COWRIE ScourSed-09

A Further Review of Sediment Monitoring Data

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Acronyms

ABPmer	ABP Marine Environmental Research Ltd
ABS	Acoustic Backscatter Sensor
ADCP	Acoustic Doppler Current Profiler
BERR	Department for Business and Regulatory Reform
BGS	British Geological Survey
CD	Chart Datum
CEFAS	Centre for Fisheries and Aquaculture Science
COWRIE	Collaborative Offshore Wind Research into the Environment
DECC	Department of Energy and Climate Change
DTI	Department for Trade and Industry
DTM	Digital Terrain Model
EIA	Environmental Impact Assessment
ES	Environmental Statement
FEPA	Food and Environmental Protection Act
GBF	Gravity Base Foundation
LAT	Lowest Astronomical Tide
MUMM	Management Unit of the North Sea Mathematical Models
MSL	Mean Sea Level
NERC	Natural Environment Research Council
OBS	Optical Backscatter Sensor
ODN	Ordnance Datum Newlyn
OWF	Offshore Wind Farm
PSA	Particle Size Analysis
UKHO	United Kingdom Hydrographic Office
RAG	Research Advisory Group
ROV	Remotely Operated Vehicle
SMP	Shoreline Management Plan
SPM	Suspended Particulate Matter
SSC	Suspended Sediment Concentration
SSS	Sidescan Sonar

Units

GW	Giga Watt
MW	Mega Watt

Executive Summary

The aim of this report is to carry out a further review of sediment monitoring data from built and currently being constructed offshore wind farms and produce recommendations on future sediment monitoring practices and procedures, which will be of particular benefit to Round 3 offshore wind farm development projects. This report builds on the results of an earlier study carried out in 2006 and 2007 and published on behalf of DECC, “Review of Round 1 sediment process monitoring data – lessons learnt” (DECC, 2008a). The specific objectives of this current study are:

1. To enable the present evidence base, developed previously on behalf of DECC (DECC, 2008a), to be extended;
2. To review the new information and consider any new lessons learnt; and
3. To disseminate the findings to usefully inform the consents process facing new Round 3 projects.

Monitoring information and data were obtained from offshore wind farm managers, publicly available documents and record archives held by the authors. Information was collated in the form of reports, report summaries, survey and modelled data. The information was split into three technical categories of suspended sediments, seabed morphology and scour for further review.

Following the data review, any lessons learnt and recommendations for future sediment monitoring were made for each of the three categories. The recommendations made in the earlier study were also still found to be relevant.

1. Introduction

1.1 Background

In 2005, a Research Advisory Group (RAG) was established by the DTI to consider research priorities in relation to the potential environmental impacts of offshore wind farm developments and their impacts on other users of the sea. Three priority research projects were taken forward:

- Review of Round 1 sediment process monitoring data – lessons learnt (SED01);
- Dynamics of scour pits and scour protection (SED02); and
- Review of channel migration (SED06).

In 2006, a consortium of research partners comprising ABPmer, CEFAS and HR Wallingford was commissioned to carry out the SED01 project. The aim of SED01 was to draw together the sediment process monitoring work carried out on Round 1 offshore wind farm developments and review the methods, data, results and impacts in order to identify lessons learnt and to provide relevant recommendations for monitoring of Round 2 developments (DECC, 2008), whilst establishing an accessible evidence base.

The SED01 report forms the basis of this further review of sediment monitoring data and should be read in conjunction with this report.

1.2 Project Objectives

The objectives of this current project are to enable the present evidence base, developed previously under SED01, to be extended, to review the new information and consider any new lessons learnt, and to disseminate the findings to usefully inform the consents process facing further rounds of offshore wind development, particularly Round 3.

The format for this further review extends the successful approach already developed from the SED01 review. The scope of this study aims to:

- Collate and review new monitoring evidence from projects considered in SED01 (Barrow, Horns Rev, Kentish Flats, North Hoyle and Scroby Sands);
- Collate and review new monitoring evidence from projects not included in SED01 (Burbo Bank, Greater Gabbard, Gunfleet Sands, Lynn & Inner Dowsing, Robin Rigg and Rhyl Flats);
- Collate and review new monitoring evidence from other European projects (Thornton Bank and Q7);
- Provide an updated evidence base for sediment monitoring around offshore wind farms; and
- Disseminate findings to industry to assist Round 3, including the submission of a report to be made available via the COWRIE website.

The project scope has the deliberate objective of extending the previous sediment monitoring review and also integrating with a new related study referred to as “ME1117 Strategic Review of Offshore Wind Farm Monitoring Data Associated with FEPA Licence Conditions” which is to be delivered by CEFAS in spring 2010. It is presently understood that ME1117 aims to collate and strategically review the FEPA monitoring reports before comparing these findings against information on offshore wind farms from international sources. The output will be a report describing the key findings from the FEPA monitoring, lessons learned and recommendations for future monitoring. At the time of writing, a draft version of the ME1117 report was available.

2. Approach

The framework for this further review process followed the same approach successfully delivered in SED01. The same consortium of partners (ABPmer, CEFAS and HR Wallingford) was also used in this study to carry out the data review (see Section 2.3).

2.1 Overview

The data collation activity covered the Round 1 offshore wind farm developments which were included in SED01 (Barrow, Blyth, Kentish Flats, North Hoyle, Scroby Sands) as well as Arklow Bank in Ireland, and the European sites of Horns Rev and Nysted, Round 1 developments which were not included in SED01 (Beatrice, Burbo Bank, Robin Rigg, Rhyl Flats, Gunfleet Sands I, Lynn and Inner Dowsing), Round 2 projects (Thanet, Gunfleet Sands II and Greater Gabbard) and other European projects (Thornton Bank, Q7/Princess Amalia). Details of these wind farms are shown in Table 2-1 below and their locations are shown in Figure 2-1.

Table 2-1 Offshore Wind Farms