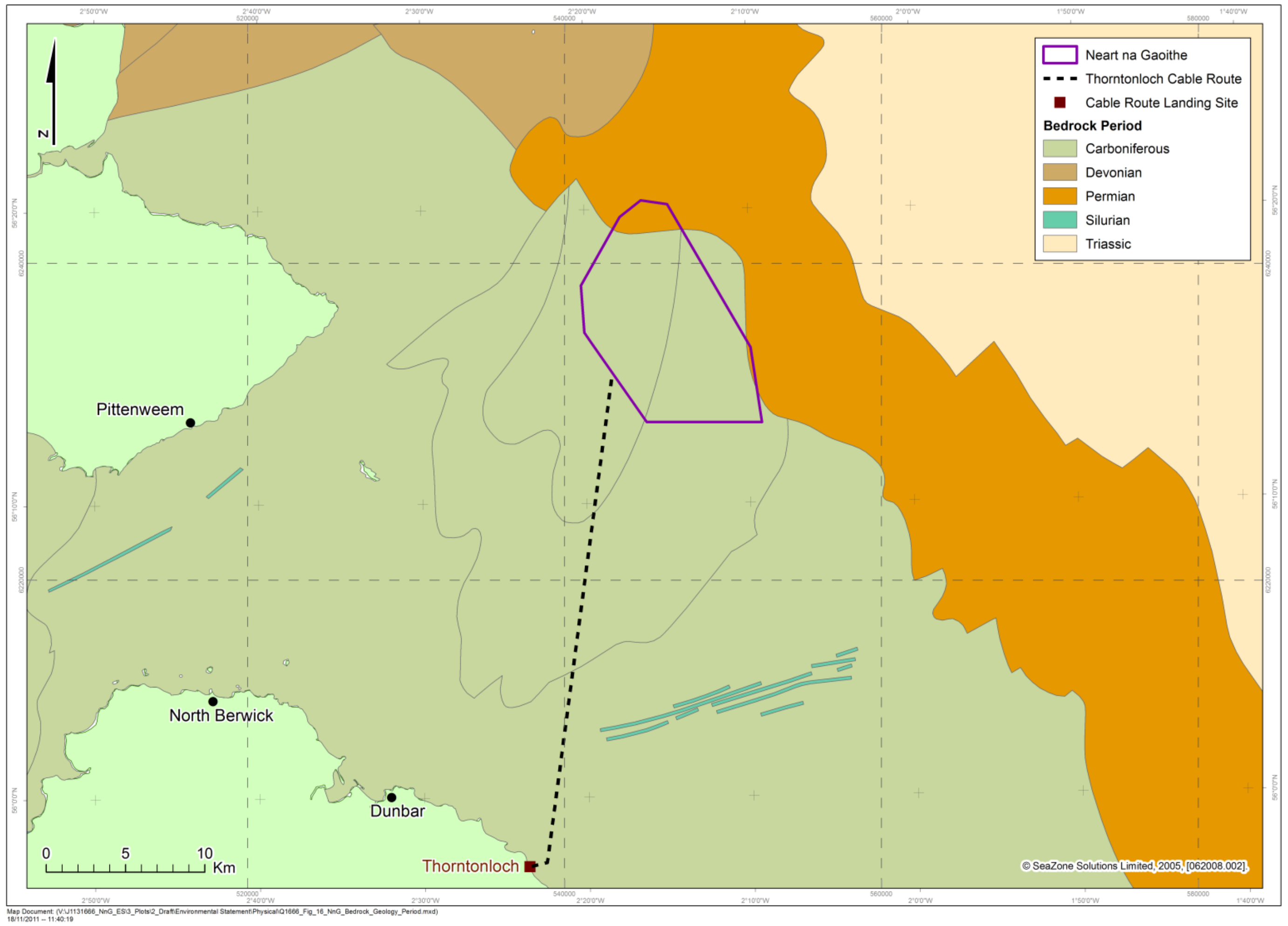

Figure 8.17: Regional solid geology

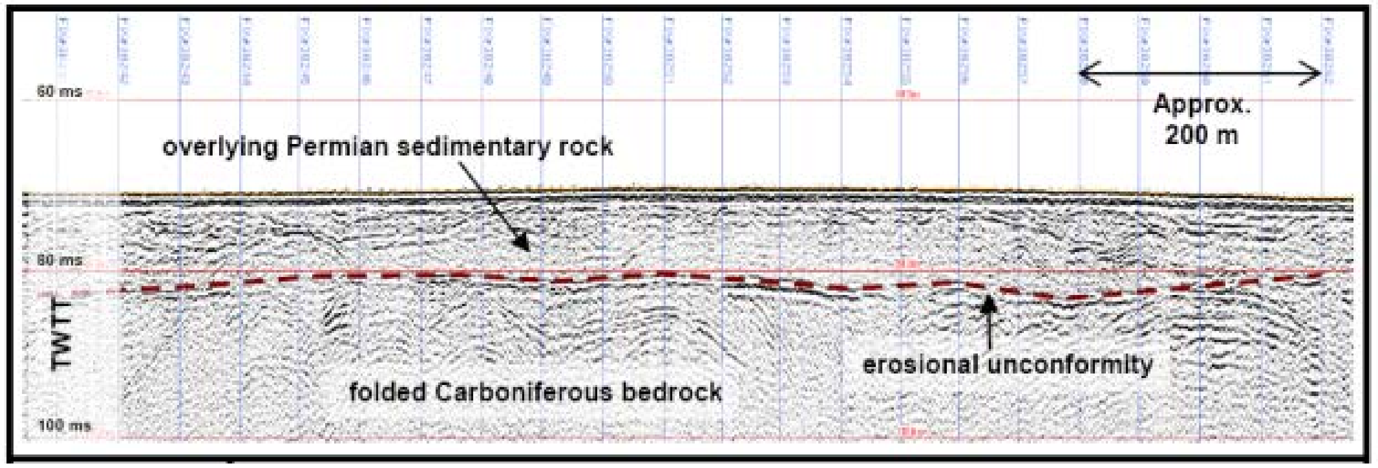

Figure 8.18: Seismic (boomer) cross-section from north end of the offshore site, showing erosional unconformity between Carboniferous and overlying Permian sedimentary rock. Note: 20 ms approximates to 16 m along vertical scale. Source: EMU, 2009

66 The depth to the eroded bedrock surface (rockhead) across the survey area ranges from of 0 to 70 m below seabed, with a mean of 12.9 m (EMU, 2009). The greatest depths to the bedrock surface are at the base of two infilled valleys (refer to Figure 8.14). One of these valleys trends from the northwest towards the southeast across the offshore site, with a maximum depth to bedrock surface of 90 m, which is approximately 30 m deeper than the surrounding bedrock surface levels. A second infilled valley trends approximately southwest to east-northeast in the southeastern part of the site. Within this valley, the maximum depth to the bedrock surface is up to 120 m, approximately 60 m deeper than the surrounding bedrock surface.

8.5.6.3 Export Cable Route

67 The bedrock geology of the proposed export cable route comprises the Carboniferous Limestone Group (refer to Figure 8.17). In addition, several igneous dykes have intruded into the Carboniferous geology - these are exposed on the seabed at the southern end of the proposed cable route (refer to Figure 8.19), approximately 8 km from the shoreward cable connection point.

68 Depths to the bedrock surface range from approximately 12 m to 102 m below LAT. The bedrock is exposed on the seabed along two locations: at the inshore section for approximately 2.5 km and along the last 2 km of the cable route near the boundary with the proposed offshore site. From 3.2 to 7.3 km offshore, the depth to bedrock ranges from 38 to 65 m, and between 7.3 and 8.3 km outcropping or subcropping igneous dykes were identified. The deepest location to the bedrock surface, up to 102 m below LAT, is within an infilled valley approximately 8.5 km from the shoreward starting point.

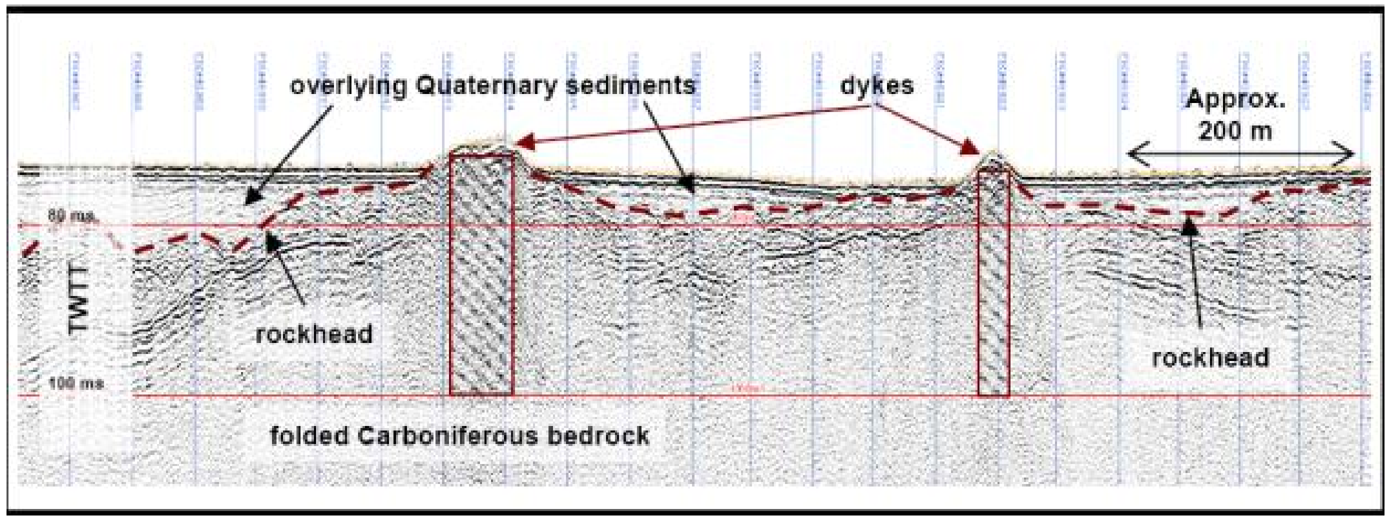

Figure 8.19: Seismic (boomer) example of outcropping igneous dykes along southern end of the proposed cable route. The solid geology comprises folded Carboniferous bedrock. Source: EMU, 2009

8.5.7 Regional Coastal Characterisation

69 This section summarises the main geologic, geomorphologic and related anthropogenic (e.g., coastal infrastructure) characteristics of the Scottish North Sea coastline in the vicinity of the proposed Neart na Gaoithe wind farm and cable route. The characterisation extends from approximately St Abbs Head in the south to Arbroath in the north (refer to Figure 8.20). For detailed coastal descriptions, refer to Scottish Natural Heritage Research, Survey and Monitoring Reports (Ramsey and Brampton, 2000a, 2000b) on which this section is primarily based. Other relevant publications include Robertson and Miller (1997) and Bates *et al*. (2003).

70 Coastal cells (which are further divided into sub-cells) and Shoreline Management Plans (SMPs) are appropriate methods of dividing and subsequently managing different coastal sections. SMPs have been adopted in England and Wales, and similar methods are being considered in Scotland (Hansom *et al*., 2004).

71 In essence, coastal cells are self-contained natural divisions based on coastal orientation, geological characteristics, sediment transport and coastal patterns of erosion/accretion. They are also useful in considering wider aspects of a shoreline segment, including coastal hydrodynamics, ecology and geomorphology, infrastructure, tourism, recreation and natural heritage.

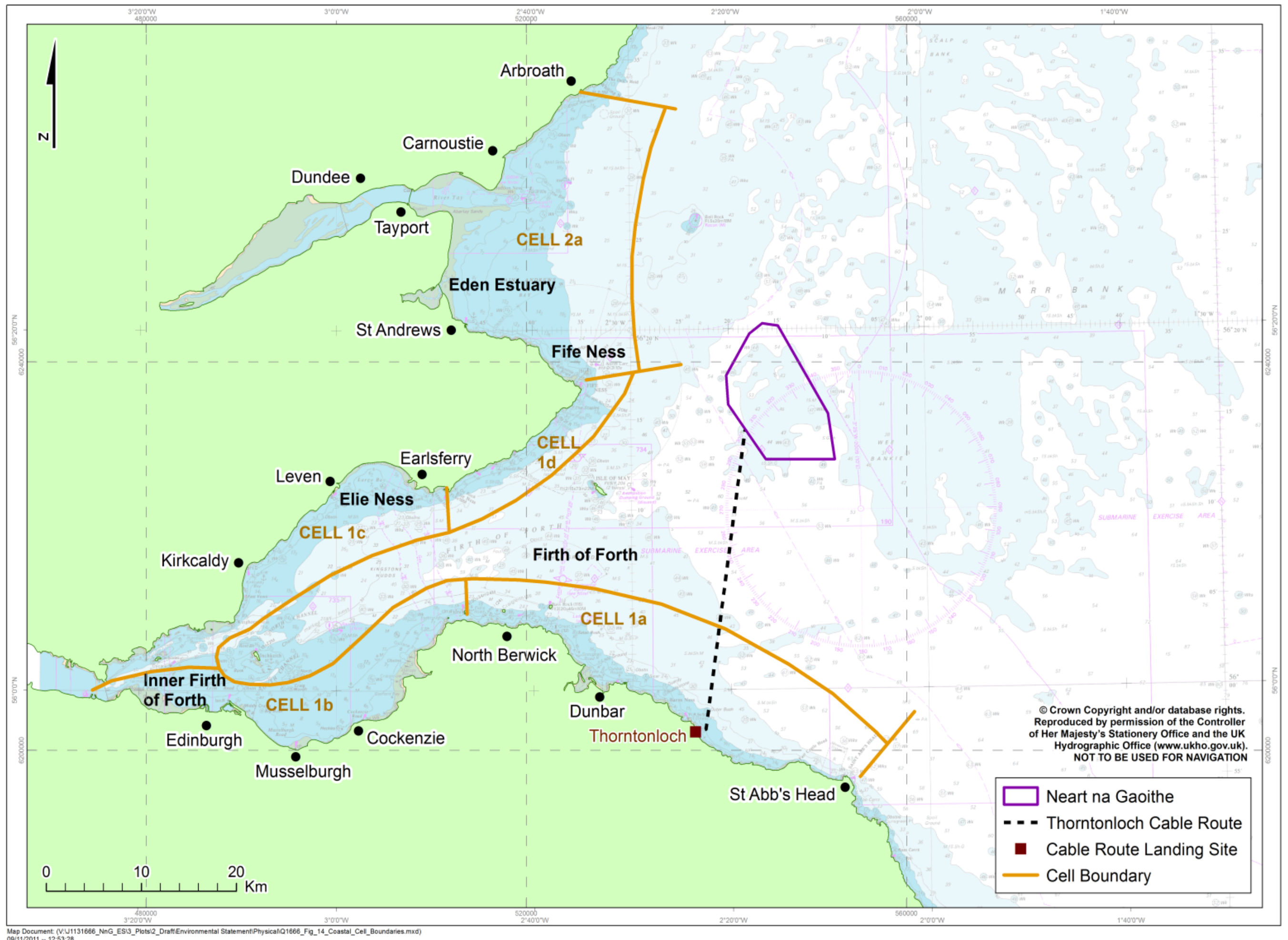

Figure 8.20: Regional coastal characterisation, illustrating location of cells and sub-cells discussed in text. Source: Ramsey and Brampton, 2000a; Google Earth

8.5.7.1 Cell Overview

72 Cell 1 has been divided into four smaller sub-cells (a-d), mainly on the basis of coastal orientation and exposure to oceanographic forcing (Ramsey and Brampton, 2000a). Sub-cells 'a' and 'd' comprise the exposed and higher energy coastlines located to the south and north of the Firth of Forth. Sub-cells 'b' and 'c' are located along the more sheltered coastlines within the Firth of Forth (refer to Figure 8.20).

73 Within cell 2, only sub-cell 'a' is relevant to this study.

74 The dominant littoral processes and transport for sub-cells 1a-d and 2a are summarised in Table 8.6 (DECC, 2004). The explanation for these processes is given in greater detail in the following sections.

Sub-Cell	Erosion/accretion	Littoral processes
1a	Local erosion and accretion.	Low rate of wave induced east to west littoral drift along coastline.
1b	Local erosion and accretion.	Generally low, but locally moderate wave induced east to west littoral transport
1c	Local erosion and accretion.	Wave induced transport. Westerly wave induced drift occurs along much of the southeast facing frontage.
1d	Local erosion and little significant accretion.	Erosion and low levels of wave dominated longshore transport.
2a	Local erosion and accretion.	Wave induced longshore transport although tidal currents important for circulation of sediment within the estuary.

Table 8.6: Littoral processes and transport within coastal sub-cells 1a-d and 2a. Source: DECC, 2004

8.5.7.2 Sub-Cell 1a – St Abbs Head to North Berwick

Geology

75 The solid geology of this coastal sub-cell is variable, comprising Silurian and Carboniferous units overlain by a range of more recent glacial and post-glacial deposits (Ramsey and Brampton, 2000a). From St Abbs Head to Dunbar, the bedrock is often exposed and comprises up to 6 m thick greywackes, siltstones and shales of the Silurian Queensbury Grits. Near Siccar Point, there is some younger outcropping Old Red Sandstone which unconformably (i.e., not in normal succession) overlies the Silurian deposits. Further north along the coast, outcropping Carboniferous deposits become more prevalent up until the Southern Upland Fault near Dunbar.

76 North of Dunbar, the dominant coastal outcrops are associated with Carboniferous limestones and both intrusive and extrusive igneous basalts and dolerites, especially in the vicinity of North Berwick. The morphology of the coastline is controlled by these different rock types, resulting in rocky headlands associated with the harder igneous rocks and more erodible shore platforms comprising the Carboniferous limestones.

77 Although glacial, glacio-fluvial and post-glacial deposits are relatively thin along much of this sub-cell; some exceptions include the raised beaches in Belhaven Bay and Ravenshaugh in the north, which are post-glacial in origin, and the raised beach at Barns Ness in the south, which is fluvio-glacial in origin.

Coastal Sediments and Transport

78 This coastal sub-cell is exposed directly to the North Sea and is therefore susceptible to high-energy storm conditions which occur frequently in the region, particularly in the winter. The beaches that comprise this sub-cell have been formed from either cliff erosion (e.g., Dunbar and Pease Bay) or from glacially derived sediments (e.g., Belhaven Bay, Barns Ness and Thorntonloch). Modern input of beach sand and gravels is scarce along much of this sub-cell.

79 Where beaches are present, they are mostly headland-embayment type small beaches, constrained by rocky outcrops. Minimal, if any, sediment transport is predicted to take place with neighbouring beaches, where present. Between Cockburnspath and Dunbar the coastline is predominantly rocky, occasionally broken up by small sandy pocket beaches.

80 Pease Bay is a small and relatively stable sandy pocket beach which may be susceptible to erosion during storm conditions. Thorntonloch, which is where the export cable landfall is proposed, is a sandy beach with a shingle ridge, separated by rock outcrops. There is a caravan site and nuclear power station in the vicinity. Small embayment/pocket beaches and coves are also common between Chapel Point and Mill Stone Neuk near Barns Ness Lighthouse. These include the sandy beaches located to the south and the shingle beaches located to the west of the lighthouse (e.g., White Sands).

81 The River Tyne Estuary, constrained by Dunbar to the south and St Baldreds Cradle to the north, is a mostly stable embayment, with a wide sandy beach fronting saltmarsh and intertidal mudflats near its outlet to the north (refer to Figure 8.21). Longshore transport is not obvious, probably due to its perpendicular orientation to storm events approaching from the northeast. The dunes along the beach do erode occasionally during storm events, though the erosion is not significant. There is also a well-vegetated spit, known as Sandy Hirst, which extends off the northern margin of the beach, adjacent to the main channel backing the salt marsh. The spit is occasionally susceptible to overwash during storm events and is predicted to move westwards onto the salt marsh with predicted rises in sea level (Hall, 2011). This area is potentially the only location along this sub-cell where significant erosional and geomorphological changes may occur.

82 Between St Baldreds Cradle and North Berwick there are also a number of small and stable sandy pocket/embayment beaches, constrained between rocky headlands. The main ones include Peffer Sands and Ravensheugh, located just to the north of the Tyne. Some erosion is apparent, but does not appear to be significant. Some small sandy coves and pocket beaches are also located near Audhame and Canty Bay.

Figure 8.21: Seaward looking photograph of the Tyne Estuary showing forested Sandy Hirst Spit in the centre. Source: Hall, 2011

Coastal Defences

83 The few areas where coastal defences are present along this sub-cell include the seawalls in Dunbar Harbour and the rock revetment and seawall which protect the Torness Power Station. Other smaller defences include a rockwall and gabions which protect the seaward margin of two caravan parks located south of Torness and in Pease Bay.

8.5.7.3 Sub-Cell 1b – North Berwick to the Inner Forth of Firth

Geology

84 The solid geology of this coastal section comprises predominantly Carboniferous sandstones, limestone, mudstones and coal deposits. Intrusive and extrusive igneous outcrops of basalt in the form of sills and dykes are also present. The geomorphology and planshape of this sub-cell is often controlled by these different units: the harder igneous outcrops often form the headlands and shore platforms in the area; whereas the less resistant sedimentary rocks are eroded and cut back, forming many of the beaches.

85 Glacial and post glacial deposits are very common along this sub cell, with boulder clays, sand and gravels overlying the underlying older geology (Ramsey and Brampton, 2000a). Raised beaches are prevalent within the region, especially along the coast from Cockenzie to Cramond. The more sheltered northwest orientated beaches in the eastern section of the Firth of Forth are overlain with post glacial blown sand, whereas boulder clays, and to a lesser extent, glacial boulders, are common west of Cramond.

Coastal Sediments and Transport

86 Coastal sub-cell 1b is highly variable, transitioning from the mostly natural coastline between North Berwick and Dalmeny Estate, to a heavily developed coastline between Port Seton to Cramond, including the coastal suburbs of Edinburgh. The dominant sand transport mechanism is wave-driven and westerly, although potential transport is reduced significantly by the presence of numerous headlands comprising igneous outcrops. Areas east of Leith Docks are significantly higher energy than the more sheltered areas west of Leith. Tidal currents play a lesser role in the overall sediment transport, although they are important within localised and sheltered coastal areas comprised of sands and muds (BGS, 1986a).

87 The north facing embayment beaches in North Berwick e.g., Milsey Bay, which are more susceptible to storm erosion, are morphologically attuned to seasonal changes, experiencing dune erosion in the winter and accretion in the summer (Ramsey and Brampton, 2000a). However, the long-term coastal trend appears to be one of stability.

88 Aberlady Bay is a sink for east to west sediment, with a series of prograding and healthy dunes on its eastern margin. In contrast, Gosford Bay, located to the south and west of Aberlady Bay and orientated towards the west, is relatively sediment poor with only a thin layer of sediment present. It is presumed that sediment moving east to west bypasses Gosford Bay to locations further west.

89 From Seton Sands to Musselburgh, the coastal zone is mostly rocky, with small sandy stretches. The northeast facing beach at Portobello, which is periodically nourished, may act as a drift divide point, with westerly flows along the Portobello frontage and weak easterly eddies towards Fisherrow (HR Wallingford, 1998). Westwards from Portobello, very few sandy areas exist, predominantly due to large scale coastal projects, including Leith Docks and Granton Harbour.

90 West of Granton towards Hound Point there are extensive sandflats. The causeway and breakwater linking Cramond Island to the mainland traps westward moving sediments, resulting in downdrift erosion and an offset on the west side of Cramond. A long sandy beach, backed by vegetation, is present to the southeast of Barnbougle Castle. Between Hound Point and the headland at Blackness, the coastal zone is low lying, with raised beach deposits and occasional rocky outcrops. West of Blackness comprises a series of mudflats and reclaimed land (Historic Scotland, 1999).

Coastal Defences

91 This shoreline is one of the most developed and heavily protected areas in Scotland, especially west of Cockenzie (Ramsey and Brampton, 2000a). The only protected shoreline segment to the east of Cockenzie is a 200 m long seawall along North Berwick Bay. The coastline between Cockenzie and Joppa has a series of seawalls with rock armouring constructed along the rocky outcrops, which are common in the area. The Portobello frontage is protected via a series of measures, including a concrete seawall, beach nourishment and a number of wooden jetties.

92 The highly developed and industrial shoreline fronting Edinburgh, especially Leith Docks and Granton Harbour, has been heavily developed with large-scale harbour walls, seawalls and concrete revetments, including rock dumping and builders waste (Ramsey and Brampton, 2000a). A range of different hard defence measures exist from Granton Harbour to Cramond, including seawalls and different kinds of revetments. The shoreline along Dalmeny Estate has approximately 800 m of seawall and rock armour around the promontory. Further west along the Firth of Forth, there are a number of localised areas with hard structures, including seawalls, rock armour and rock groynes. The coastline of Queensferry is also protected with a range of seawalls, revetments and rock armour.

8.5.7.4 Sub-Cell 1c – Inner Firth of Forth to Elie Ness

Geology

93 The solid geology along the northern and inner Fife coast is similar to that in the south, predominantly comprising Carboniferous sedimentary rocks separated by intrusive igneous basalts (lavas and sills) which form the shore cut platforms and rocky outcrops. North Queensferry and Kinghorn headlands are excellent examples of the igneous rock exposures. An agglomerate, comprising broken rock fragments of volcanic material, is present near Ruddons Point Headland, in the east of the sub-cell.

94 The majority of the glacial material overlying the solid geology comprises boulder clay, which makes up many of the cliffs. Erosion of these glacial cliffs has resulted in the formation of the many shingle beaches in the area. Other glacial remnants include raised beaches, e.g., at Kincraig.

Coastal Sediments and Transport

95 The majority of the beach material along this sub-cell is glacial, although coal mining waste has also contributed significant material to the beaches (Ramsey and Brampton, 2000a). From Forth Bridges to Kinghorn, the shoreline is made up of a series of self-contained embayment sandy beaches and coves, with some gravel and shell material. Although tidal currents and wave action are strong, the beaches are in equilibrium with these conditions. Backshore armouring and coastal defences have prevented any new input of sediment into the system.

96 Active sediment transport processes are evident between Kinghorn and Ruddons Point, with strong westerly longshore transport. The seafront along Kirkcaldy is sediment starved and eroding, with bedrock forming much of the coast. This is due to the downdrift trapping of sand from the harbour jetty to the north, which prevents sediment from entering Kirkcaldy. The seawalls at Kirkcaldy may also play a role in reflecting wave energy back out to sea, in effect, forcing any potential sand along the seafront offshore. To the north of the harbour there is a series of sandy embayment beaches separated by rocky outcrops and coastal infrastructure, especially small harbours.

97 The coastline between Dysart and East Wemyss has been anthropogenically altered and created, with the introduction of significant quantities of coal waste, which was deposited on the shoreline. These activities have now stopped and it is estimated that erosion will become very prevalent as the beach regains equilibrium (HR Wallingford, 1998). This is further exacerbated due to significant land subsidence in the area (McManus, 1998). The coast from Buckhaven to Leven is mostly rocky, particularly since much of the southerly longshore transport is trapped by Methil Harbour to the north.

98 The beach at Leven Links is mostly sandy with rocky outcrops along its northern margin, forming the western half of Largo Bay. The bay may be a drift divide point, as evidenced by the rock platform in the centre. Sediment transport is typically westward to the left of the outcrop, although easterly transport may occur when waves approach from the southwest.

99 There are numerous small south-facing sandy pocket beaches and coves around Earlsferry and Elie which are separated by rocky headlands.

Coastal Defences

100 A range of coastal defence structures is present along this developed shoreline segment. The coast between Queensferry and Aberdour has a range of jetties, wharfs and seawalls. Seawalls are present east of Silversands Bay and Burntisland to protect the railway track. Most of the Kirkcaldy coast is protected with seawalls, as is Dysart and West Wemyss. East Wemyss, Buckhaven and Leven are all fronted by a revetment. Concrete seawalls protect Methil Docks. Seawalls are also present along Lundin Links, Largo and Elie. A range of protective measures are in place east of Wood Haven Harbour, including seawalls, piling walls, anti-tank blocks, a rock revetment and gabion baskets (Ramsey and Brampton, 2000a).

8.5.7.5 Sub-Cell 1d – Elie Ness to Fife Ness

Geology

101 The solid geology of this coastal sub-cell is predominantly lower Carboniferous, comprising sandstones and mudstones. Other units include agglomerates near Elie Ness and volcanic vents along the Ardross Fault. Thin raised beaches are also common, overlying raised shore platforms which have been incised into the relatively soft Carboniferous rocks (Ramsey and Brampton, 2000a).

Coastal Sediments and Transport

102 This coastal segment is predominantly a continuous rock platform, with only a few small coves and pocket beaches which are comprised of sand, shingle or cobble. Cliff erosion does occur, but is reduced by the presence of the wave cut platforms which dissipate the incoming wave energy.

Coastal Defences

103 Coastal defences are relatively rare along this sub-cell, with some seawalls protecting the few small fishing villages that occur along the coastline and some of the eroding cliffs.

8.5.7.6 Sub-Cell 2a – Fife to Arbroath

Geology

104 This coastal sub-cell, which includes the Fife estuary, primarily comprises Carboniferous rock lithologies; an older Calciferous Sandstone comprising sandstones, mudstones and marine limestones is overlain by the younger Lower Limestone Group, also made up of sandstones, mudstones, limestones and coals (Ramsey and Brampton, 2000a).

105 Additionally, there are a number of notable (igneous) volcanic vents, especially within the St Andrews to Craig Hartle Site of Special Scientific Interest (SSSI). Other igneous lavas and tuffs are present to the west of Tayport. There is also a band of Upper Devonian Old Red Sandstone which traverses the Fife in a northeast/southwest orientation and Lower Devonian rocks near Tayport and from Monifieth to Arbroath.

106 Glacial processes resulted in the widespread deposition of boulder clays around Fife and Tayside and glacial sands and gravels near Wormit and the northern coast of Fife. Reworking of these deposits during subsequent sea-level rise produced a series of raised beaches in the hinterland. As sea-levels fell around 6,000 years ago, the intertidal sands dried up and were blown inland forming many of the coastal links areas of Tentsmuir and Barry Buddon (Bates *et al*., 2003).

Coastal Sediments and Transport

107 The majority of coastal sediments in this sub-cell are derived from reworked fluvial sources associated with melting glaciers and marine inundation and retreat. Modern fluvial sources of coastal sediments however are scarce except for fine grained material from the River Tay which is either deposited on the intertidal sandbanks or transported offshore.

108 From the headland at Balcombie to St Andrews, the coastline is predominantly comprised of rocky shore platforms, backed by cliffs. There are some small beaches located around Balcombie and Cambo. The first prominent sandy beach is East Sands, located to the south of St Andrews. The large and dynamic West Sands-Outhead spit-dune system, located to the north of St Andrews, protects the entrance to the Eden Estuary. The Eden Estuary, a long, thin and sheltered coastal indentation, is made up of (sequentially from the coast towards the west): mudflats, saltmarsh, brackish swamp, freshwater marsh, fen and wet grasslands (Bates *et al*., 2003). The intertidal sands and shingle and dune systems of the Outer Tay foreshore merge with the prograding Tentsmuir dunes, which are one of the most extensive dune complexes in Scotland.

109 The southern coast of the Firth of Tay is mostly cliff with narrow rock platforms, overlain with cobbles and shingle. Glacial erratics in the form of boulders are also present. The character of the (inner estuary) coast changes further west, transitioning into marsh with shingle bars, reflecting the lower energy environment. East of Monfieth, the prominent and south-facing Buddon Ness dune complex occupies the north flank of the estuary as far as Carnoustie. The coastal zone and foreshore north of Carnoustie and as far as Easthaven, is primarily exposed rock and cliffs, with some sand along the backshore and base of the cliffs.

Coastal Defences

110 The majority of coastal defences, which are fairly limited within this sub-cell, are centred around St Andrews and the Eden Estuary (Ramsey and Brampton, 2000b). Most of East Sands is protected with a seawall, as is the southern end of West Links. The Eden Estuary is protected by a range of different measures, including gabions, sloping mattress, vertical baskets, groins, rip-rap, and seawalls.

111 The airbase frontage at Leuchars also has a range of hard protective measures. The west of Broughty is completely artificial and the east is protected by wooden groins, which has resulted in erosion of adjacent unprotected coastal stretches. The (scarce) dune system at Monfieth is protected with rock revetment. Carnoustie Bay is protected with approximately 2 km of rock revetment, protecting the dune face along Barry Sands. The East and West Links in Arbroath are protected by vertical and sloping seawalls.

8.5.8 Offshore Water Quality

112 The distance of the proposed Neart na Gaoithe site from coastal or industrial sources of contaminants indicates that contaminants are unlikely to be an issue at the site. However, offshore areas have the potential to be influenced by the disposal of waste material in the region.

113 The disposal of industrial waste at sea has been prohibited since 1992 and the disposal of sewage sludge was phased out during 1998. Dredged spoil now makes up the majority of material disposed of at sea; but it must undergo testing for contaminants as part of the application for a licence for disposal. During the period of 2005 to 2009, 112 one-year licences for the disposal of dredged material at sea were issued (Scottish Government, 2011b), but no disposal sites were within the proposed development boundary or cable route. The nearest disposal site is more than 20 km from the cable route and offshore site.

114 Two sites in the vicinity of Neart na Gaoithe were historically used for the disposal of sewage sludge produced in the Edinburgh area. These were Bell Rock and St Abbs Head, which were operational from 1978 to 1998 (approximately 14 km northeast and 18 km southeast of Neart na Gaoithe, respectively). A combined total of 5.85 million tonnes of liquid sludge were disposed at these sites throughout their operational period. Monitoring during operation suggested that the sites were highly dispersive, as low concentrations of metals were detected in surface sediments, though slightly elevated levels of faecal bacteria were detected (Hayes *et al*., 2005).

115 Suspended sediment concentrations for the development area were measured to inform the physical processes modelling. Concentrations were found to be very low (10 mg/l) during fair weather, and would only increase during storm events (refer to Appendix 9.1: Physical Processes Technical Report).

8.5.9 Contaminants in Sediments

116 Historic data show that low concentrations of contaminants have been sampled at the offshore site (ICES, 2009). Contaminants will adsorb[2] more readily to smaller sediment fractions, making the finer sediments a sink for pollutants; an analysis of the sediment particle size distribution for Neart na Gaoithe and the export cable can be found in Section 8.5.3. In 1995 samples of surface sediments, from the eastern side of the Neart na Gaoithe site (56.25˚ N, 2.30˚ W), were analysed for contaminants (ICES, 2009). The concentrations of contaminants for all samples were well below Canadian interim marine sediment quality guidelines (ISQGs; given in Table 8.7). Canadian ISQGs have been developed using observed field evidence of biological effects to concentrations of sediment contaminants; and so are highly suggestive of potential eco-toxicological effects of sediment contamination on benthic organisms. Concentrations below ISQGs rarely cause adverse biological effects.

[2] Adsorption: the process by which a substance, such as a gas or liquid, is retained on the surface of another substance, such as a solid.

117 A more recent survey of surface sediment samples (EMU, 2010), undertaken to inform this environmental impact assessment (EIA), indicates that total sediment concentrations of all the contaminants tested were well below Canadian Probable Effects Levels (Canadian PELs), which are given in Table 8.7. Concentrations above Canadian PELs frequently cause adverse biological effects, whereas concentrations below Canadian PEL, but above ISQG, occasionally cause adverse effects. Concentrations of arsenic, at a point in the southern part of the offshore site, and cadmium, along the export cable and the reference site to the east of the offshore site, were greater than the Canadian ISQGs, suggesting that they may occasionally cause adverse effects in biota. Concentrations of the different tin and organochlorine pesticides tested were below analytical detection levels at all sites. Locations of the sampling sites can be viewed in the full Benthic Characterisation Survey Report, Appendix 14.1: Benthic Ecology Characterisation Survey.

Sample (location)	Arsenic (dry wt mg/kg)	Cadmium (dry wt mg/kg)	Chromium (dry wt mg/kg)	Copper (dry wt mg/kg)	Lead (dry wt mg/kg)	Nickel (dry wt mg/kg)	Zinc (dry wt mg/kg)	Mercury (dry wt mg/kg)	Total PAHs[3] (dry wt ng/kg)	Total Hydrocarbons (dry wt ug/kg)
1995 sampling[4] (turbine site)	2.3	0.01	16.6	2.8	11.31	6.5	21.4	-	-	-
7 (turbine site)	4.8	0.6	22.3	8.0	12.2	8.9	27.3	0.012	41.2	9556.7
13 (turbine site)	7.1	0.8	29.6	10.3	13.3	10.6	23.0	0.014	79.3	13505.2
21 (turbine site)	5.1	0.7	27.2	10.2	12.4	12.1	23.9	0.011	55.7	10101.3
26 (turbine site)	5.3	0.5	25.5	8.6	12.2	9.7	18.5	<0.01	41.7	7666.8
28 (turbine site)	4.5	0.6	23.6	9.0	12.8	8.7	20.9	0.012	115.6	16049.1
32 (turbine site)	6.7	0.6	23.9	6.8	13.3	9.5	23.3	0.013	71.3	12807.3
36 (turbine site)	6.6	0.5	23.7	7.8	12.7	9.7	21.5	0.025	39.4	8282.8
38 (turbine site)	10.3	0.7	11.7	5.8	10.8	5.7	15.5	0.010	41.9	6773.5
46 (turbine site)	4.5	0.7	17.5	14.6	12.3	10.8	18.9	0.014	58.8	8903.5
43 (export cable)	4.8	0.9	23.0	12.0	13.8	10.1	28.3	0.020	122.9	14730.9
90 (export cable)	4.5	1.1	26.4	10.0	16.5	10.6	24.6	0.023	198.9	17890.5
94 (export cable)	4.4	1.2	27.4	9.6	17.1	11.3	27.8	0.027	139.2	14584.7
99 (export cable)	5.3	1.1	24.0	8.1	14.4	11.2	27.6	0.026	159.4	17945.4
55 (export cable)	6.6	0.6	23.5	8.2	13.6	9.6	23.4	0.021	19.4	7227.1
61 (reference site)	5.1	1.2	26.3	17.9	15.9	11.4	30.8	0.018	80.4	10324.8
86 (reference site)	4.2	0.6	17.6	8.4	11.8	7.5	19.8	0.013	78.1	7651.3
Canadian ISQG	7.2	0.7	52.3	18.7	30.2	15.9	124.0	0.1	-	-
Canadian PEL	41.6	4.2	160.0	108.0	112.0	42.8	271.0	0.7	-	-

Table 8.7: Sediment chemistry analysis for the offshore site, coloured cells indicate concentrations that exceed Canadian ISQGs. Source: Appendix 14.1: Benthic Ecology Characterisation Survey

8.5.10 Designated Bathing Waters

118 To ensure standards are monitored, the Scottish Environment Protection Agency (SEPA) must undertake annual assessments for the parameters shown in Table 8.8, and class the status of each bathing water as either ‘excellent’, ‘good’, sufficient’ or ‘poor’. Under the Bathing Water Directive all bathing waters will be required to meet or surpass ‘sufficient’ standards by 2015 and monitoring must commence by 2012.

[3]Polycyclic Aromatic Hydrocarbons - The Environmental Protection Agency 16 priority PAHs
[4]Data from ICES, 2009 - represents no data

Parameter	Excellent	Good	Sufficient	Poor
Intestinal enterococci[5]	100[6]	200[6]	185[7]	>185[7]
***Escherichia coli*[5]**	250[6]	500[6]	500[7]	>500[7]

Table 8.8: Standards for coastal and transitional waters under the Bathing Water Directive (76/160/EEC)

119 Under the former Bathing Water Directive (76/160/EEC) sites were classed as ‘guideline’, ‘mandatory’ and ‘fail’. The ‘guideline’ category set more stringent targets and was roughly equivalent to the new ‘good’ standard. The old classing system was used until the 2011 season, when SEPA began to assess sites under the new system as defined in Table 8.8.

120 In Scotland, 83 bathing water sites were designated for the 2011 bathing season (01 June to 15 September). Results from the 2011 season indicate that 5% of Scottish bathing waters were of ‘poor’ status, 47% were ‘good’, and 48% were ‘excellent’ (SEPA, 2011a). Of the 83 sites, 29 are on the east coast in the Firth of Forth, and up to 35 km from Neart na Gaoithe (refer to Figure 8.22). The current and historic status of these bathing waters is displayed in Appendix 8.1: Shellfish and Bathing Water Quality Information. Currently, 72% are of ‘excellent’ status and the remaining 28% are of ‘good’ status. Since 2001, seven of the sites in the vicinity of the proposed development sites have failed to meet mandatory standards during monitoring, though four of these instances occurred before the relevant site was designated as bathing water. Failures are usually attributed to heavy rainfall events, which increase run-off from urban and agricultural land and may cause discharges from sewer overflows (SEPA, 2010).

121 The proposed cable route lands within the Thorntonloch designated bathing water (refer to Figure 8.22). This bathing water is approximately 1 km southeast of the Torness power station and has consistently achieved guideline standards since it was designated in 1999, and achieved ‘excellent’ status under the new classification system in 2011.

8.5.11 Designated Shellfish Waters

122 The nearest shellfish water (designated under the Shellfish Waters Directive) to the proposed Neart na Gaoithe site is Fife Ness to Elie, approximately 15 km west of the site boundary (refer to Figure 8.22). Fife Ness to Elie covers 16.95 km^2 along approximately 18 km of coast.

123 Under the Shellfish Waters Directive, and implementing regulations, shellfish waters fail to meet standards if they experience discharges that cause the site’s suspended solids to increase 30% over normal levels for 75% of the time (see Appendix 8.1: Shellfish and Bathing Water Quality Information). Fife Ness to Elie shellfish water has not historically experienced increases to suspended sediments that have caused the site to fail to meet these standards (SEPA, 2010).

124 The Fife Ness and Elie shellfish waters have consistently failed to meet the guideline levels of faecal coliforms since the site was designated in 1998. The site passed guideline standards for all other contaminants in all years apart from in 2007, 2008 and 2010 when arsenic was detected slightly above the guideline levels (but well within mandatory levels). It is thought that the source of arsenic is from rocks at Burntisland, approximately 30 km southwest of Elie, as there are no point sources in the area (SEPA, 2009).

125 There are three areas classed as shellfish harvesting areas, by the Food Standards Agency (FSA), in the region of the Fife Ness to Elie shellfish waters. These are Pittenweem and Anstruther in the southern end of the shellfish waters, and Largo Bay, approximately 5 km east of the shellfish waters (refer to Chapter 22: Other Users). Surf clams *Spisula solida* and razors *Ensis arcuatus* are harvested from these areas.

[5]Colony forming units per 100 millilitres (cfu/100 ml)
[6]Based upon a 95-percentile evaluation – see Annex II of revised Bathing Water Directive 2006/7/EC
[7]Based upon a 90-percentile evaluation – see Annex II of revised Bathing Water Directive 2006/7/EC

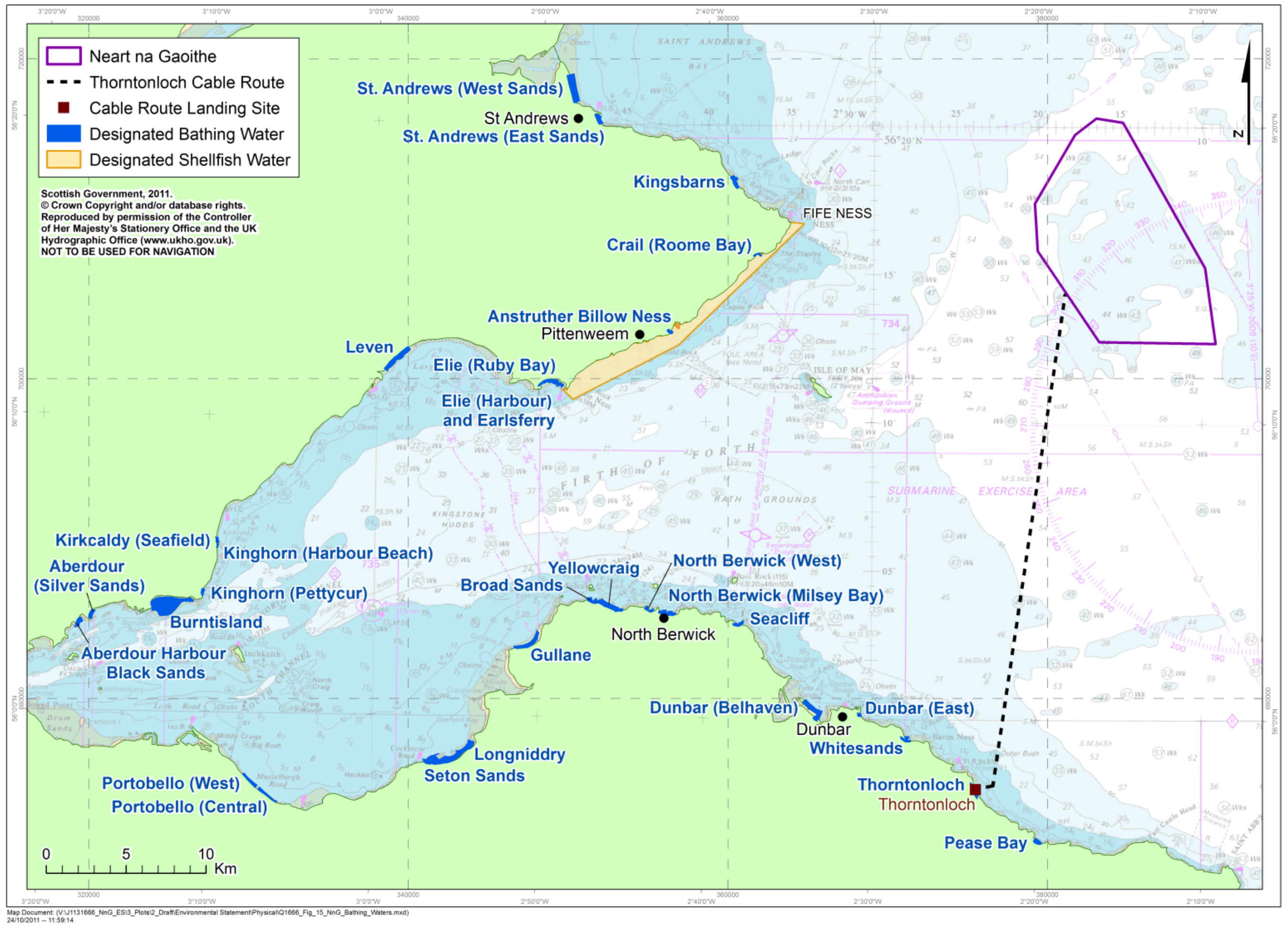

Figure 8.22: Locations of designated bathing waters and shellfish waters in the vicinity of Neart na Gaoithe. Source: Scottish Government, 2011b

126 Annex II of the Hygiene Regulation lays down controls that must be adhered to when classifying designated shellfish harvesting areas, Under the Hygiene Regulation, the FSA must classify harvesting areas according to the concentrations of bacteria in the shellfish flesh. The classes are 'A', 'B', 'C' and 'P' where Class A is the highest standard (suitable to go directly for human consumption); Class B shellfish require depuration or heat treatment before consumption; Class C shellfish need to be relayed for two months and treated; and Class P indicates that collection for human consumption is prohibited. The monitoring of the bacteria in the shellfish can be used as an indirect measure for water quality since the concentration of bacteria in the flesh relates to the quality of the water in which the shellfish grew. Two of the three harvesting areas in the Fife Ness to Elie shellfish waters are classified as Class A for part of the year, indicating that the water is of favourable quality.

8.5.12 Designated Water Bodies under the Scotland RBMP

127 The cable route runs through the 'Barns Ness to Wheat Stack' water body (ID: 200038) and the 'Firth of Forth Outer – Offshore' water body (ID: 200055). In 2008, both of these water bodies were classified as 'Good' (with overall ecological status of 'Good' and overall chemical status of 'Pass'), the water bodies will be assessed again in 2015; it is a requirement under the Water Framework Directive that there is no deterioration in status of these sights.

128 The chemical status is based on the concentrations of substances outlined in The Scotland River Basin District (Surface Water Typology, Environmental Standards, Condition Limits and Groundwater Threshold Values) Directions 2009 (Scottish Government, 2009). This includes pollutants such as metals, pesticides, polycyclic aromatic hydrocarbons and other organic substances. The ecological status is assessed by the concentrations of dissolved oxygen and inorganic nitrogen, as well as ecological quality ratios (EQRs). These are based on the condition of benthic invertebrate fauna, microalgae and phytoplankton, as well as the presence of invasive species. The water bodies are also assessed on the pressures to hydromorphology such as structures on the seabed that extend from the shoreline; however, this does not apply to outfalls pipes or cables.

8.6 Impact Assessment

129 This section considers the potential impacts of the offshore wind farm on the following receptors:

- Coastline;
- Sandbanks; and
- Water Quality.

130 The assessment takes into consideration the potential impacts on the receptors during construction, operational and decommissioning stages of the offshore wind farm and associated cable route. An assessment of cumulative and in-combination impacts has been undertaken. Monitoring or mitigation measures have been described where impacts have been assessed as moderate or major.

131 The changes to hydrodynamics (waves and tides) are discussed in Chapter 9: Physical Processes and the indirect effects of sediment deposition, movement and water quality on other receptors, such as marine mammals (Chapter 13: Marine Mammals), fish (Chapter 15: Fish and Shellfish Ecology) and benthic communities (Chapter 14: Benthic Ecology), have been assessed under the relevant chapters and, therefore, are not discussed here.

8.6.1 Impact Assessment – Coastline

132 This section identifies the potential environmental impacts the proposed development may have on the coastline. This section considers the coastline to be a sensitive receptor, and includes the coastal areas from St Abbs Head to Arbroath, including the Firth of Forth, as discussed in Section 8.7.

8.6.1.1 Offshore Site

133 Numerical modelling results (refer to Chapter 9: Physical Processes, and Appendix 9.1: Physical Processes Technical Report) predict that there will be no overlap of changes in hydrodynamic effects (waves, tides and critical shear stress) with any part of the coastline; this is primarily due to the considerable distance of the turbines from the coast. Although increased changes in waves due to cumulative developments are shown to potentially overlap with the coast (refer to Section 8.8: Cumulative and In-combination Assessment), the magnitudes (less than 2 cm) of these changes to waves are negligible. The coastline is not exposed to any predicted changes in hydrodynamics due to construction, operational and decommissioning phases of the development or similar developments in the region. As a result, the offshore site will have no impact on the coastline and has been screened out of this assessment.

8.6.1.2 Export Cable Route – Construction Phase

134 The majority of the export cable route will not have any potential impact on the coastline; however, it is important to assess the potential impacts on the nearshore zone, especially the shallow intertidal area. Potential impacts may include changes in sediment transport processes, beach erosion, beach drawdown and impacts on water quality. Since there is uncertainty regarding the seabed conditions up to 1 km from the coast, precise cable installation methods for the intertidal area have not yet been finalised. Therefore, several possible techniques have been assessed. These include directional drilling, trenching and rock armouring, and trenching and rock cutting. Further studies should be undertaken once the installation contractor has been determined and the preferred methods should be agreed, post-consent.

Impacts from Directional Drilling

135 Directional drilling would be undertaken from onshore, a duct would be drilled to approximately 600 m offshore and then the cable pulled through. This method is therefore unlikely to have an impact on the coastal hydrodynamics since there will be no structure exposed on the seabed which could interfere with currents, waves and sediment transport. As a result it is anticipated directional drilling would have no effect on coastal hydrodynamics during any of the different phases of cable route construction, operation or decommissioning, meaning the magnitude of the effect is negligible. The coastline would have high adaptability, tolerance and recoverability to such an effect, making its vulnerability negligible. Therefore the impact of directional drilling is assessed as being ***not significant*** on the coastline. This is summarised in Table 8.9.

Source	Pathway	Receptor	Magnitude of effect	Vulnerability of receptor	Significance of impact	Qualification of significance
Directional drilling	Below seabed surface changes	Coastline	Negligible	Negligible	Not Significant	Uncertainty is low Probability is low Directional drilling occurs below the seabed surface and would not affect coastal hydrodynamics.

Table 8.9: Impact assessment conclusions for impact of export cable installation for coastline (directional drilling)

Impacts from Trenching and Rock Armouring

136 Trenching and rock armouring – if directional drilling is not possible, the cable may be laid in a trench up to the rocky zone and then laid on top of the hard (rocky) substrate and covered with rock armour. The details of the rock armouring are not known at this stage, so a precautionary approach to assessment has been taken. Potential changes to the coastal hydrodynamics caused by construction machinery and localised changes to seabed depths are anticipated to be highly localised and of low duration. Therefore, the magnitude of the effect of changes to hydrodynamics due to machinery and trenching and rock armouring is considered to be low. Since the Thorntonloch beach is considered to be a fairly closed and stable system, due to the presence of rocky outcrops to the north and south (Moore and Wilson, 2006; Ramsey and Brampton, 2000a), the coastline is anticipated to have negligible sensitivity to this effect. Therefore the impact of trenching and rock armouring on the coastline during construction is assessed as being of ***minor significance***. This is summarised in Table 8.10.

Source	Pathway	Receptor	Magnitude of effect	Vulnerability of receptor	Significance of impact	Qualification of significance
Trenching and rock armouring	Changes to hydro-dynamics due to machinery, trenching and rock armouring	Coastline	Low	Negligible	Minor significance	Uncertainty is medium Probability is medium Localised changes to coastal hydrodynamics may be possible, although these would be short in duration.

Table 8.10: Impact assessment conclusions for impact of export cable installation on coastline (trenching cable plus rock armouring)

Impacts from Trenching and Rock Cutting

137 Trenching and rock cutting – this will involve trenching in the sand as far as possible and then cutting into the bedrock by use of a jack up barge, for water depths up to 10 m LAT, or a remotely operated vehicle (ROV) for deeper areas. The cable will then be installed and the trench infilled. Potential changes to coastal hydrodynamics during trenching and rock cutting relate principally to the presence of machinery and trenching and rock cutting processes. The magnitude of the effect of changes to hydrodynamics due to machinery, trenching and rock cutting is considered to be low. Since the sizes of the jack up legs are relatively small compared to the wavelength of typical waves, the effects on waves (as well as tides and sediment transport) are considered negligible. However, jack-up barge legs may create small depressions in the seabed; these have been observed to be 0.5 to 2.0 m deep in sandy gravelly areas of the Kentish Flats wind farm (EMU, 2005). It is likely that the jack-up barge will only be used in areas where there is hard substrate; even so, the sandy sediment veneer at Thorntonloch beach has high potential to infill any depressions.

138 The monitoring of the depressions found at the Kentish Flats wind farm showed that they infilled at a rate of 0.2-0.5 m every six months (EMU, 2008), proving the effect to be temporary. Since the Thorntonloch beach is considered to be a fairly closed and stable system due to the presence of rocky outcrops to the north and south (Moore and Wilson, 2006; Ramsey and Brampton, 2000a), the coastline is anticipated to be highly adaptable and tolerant to change and therefore, has negligible vulnerability to this effect. Therefore the impact of trenching and rock cutting on the coastline during construction is assessed as being of ***minor significance***. This is summarised in Table 8.11.

Source	Pathway	Receptor	Magnitude of effect	Vulnerability of receptor	Significance of impact	Qualification of significance
Trenching and rock cutting	Changes to hydro-dynamics due to machinery and trenching and rock cutting	Coastline	Low	Negligible	Minor significance	Uncertainty is medium Probability is medium Localised changes to coastal hydrodynamics may be possible, although these would be short in duration.

Table 8.11: Impact assessment conclusions for impact of export cable installation for coastline (trenching cable plus rock cutting)

8.6.1.3 Export Cable Route – Operation and Maintenance Phase

Impacts from Presence of Export Cables

139 If the cable is buried through the nearshore area (i.e., for trenching and rock cutting), it is presumed that the seabed will be returned to its original elevation (i.e., the trench will be infilled). Therefore changes to the coastal

hydrodynamics would be negligible, unless maintenance of the cable was required. If that occurs, then the effects would be similar to the construction phase.

140 If the cable is laid on top of the seabed and protected by rock armour, it is presumed that the rock armour will result in localised changes in the seabed topography up to 1 m. The presence of rock armouring in the intertidal zone may potentially impact coastal hydrodynamics (see Chapter 9: Physical Processes). Although this change is predicted to be localised, it would be permanent. The coastline is anticipated to have low vulnerability to these localised, though permanent, effects. Therefore the impact of trenching and rock armouring on the coastline during the operational phase is assessed as being of ***minor significance***. This is summarised in Table 8.12.

Source	Pathway	Receptor	Magnitude of effect	Vulnerability of receptor	Significance of impact	Qualification of significance
Rock armouring	Changes in hydro-dynamics due to rock armouring installation	Coastline	Low	Low	Minor significance	Uncertainty is medium/high Probability is medium/high Localised changes to coastal hydrodynamics may be possible; however, these would be permanent.

Table 8.12: Impact assessment conclusions for impact of export cable operation on coastline (rock armouring over cables)

8.6.2 Impact Assessment – Sandbanks

141 There are no sandbanks (or significant bedforms) within the development area, its vicinity or along the cable route (refer to Sections 8.5.2 to 8.5.4), hence this receptor has been screened out of the assessment. Therefore, potential impacts on sandbanks are not considered further.

8.6.3 Impact Assessment – Water Quality

142 This section identifies the potential environmental impacts the proposed development may have on water quality receptors. This section considers water quality monitoring sites to be sensitive receptors. For the outer Firth of Forth, these are primarily designated bathing waters, shellfish waters and the Scotland RBMP water bodies, which must conform to the requirements of the Water Framework Directive.

8.6.3.1 Offshore Site - Construction Phase

Disturbance to Contaminated Sediments

143 Natural and anthropogenic activities have the potential to disturb contaminated sediments and sediment pore water allowing sediment bound contamination to be remobilised into the water column. The construction of the proposed development will cause disturbance to sediments during foundation and cable installation.

144 Disturbances of sediments can expose those with a low redox potential (reducing environment). On mixing with the water column, contaminants can partition from the sediments into the water column. Once in the water column, contaminants are bioavailable to organisms. Surface sediments were tested for contaminants during the Benthic Characterisation Survey (see Appendix 14.1 Benthic Ecology Characterisation Survey). The results, summarised in Section 8.5.9, show that none of the samples exhibited levels of contaminants greater than Canadian PELs, which are concentrations likely to frequently cause adverse effects to organisms if ingested.

145 One sample from the site exhibited concentrations of arsenic higher than Canadian ISQGs (Arsenic = 10.3 mg/kg, and ISQG = 7.2 mg/kg), this sample was taken from the southeastern area of Neart na Gaoithe (grab site number 38, see Appendix 14.1: Benthic Ecology Characterisation Survey). It is thought that there is a natural source of arsenic from the geology at Burntisland, in the Forth Estuary, to which elevations may be attributed (SEPA, 20011b). The concentration remains below Canadian PEL and therefore can occasionally cause adverse effects in biota if ingested. One sample within the northwest of the Neart na Gaoithe site also exceeded the Canadian ISQGs for cadmium with a concentration of 0.8 mg/kg compared to the ISQG of 0.7 mg/kg (grab site number 13, see Appendix 14.1: Benthic Ecology Characterisation Survey. Since this is well below the PEL (of 4.2 mg/kg) it may occasionally cause adverse ecological effects. All other contaminants were below the ISQG and therefore are unlikely to cause adverse effects on biota.

146 There are currently no water quality monitoring conditions assigned to neighbouring offshore wind farms as they are still in the process of applying for a marine licence. Therefore, the nearest sensitive receptors are Scotland RBMP water bodies, shellfish waters and bathing waters; approximately 15 km and 18 km from the site respectively.

147 Due to low concentrations of existing contaminants and the distance of the site from designated waters, the effect of contaminant disturbance is considered to be of negligible magnitude.

148 The receptors include Scotland RBMP water bodies, shellfish waters and bathing waters. The vulnerability of the receptors is considered medium due to the international designation and the inability to adapt, but in these circumstances (where the contaminants will be heavily diluted if they travel as far as the receptors) the sites will be able to tolerate and recover from small changes. There is an extremely low probability that sediment-bound or aqueous contaminants will dissipate as far as the receptors, and reach the coast in harmful concentrations. Therefore, the impact of disturbance to sediments is considered to be ***not significant*** (refer to Table 8.13).

Source	Pathway	Receptor	Magnitude of effect	Vulnerability of receptor	Significance of impact	Qualification of significance
Piling and cable trenching	Disturbance to contaminated sediments	Designated waters	Negligible	Medium	Not significant	Uncertainty is low and the probability of the impact is extremely low. Given the dynamic nature of the environment, the probability is extremely low due to the mixing and dilution of contaminants.

Table 8.13: Impact assessment conclusions for offshore site for impact of contaminated sediment disturbance on water quality/designated waters

Discharge of Contaminants from Machinery and Vessels

149 The presence of vessels and machinery creates the potential for the occurrence of spillages of oil, lubricants and building materials during construction. The probability of pollution from ships will be minimised by abiding by the MARPOL Convention regulations and following best practice, including on site monitoring and reporting.

150 The magnitude of the effect of a spill will vary greatly depending on the circumstances. A precautionary approach has been taken for the impact assessment, assuming that the spillage will be large and composed of a hazardous substance. In this case the magnitude of the effect will be high.

151 The vulnerability of the shellfish water quality is considered high. Given that the designation depends on thresholds for contaminant concentrations, it will not tolerate pollution incidents and cannot adapt. The site is designated under international legislation, meaning it is of high value and, depending on the type of spill, may take years to recover.

152 This vulnerability means that if any release of contaminant occurs, there will be a ***major significance.*** However, the probability of a contaminant spill is extremely unlikely and there is high uncertainty over the potential spill circumstances, therefore the overall impact has been lowered to ***moderate significance*** (refer to Table 8.14).

Source	Pathway	Receptor	Magnitude of effect	Vulnerability of receptor	Significance of impact	Qualification of significance
Presence of vessels and machinery	Accidental spills or leaks of pollutants	Designated waters	High	High	Moderate Significance	Uncertainty is medium. Probability is very low. As a precautionary approach, the magnitude and vulnerability are considered high which would result in the impact being considered as major significance but due to uncertainty and an extremely low probability the impact is considered overall to be of ***moderate significance***.

Table 8.14: Impact assessment conclusions for offshore site for impact of accidental discharge on water quality/designated waters

Increased Suspended Sediments

153 Sediment plumes from the construction of Neart na Gaoithe were predicted to reach localised peaks of 300 mg/l, but remain within the offshore site and settle out within one day (refer to Appendix 9.1: Physical Processes Technical Report). There are no bathing or shellfish waters within approximately 8 km of the offshore site; therefore, the increase in suspended sediment is unlikely to affect the status of any designated bathing waters.

154 To pass the criteria set by the Shellfish Waters Directive, Fife Ness to Elie (the nearest designated shellfish waters) must not experience discharges that cause the site's suspended solids to increase 30% above normal levels for 75% of the time. Fife Ness to Elie is approximately 15 km from the offshore site, so sediment plumes from the proposed development are unlikely to affect the status of this site. Since there are no water quality receptors in the proximity of Neart na Gaoithe, it is anticipated that increases in suspended sediment resulting from the project will have no impact on water quality receptors.

8.6.3.2 Offshore Site - Operation and Maintenance Phase

Discharge of Contaminants from Maintenance Machinery and Vessels

155 Routine maintenance of the turbines has potential to introduce contaminants during the replacement of lubricants and hydraulic fluids. Best practice methods will be used for the transportation and storage of hazardous substances, which will be disposed of on land. Vessels will also undergo correct servicing to prevent the leakage of vessel fuel and lubricants.

156 The impacts of this effect during operation are anticipated to be similar or less than those described for construction (refer to relevant subsection in Section 8.6.3.1: Offshore Site - Construction Phase). This concluded that the impact is of ***moderate significance***.

Increased Suspended Sediment

157 During operation of the proposed development, concentrations of suspended sediments may increase slightly due to small changes to water current velocities, caused by the presence of the foundations, thereby creating a scour effect. Increases due to scour are expected to be very localised and return to normal levels 250 m from the structures. Since there are no sensitive water quality receptors within this distance, the effect is anticipated to cause no impact.

8.6.3.3 Export Cable Route – Construction Phase

Disturbance to Contaminated Sediments

158 Approximately 13.5 km of the proposed export cable will pass through the outer Firth of Forth, designated in accordance with the Water Framework Directive and the Scotland RMBP. A survey of the surface sediments along the export cable route showed that contaminant concentrations were below Canadian PELs, with only the concentration of cadmium being greater than ISQGs (highest observed concentration equalled 1.2 mg/kg, compared to an ISQC is 0.7 mg/kg and PEL is 4.2 mg/kg). Levels below ISQGs are rarely considered to cause adverse biological effects. Concentrations exceeding the ISQG, may occasionally cause adverse effects. The elevated levels of cadmium are thought to be due to the accumulation of past sewage discharges at a historical industrial discharges site at Wallyford, further within the Firth of Forth (SEPA, 1998). The desorption rates of cadmium into the dissolved phase increase in areas of high salinity (Comber *et al*., 1995) but cadmium becomes less bioavailable in higher salinities due to complexation with chloride ions and organic binding competition with other metals (Forstner, 1989). Although there is high uncertainty when estimating the quantity of sediment-bound contaminants that will desorb. The salinity of the Firth of Forth generally increases with distance from Stirling (SEPA, 2000), making the export cable route an area of marine salinity (approximately 34 practical salinity units (psu) measured at 55 m depths within the offshore site) (ICES, 2009); average ocean salinity ranges from 32 to 37 psu). However, the existing sediment concentrations will not frequently cause adverse biological effects.

159 Due to the negligible concentrations of contaminants, the negligible frequency of disturbance over a single point and the small extent, the magnitude of the effect to contaminant disturbance is considered to be ***negligible***. The receptors are the Scotland RBMP water bodies and Thorntonloch bathing waters (shellfish waters and other bathing waters are considered to be outside the extent of the effect). These have high value and a low tolerance, which are dictated by legislation. Due to the dissipation of contaminants in this high energy environment the receptors are considered to have high recoverability therefore, they are of medium vulnerability. Overall, the impact is assessed to be of ***minor significance***. This is summarised in Table 8.15.

Source	Pathway	Receptor	Magnitude of effect	Vulnerability of receptor	Significance of impact	Qualification of significance
Cable trenching	Disturbance to contaminated sediments	Designated waters	Negligible	Medium	Minor Significance	Uncertainty is high. Probability is medium. There is high uncertainty regarding the potential for contaminants to be released into the water column due to trenching. The magnitude of the effect is likely to be negligible and the vulnerability of the receptors are medium.

Table 8.15: Impact assessment conclusions for export cable route for impact of contaminated sediment disturbance (construction) on water quality/designated waters

160 The export cable runs through the Thorntonloch bathing water; the status of designated bathing waters is not sensitive to contaminant concentrations and is completely dependent on bacterial concentrations (impacts to these are further discussed in the subsection 'Increased Suspended Sediments', in this Section: 'Cable Route', and 'Construction') and is not considered sensitive to this effect. The nearest shellfish waters are Fife Ness to Elie (approximately 17 km from the export cable at the nearest point). To pass the criteria set in the Shellfish Waters Directive, this water must not have concentrations of metals, organohalogenated substances or hydrocarbons that will cause harm to shellfish and their larvae. It is therefore considered to be a sensitive receptor. However, the distance from the works means that any water-bound contaminants will be sufficiently diluted before reaching the shellfish waters so the effect will not overlap with the receptor. Overall the disturbance will cause no impact to bathing or shellfish waters.

Discharge of Contaminants from Machinery and Vessels

161 The presence of vessels and machinery creates the potential for the occurrence of spills or leaks of hazardous substances. The substances used for the installation of the cable are less toxic than those used for the construction on site; these are described in Chapter 5: Project Description. The probability of pollution from ships will be minimised by abiding by the MARPOL Convention regulations and following best practice.

162 The magnitude of the effect of a spillage will vary greatly depending on the circumstances but are not expected to consist of large amounts of hazardous substances (as the cable does not require any) but the precautionary approach will be taken for the impact assessment. In this case the magnitude of the effect is considered medium.

163 The status of bathing waters are not assessed based on contaminants (relying solely on bacterial concentrations), therefore they are not directly sensitive to potential spills. Dependent on the substance, spills may indirectly increase the organic matter available to bacterial colonies and cause increases in concentrations. The vulnerability of designated shellfish waters is considered to be high. Given that its designation depends on thresholds for contaminant concentrations, it will not tolerate pollution incidents and cannot adapt. The site is designated under international legislation, meaning it is of high value but due to the nature of the potential effect, will recover quickly.

164 Consequently, if a spill occurs, it is likely to have an impact of ***major significance***. However, the probability of a contaminant spill is extremely unlikely and there is high uncertainty over the potential spill circumstances, therefore the overall impact has been lowered to ***moderate significance***. This is summarised in Table 8.16.

Source	Pathway	Receptor	Magnitude of effect	Vulnerability of receptor	Significance of impact	Qualification of significance
Presence of vessels and machinery	Accidental spills or leaks of pollutants	Designated waters	Medium	High	Moderate significance	Uncertainty is medium. Probability is very low. As a precautionary approach, the magnitude and vulnerability are considered high which would result in the impact being considered as major significance but due to uncertainty and an extremely low probability the impact is considered overall to be of ***moderate significance***.

Table 8.16: Impact assessment conclusions for export cable route for impact of accidental spillage (construction) on water quality/designated waters

Increased Suspended Sediments

165 During the construction of the proposed development, suspended sediments will be generated as a result of disturbances to the seabed. Disturbances to sediments indirectly affect water quality by causing inflows of dissolved oxygen into previously anoxic sediments, which results in increases of microbial (especially thiobacteria) activity. It also encourages the growth of other aerobic bacteria that may make use of any organic material that has become available from within the sediments. Both these effects have the potential to lower water column dissolved oxygen concentrations. Sediment samples from the offshore site, taken in 1995, suggest that a low percentage of organic carbon was present in the sediment (0.23%) (ICES, 2009).

166 The increase in turbidity, resulting from higher concentrations of suspended sediments, also restricts sunlight penetration. Sunlight has been shown to have a bactericidal effect on faecal coliforms and faecal streptococci in seawater (Fujioka *et al.*, 1981). Areas with elevated suspended sediment concentrations may exhibit small increases in bacteria levels, which may temporarily affect bathing water standards of designated sites. The proposed landfall is in Thorntonloch bathing water, which must be monitored for faecal bacteria annually during the bathing season to meet levels defined by the Bathing Water Directive.

167 The Neart na Gaoithe Physical Processes Technical Report (Appendix 9.1: Physical Processes Technical Report) predicted that suspended material concentrations around the offshore export cable route may peak at 30 mg/l during installation, but will settle out within a few hours of disturbance, making the effect relatively short-lived. The Physical Processes Technical Report also confirmed that sediment plumes will not be advected as far as 5 km, and the sediment will be deposited within 2 km of the cable. The next nearest bathing waters (after Thorntonloch) are Whitesands and Pease Bay (refer to Figure 8.22), which are 5 and 5.3 km respectively from the cable route and are, therefore, unlikely to be affected by sediment plumes resulting from the cable installation. The nearest shellfish waters are Fife Ness to Elie, approximately 17 km from the export cable and will therefore not be impacted.

168 The effect will cover a relatively small extent and have a very short duration. The change is not severe and will only occur during the installation of the cable; therefore the magnitude of the effect is negligible.

169 The bathing water will not be able to adapt to effects, and is of high value, but the effects will be very small (given the low percentage of sediment organics) and tolerable. The dynamic nature of the area also means that the recovery will be fast. Therefore, the vulnerability of the receptor is considered to be low.

170 Due to the low probability of turbidity causing sufficiently large increases in microbial levels to cause a failure of the bathing water, the impact has been assigned a ***minor significance***. This is summarised in Table 8.17.

Source	Pathway	Receptor	Magnitude of effect	Vulnerability of receptor	Significance of impact	Qualification of significance
Cable trenching	Increased suspended sediments	Designated waters	Negligible	Low	Minor significance	Uncertainty is high. Probability is low. Although there is potential for suspended sediments to indirectly affect the microbial concentrations at Thorntonloch bathing water, it is unlikely that these will cause the site to fail its assessment.

Table 8.17: Impact assessment conclusions for export cable route for impact of increased SSC (construction) on water quality/designated waters

Nearshore Cable Route Assessment - Increased Suspended Sediments

171 Although cable burial methods at the landfall have not been decided, direct-drilling is the preferred option. There is a slight chance that the drilling lubricant (bentonite - an inert substance) might be released at the end of the bore, when the drill breaks the surface. Since the lubricant used is a non-hazardous substance, and will be monitored by the contractor, the effect of the release of this substance is mostly of concern in terms of increases to suspended solids, discussed below.

172 Since there is uncertainty regarding the seabed conditions up to 1 km from the coast, precise cable installation methods have not yet been finalised. Therefore, several possible techniques have been assessed.

173 Directional drilling may be used to create a duct under the shore and intertidal area (to approximately 600 m offshore), through which the cable can be passed. Drilling presents a potential source of sediments as they are ejected from the duct route; however, arisings will be circulated back to shore and stored within the onshore working area. Some drilling lubricant (bentonite) may enter the water column as the drill breaks the seabed surface, however, this event will be monitored by the contractors. It is anticipated that the magnitude of the effect will be negligible, due to the lack of finer sediments and the low duration and frequency of works. The receptor (Thorntonloch bathing water and the Scottish RBMP water bodies) are of medium vulnerability due to their high value but is thought to be tolerant to this effect as it is of a small magnitude. There is uncertainty as to whether this effect will occur, and the sediment plume generated from drill arisings has not been modelled, hence, it has high uncertainty. Therefore, the significance of the impact is assessed to be of ***minor significance***. This is summarised in Table 8.18.

174 Of the remaining options (trenching and rock cutting or trenching and rock armouring), trenching with rock cutting is considered to be the worst case in terms of suspended sediment production. Cutting of the bedrock may cause dispersion of the overlaying sand veneer and fine rock cuttings. The suspension of the sand will be short-lived and rapidly return to background levels, as this is a dynamic environment with sand as the natural seabed. Larger rock fragments are considered to settle out quickly as, generally, larger and denser particles have higher settling velocities (Curran *et al*., 2007). The production of suspended sediment in this dynamic environment is unlikely to provide conditions to allow bacteria levels to increase or affect the status of the Barns Ness to Wheat Stack coastal water body with relation to the Water Framework Directive. Therefore, the effect is considered to be of negligible magnitude. The receptor remains of medium vulnerability due to the high value but is thought to be tolerant to this effect due to the highly dynamic nature of the intertidal area. There is uncertainty associated with this effect as the sediment plume generated from rock cutting has not been modelled, so it has high uncertainty. The significance of the impact is anticipated to be of ***minor significance.***

Source	Pathway	Receptor	Magnitude of effect	Vulnerability of receptor	Significance of impact	Qualification of significance
Direct drilling in the coastal and intertidal areas	Increased suspended sediments	Designated waters	Negligible	Medium	Minor significance	Uncertainty is high Probability is high. Although there is potential for suspended sediments to indirectly affect the microbial concentrations at Thorntonloch bathing water, it is unlikely that these will cause the site to fail its assessment.
Trenching and cutting into bedrock	Increased suspended sediments	Designated waters	Negligible	Medium	Minor significance	

Table 8.18: Impact assessment conclusions for export cable route for impact of increased SSC (construction) on water quality/designated waters (nearshore)

8.6.3.4 Export Cable Route - Operation and Maintenance

Increased Suspended Sediments

175 Based on the scenario modelled for the assessment of physical processes (Chapter 9: Physical Processes), the subtidal part of the cable, during operation, is not likely to affect concentrations of suspended sediments as the cable will be buried and will not cause any scour effects. Therefore, the effects of changes to water quality, caused by the buried export cable operation, have been screened out as they will not occur. If re-burial of the cable is required, the impacts will be similar to those assessed for the construction period.

Nearshore Cable - Increased Suspended Sediments

176 During operation, if directional drilling or trenching/rock cutting were used to install the cable, there would not be a substantial change to the hydrodynamics at the site as the seabed would remain the same as baseline conditions. However, if rock dumping is used, the resulting raised substrate may cause a scour effect and increase suspended sediment concentrations. Since this scenario has not been modelled, there is very high uncertainty as to the magnitude of the effect, however it is likely to be localised. If this method is used near the coast it may affect suspended sediment concentrations at Thorntonloch bathing water. The status of the site does not depend on these concentrations but they may have a secondary effect on bacteria levels as sunlight penetration is reduced, therefore this secondary effect will be assessed.

177 The magnitude of the effect of increased bacterial levels will be negligible as areas where rock dumping may be required are limited to shallow waters according to the BGS maps (approx. 40 m depths) where sunlight penetration will be high, limiting bacterial production (Fujioka *et al*., 1981). The receptor is Thorntonloch bathing water; this site will be sensitive to potential increases in bacterial production. Due to the high-energy nature of the water at this site, recoverability is anticipated to be rapid. Existing raised structures exist in the region (e.g., The Reef, approximately 200 m north of the cable as it passes through mean low water). Thorntonloch bathing water has remained as guideline/excellent status despite the scour effect of this feature, indicating that this effect does not cause considerable increases in bacterial concentrations at this site. Therefore the impact is considered to be ***not significant***. This is summarised in Table 8.19.

Source	Pathway	Receptor	Magnitude of effect	Vulnerability of receptor	Significance of impact	Qualification of significance
Scour effect of rock armour	Increase in suspended sediment affecting bacteria	Thorntonloch bathing water	Negligible	Negligible	Not significant	Uncertainty is high. Probability is low. Although there is potential for suspended sediments to indirectly affect the microbial concentrations at Thorntonloch bathing water, it is unlikely that these will cause the site to fail its assessment as they will be of negligible magnitude.

Table 8.19: Impact assessment conclusions for export cable route for impact of increased SSC (operation and maintenance) on water quality/designated waters (nearshore)

8.6.3.5 Decommissioning

178 The potential water quality impacts are considered to be similar to those described for construction. These will mainly comprise the suspension of sediments and the accidental spillage of contaminants during the dismantling of turbines. Machinery will contain any leakages that occurred through the operational phase but with careful working procedures and good management, spills will be unlikely. A decommissioning plan will be agreed with the regulators. This will fully assess the impacts and, where necessary, put in place mitigation measures.

8.7 Mitigation and Residual Impacts

8.7.1 Coastline

179 No mitigation measures are required, and therefore residual impacts are the same as initially assessed.

8.7.2 Water Quality

8.7.2.1 Discharge of Contaminants from Machinery and Vessels

180 The construction contractors will be required to produce Site Environmental Management Plans (SEMP) and Pollution Control and Spillage Response Plans prior to construction works. These plans will further reduce the probability of accidental spillage and formalise a contingency plan in the event that one does occur, thereby reducing the impact by restricting a pathway to potential receptors.

181 The residual impact is therefore considered to be of ***minor significance*** (refer to Table 8.20).

Source	Pathway	Receptor	Significance pre-mitigation	Mitigation	Residual impact significance	Qualification of significance
Presence of vessels and machinery	Accidental spills or leaks of pollutants	Designated waters	Moderate significance	Application of a SEMP and Pollution Control and Spillage Response Plan	Minor Significance	The plans will reduce the impact by decreasing the probability of it occurring and reducing the magnitude of the effect.

Table 8.20: Mitigation and residual impacts for impact of accidental spillage on water quality/designated waters

8.8 Cumulative and In-Combination Impacts

8.8.1 Coastline

182 Based on the physical processes model results (refer to Appendix 9.1: Physical Processes Technical Report), which has modelled other offshore wind farms in the region, no significant cumulative impacts are expected to result from changes to wave climate (refer to Figure 8.23), changes to tidal regime (refer to Figure 8.24) or bed shear stress (refer to Figure 8.25) as there is no overlap of the effect with the receptor.

8.8.2 Water Quality

183 No significant cumulative or in-combination impacts on marine water and sediment quality have been identified, except for the potential for accidental spillage or leakage. Following best practice and observation of MARPOL Convention regulations, this risk should be managed to be as low as reasonably practicable during the installation, operation and decommissioning phases. As the potential effect is associated with extremely low probability accidents, there are no predicted cumulative effects.

8.9 Monitoring

184 Based on the impact assessment, no monitoring is expected to be necessary for the coastline.

185 It is recommended that if trenching and rock cutting are undertaken in the nearshore area, the suspended solids should be monitored to ensure that concentrations remain within acceptable limits (to be agreed with regulators). If directional drilling is undertaken, the push through the seabed should be monitored to ensure lubricant fluid release is minimised, and is within acceptable levels. Further survey work should be undertaken if the use of rock armouring on the nearshore section of the cable is needed. Surveys should determine the exact nature of the seabed throughout the whole nearshore region to enable careful design of the rock protection.

186 It is anticipated that water quality monitoring at Neart na Gaoithe will not be necessary due to the Impact Assessment concluding minimal impacts. However, the requirement for monitoring should be discussed with consultees. If needed, an appropriate water quality monitoring plan should be set up and undertaken during the construction phase and early operation phase to confirm the findings of the assessment. The monitoring plan should be agreed with the Scottish Environment Protection Agency and Marine Scotland.

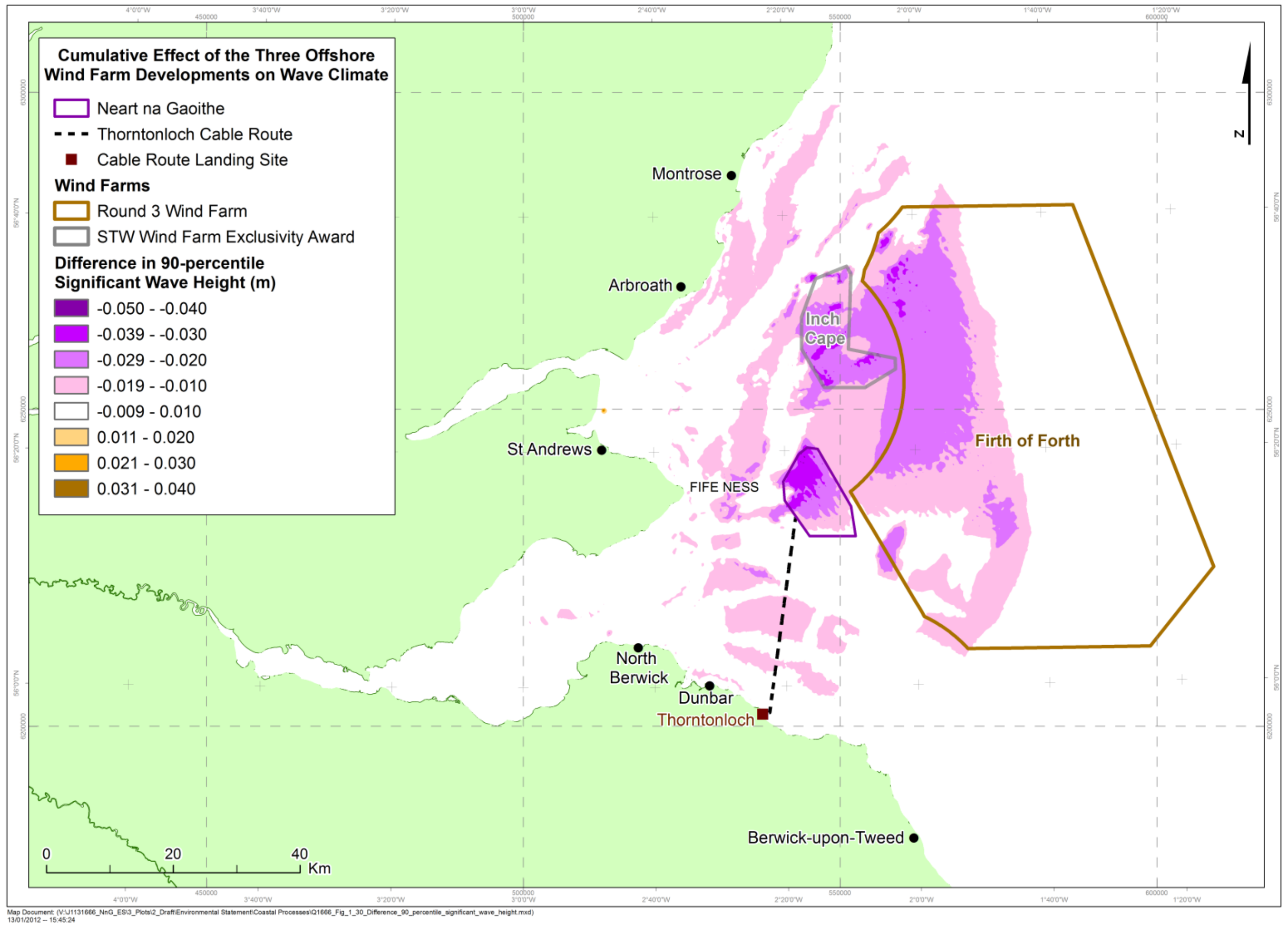

Figure 8.23: Cumulative effect of the three offshore wind farm developments on 90th percentile wave height

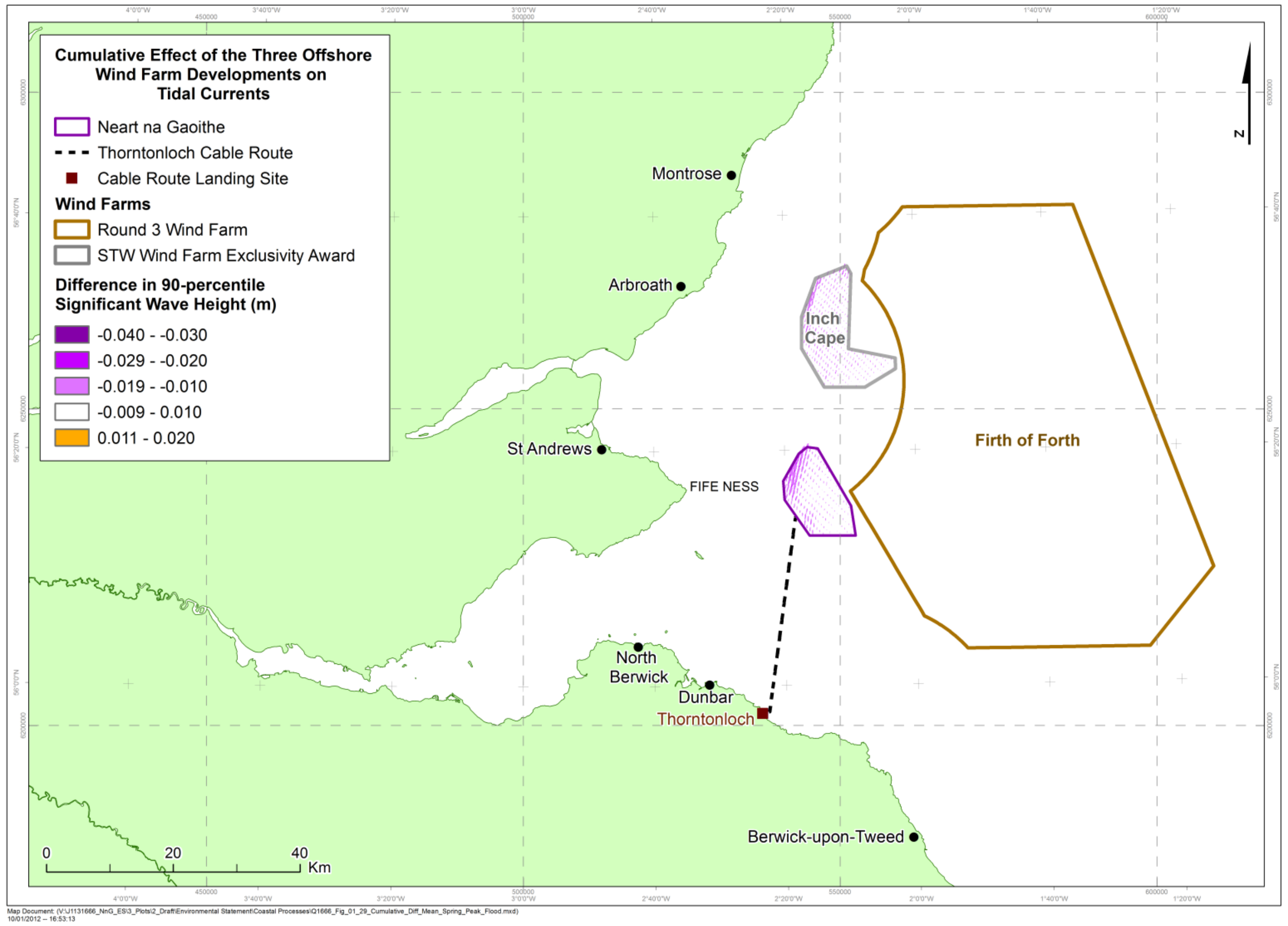

Figure 8.24: Cumulative effect of the three offshore wind farm developments to mean spring tide peak flood current speed (m/s)

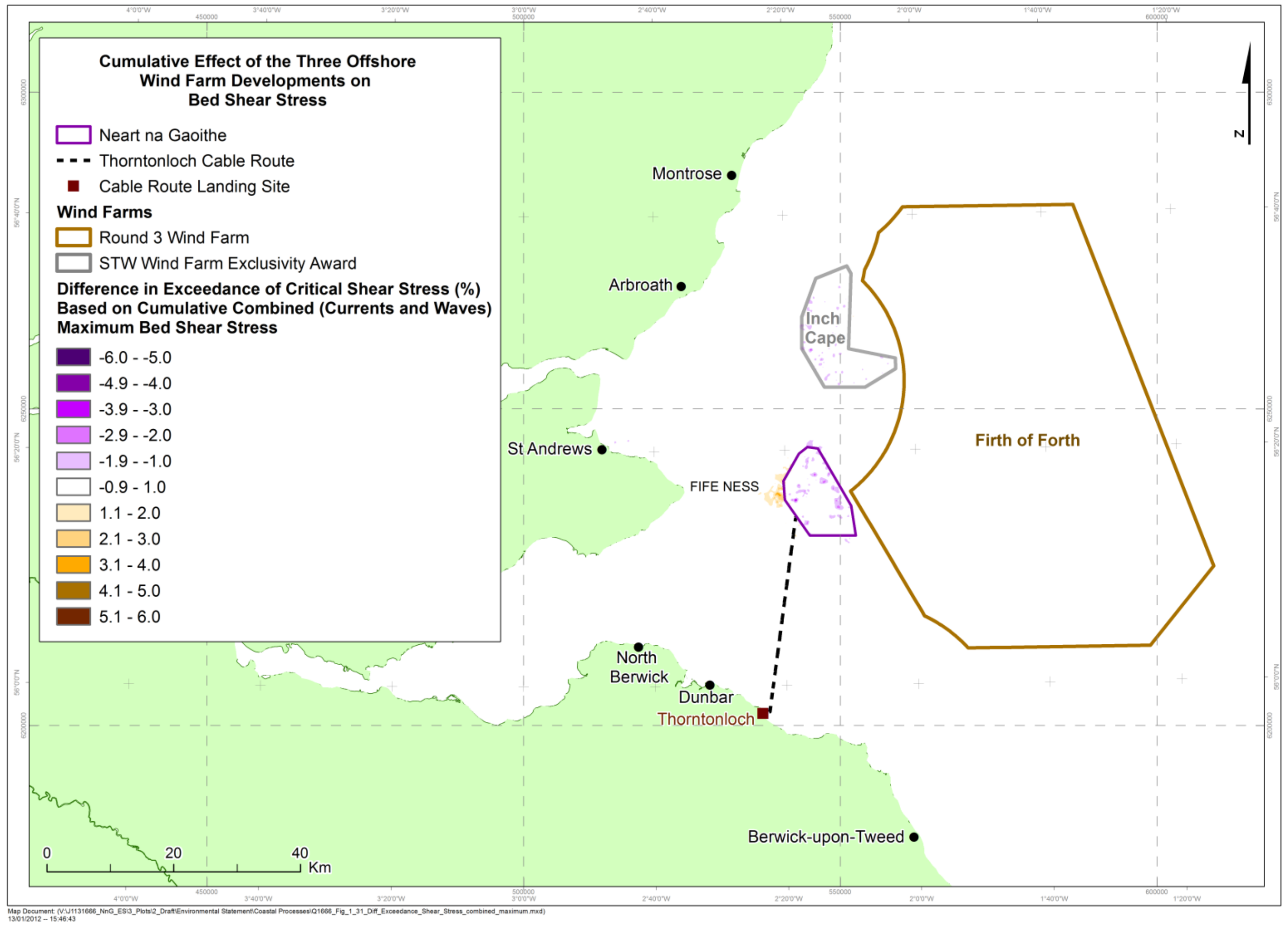

Figure 8.25: Cumulative difference in the exceedance of critical shear stress (%) – based on the combined (currents plus waves) mean bed shear stress – far-field

8.10 Summary and Conclusions

187 A summary of all assessed impacts is detailed in Table 8.21.

8.10.1 Coastline

188 No impacts due to the development are predicted on the coast since there is no overlap with changes in hydrodynamic forcing (waves and tidal currents). Although increased changes in waves, due to cumulative developments, are shown to potentially overlap with the coast (refer to Figure 8.23), the magnitudes (less than 2 cm) of these changes to waves are negligible. No overlap is predicted for changes in tidal current or critical shear stress and the coastline (refer to Figures 8.24 and 8.25).

8.10.2 Sandbanks

189 Since sandbanks are not present within the development area, in the vicinity or along the cable route, this receptor has been screened out of the assessment.

8.10.3 Water Quality

190 The offshore site has been identified as having potential impacts on designated shellfish and bathing waters of minor significance. This assumes mitigation measures, including an SEMP and Pollution Control and Spillage Response Plan, are followed. Impacts of minor significance include the potential spill or leak of contaminants from machinery or vessels (during the construction, operation and decommissioning) and the increase of suspended sediment concentrations from installation causing raised bacteria levels. Both these impacts have a low probability but a precautionary approach has been taken for the assessment.

191 The impact of disturbances to contaminated sediments and the consequent impact on Fife Ness to Elie shellfish waters was found to be not significant. It was considered that low concentrations in the sediments and large distances to the designated site meant that any changes to the receptor would not be significant and would therefore be unlikely to affect its status. Following best practice, no cumulative or in-combination impacts are anticipated.

Source	Pathway	Receptor	Significance of impact	Mitigation	Significance post-mitigation	Cumulative/in-combination impact significance	Qualification of significance
Construction							
Directional drilling (nearshore)	Below seabed surface changes	Coastline	Not significant	None identified	None identified	None identified	Uncertainty is low, probability is low. Directional drilling occurs below the seabed surface and would not affect coastal hydrodynamics.
Trenching and rock armouring (nearshore)	Changes to hydro-dynamics due to machinery, trenching and rock armouring		Minor significance				Uncertainty is medium, probability is medium. Localised changes to coastal hydrodynamics may be possible, although these would be short in duration.
Trenching and rock cutting (nearshore)	Changes to hydro-dynamics due to machinery and trenching and rock cutting		Minor significance				Uncertainty is medium, probability is medium. Localised changes to coastal hydrodynamics may be possible, although these would be short in duration.
Piling and cable trenching	Disturbance to contaminated sediments	Water quality/ designated waters	Not significant				Uncertainty is low and the probability of the impact is extremely low. Given the dynamic nature of the environment, the probability is extremely low due to the mixing and dilution of contaminants.
Cable trenching	Disturbance to contaminated sediments		Minor significance				Uncertainty is high, probability is medium. There is high uncertainty regarding the potential for contaminants to be released into the water column due to trenching. The magnitude of the effect is likely to be negligible and the vulnerability of the receptors are medium.
Presence of vessels and machinery	Accidental spills or leaks of pollutants		Moderate significance	Following best practice and observation of MARPOL Convention regulations. Application of a SEMP and Pollution Control and Spillage Response Plan	Minor significance	None identified other than the potential for accidental spillage or leakage. Following mitigation this risk should be managed to be as low as reasonably practicable during the installation, operation and decommissioning phases.	As a precautionary approach, the magnitude and vulnerability are considered high which would result in the impact being considered as major significance but due to uncertainty and an extremely low probability the impact is considered overall to be of **moderate significance**. Mitigation - the plans will reduce the impact by decreasing the probability of it occurring and reducing the magnitude of the effect.
Cable trenching	Increased suspended sediments		Minor significance	None identified	None identified	None identified	Uncertainty is high, probability is low. Although there is potential for suspended sediments to indirectly affect the microbial concentrations at Thorntonloch bathing water, it is unlikely that these will cause the site to fail its assessment.
Direct drilling in the coastal and intertidal areas	Increased suspended sediments		Minor significance				Uncertainty is high, probability low. Although there is potential for suspended sediments to indirectly affect the microbial concentrations at Thorntonloch bathing water, it is unlikely that these will cause the site to fail its assessment.
Trenching and cutting into bedrock (nearshore)	Increased suspended sediments		Minor significance				
Operation and Maintenance							
Rock armouring (nearshore)	Changes in hydro-dynamics	Coastline	Minor significance	None identified	None identified	None identified	Uncertainty is medium/high, probability is medium/high Localised changes to coastal hydrodynamics may be possible; however, these would be permanent.
Scour effect of rock armour (nearshore)	Increase in suspended sediment affecting bacteria	Thorntonloch bathing water	Not significant				Uncertainty is high, probability is low. Although there is potential for suspended sediments to indirectly affect the microbial concentrations at Thorntonloch bathing water, it is unlikely that these will cause the site to fail its assessment as they will be of negligible magnitude.

Table 8.21: Impact assessment summary for geology and water quality

8.11 References

Bates, C.R., Moore, C.G., Malthus, T., Mair, J.M., and Karpouzli, E., 2003. B*road scale mapping of habitats in the Firth of Tay and Eden Estuary, Scotland.* Scottish Natural Heritage.

BGS (British Geological Survey), 1986a. *Tay Forth, Sea Bed Sediments, 1:250 000 Series.*

BGS (British Geological Survey), 1986b. *Tay Forth, Solid, 1:250 000 Series.*

BGS (British Geological Survey), 1987. *Tay Forth, Quaternary, 1:250 000 Series.*

Comber, S. D. W., Gunn, A. M., and, Whalley, C., 1995. Comparison of the Partitioning of Trace Metals in the Humber & Mersey Estuaries. *Marine Pollution Bulletin*, 30 (12), 851-860.

Curran, K. J., Hill, P. S., Milligan, T. G., Mikkelsen, O. A., Law, B., Durrieu de Madron, X., Bourrin, F., 2007. Settling velocity, effective density, and mass composition of suspended sediment in a coastal bottom boundary layer, Gulf of Lions, France. C*ontinental Shelf Research,* 27, 1408–1421.

DECC (Department of Energy and Climate Change), 2004. *Strategic Environmental Assessment 5.* Available online from: http://www.offshore-sea.org.uk/consultations/SEA_5. [Accessed Jun 2011].

EMU, 2005. *Kentish Flats offshore wind farm post-construction swath survey.* Report to NEG Micon UK Ltd, Report Ref 05/J/1/02/0758/0477.

EMU, 2008. *Kentish Flats offshore wind farm post-construction* swath *survey* 6. Report to Kentish Flats Ltd, Report Ref 07/J/1/02/1157/0729.

EMU, 2009. *Neart na Gaoithe proposed offshore wind farm and cable routes geophysical survey for Neart na Gaoithe Offshore Wind Limited.*

EMU, 2010. *Neart na Gaoithe proposed offshore wind farm, benthic ecology characterisation Survey*. Report for Neart na Gaoithe Offshore wind Ltd.

Environment Agency, 2004. A*ssessment of sediment contaminants in estuaries*. For Habitats Directive Technical Advisory Group on Water Quality. WQTAG078K.

Folk, R. L., 1954. The distinction between grain size and mineral composition in sedimentary rock nomenclature. *Journal of Geology*, 62, 344-359.

Foundation for Water Research, 1993 *A Framework for Marine and Estuarine Model Specification in the UK*. Report No FR0374.

Forstner, U., Ahlf, W., Calmano, W., 1989. *Studies on the transfer of heavy metals between sedimentary phases with a multi-chamber device: combined effects of salinity and redox potential*. Marine Chemistry, 28, 145-158.

Fujioka, R. S., Hashimoto, H. H., Siwak, E. B., and Young, R. H. F., 1981. *Effect of sunlight on survival of indicator bacteria in seawater.* Applied and Environmental Microbiology, 41, 690-696.

Gardline, 2010. *Neart na Gaoithe offshore wind farm project preliminary geotechnical investigations.* Geotechnical report for Neart na Gaoithe Offshore Wind Ltd.

Gatliff, R. W., Richards, P. C., Smith, K., Graham, C. C., McCormac, M., Smith, N. J. P., Long, D., Cameron, T. D. J., Evans, D., Stevenson, A. G., Bulat, J., and Ritchie, J. D., 1994. *United Kingdom offshore regional report: the geology of the central North Sea.* London, HMSO for the British Geological Survey.

Golledge, N. R., and Stoker, M. S., 2006. *A palaeo-ice stream of the British Ice Sheet in eastern Scotland*. Boreas, 35, 231-243.

Hall, A., 2011. E*ast Lothian Landscapes.* Available online from: http://www.landforms.eu/Lothian [accessed Sep 2011].

Hansom, J. D., Lees, G., McGlashan, D. J., and John, S., 2004. *Shoreline management plans and coastal cells in Scotland.* Coastal Management, 32, 227-242.

Hayes, P., Russell, M., and Packer, G., 2005. *Surveys of Dredged Material and Wastewater Sludge Sea Disposal Sites for the East Coast of Scotland.* FRS Internal Report No. 08/2005.

Historic Scotland, 1999. *Coastal assessment survey: the Firth of Forth from Dunbar to the border of Fife, Part 1.*

HR Wallingford, 1998. *HR Wallingford, Coastal processes scoping study Forth of Forth OWF: Neart na Gaithe Offshore Wind Farm.* Report EX 3471.

ICES (International Council for the Exploration of the Sea), 2009. *Dataset on Ocean Hydrography.* The International Council for the Exploration of the Sea, Copenhagen.

IHO (international Hydrographic Organisation), 2008. *IHO Standards for Hydrographic Surveys*. 5th Edition, Special Publication No. 44.

Kenyon, N. H., and Cooper B., 2005. *Sand banks, sand transport and offshore wind farms.* Report for the DTI.

Marine Scotland, 2011. *Blue Seas - Green Energy: A Sectoral Marine Plan for Offshore Wind Energy in Scottish Territorial Waters. Part A: The Plan.* Available at: http://www.scotland.gov.uk/Resource/Doc/346375/0115264.pdf [Accessed Apr 2012].

MCA, 2008. Marine Guidance Note 371 (M+F), *Offshore Renewable Energy Installations (OREIs), - Guidance on Navigational Practice, Safety Issues and Emergency Response Issues*.

McManus, J., 1998. *Temporal and Spatial Variations in Estuarine Sedimentation*. Estuaries, **21** (4), 622-634.

Moore, H., and Wilson, G., 2006. *Report on Coastal Zone Assessment Survey: East Lothian & Scottish Borders.* EASE Archaeology, Commissioned by The SCAPE Trust, Funded by Historic Scotland.

Owens, R., 1981. *Holocene sedimentation in the north-western North Sea.* Special Publication of the International Association of Sedimentologists, **5**, 303-322.

PLA (Port of London Authority), 2012. *Sediment Quality*. Available online from: http://www.pla.co.uk/display_fixedpage.cfm/id/2465/site/environment [accessed 12 Apr 2012].

Ramsay, D. L., and Brampton, A. H., 2000a. *Coastal Cells in Scotland: Cell 1 – St. Abbs Head to Fife Ness.* Scottish Natural Heritage Research, Survey and Monitoring Report No. 143.

Ramsay, D.L., and Brampton, A.H., 2000b. *Coastal Cells in Scotland: Cell 2 – Fife Ness to Cairnbulg point*. Scottish Natural Heritage Research, Survey and Monitoring Report No. 144.

Robertson, M., and Davies, I., 2009. *A Review of the Sources and Scope of Data on Characteristics of Scottish Waters. An Assessment of the Adequacy of the Data and Identification of Gaps in Knowledge.* Available at http://www.scotland.gov.uk/Uploads/Documents/Int0609.pdf [Last accessed April 2012].

Robertson, P., and Miller, K., 1997. *Coastal assessment survey for Historic Scotland. Fife – Fife Ness to Newburgh.*

Scottish Government, 2009. *The Scotland River Basin District (Surface Water Typology, Environmental Standards, Condition Limits and Groundwater Threshold Values) Directions 2009*, http://www.scotland.gov.uk/Resource/Doc/298071/0092869.pdf.

Scottish Government, 2011a. *Scottish Government Spatial Data File Download.* Available online from: http://crtb.sedsh.gov.uk/spatialDataDownload/dload.asp [accessed 24 Oct 2011].

Scottish Government, 2011b. *Scotland's Marine Atlas: Information for the National Marine Plan.* Available online from: http://www.scotland.gov.uk/Publications/2011/03/16182005/0 [accessed 12 Oct 2011].

SEPA (Scottish Environmental Protection Agency), 1998. *Trace Metals in the Forth 1986 – 1996.* Tidal Waters, Report TW 17/98.

SEPA (Scottish Environmental Protection Agency), 2000. *Water Quality in the Forth Estuary 1980 – 1999.* Report TW 07/00, Edinburgh.

SEPA (Scottish Environmental Protection Agency), 2009. *Scotland river basin management plan.* Available online from: http://www.sepa.org.uk/water/river_basin_planning.aspx [accessed 17 Feb 2012].

SEPA (Scottish Environment Protection Agency), 2010. B*athing water profile: Elie (Harbour) and Earlsferry*. Available online from: http://www.sepa.org.uk/water/bathing_waters/idoc.ashx?docid=a2876e66-c6d6-417a-9adf-2675e9528194&version=-1 [accessed 07 Oct 2011].

SEPA (Scottish Environment Protection Agency), 2011a. *Season 2011: Summary of results.* Available online from: http://www.sepa.org.uk/water/bathing_waters/results/summary_of_last_season.aspx [accessed 26 Oct 2011].

SEPA (Scottish Environment Protection Agency), 2011b. F*ife Ness to Elie.* Available online from: http://apps.sepa.org.uk/shellfish/pdf/4.pdf [accessed 07 Oct 2011].

WRC Swindon, 1999. G*uidelines for managing water quality impacts within UK European marine sites*. English Nature, UK Marine SACs Project. pp 440.

Appendices

Appendix 8.1: Shellfish and Bathing Water Quality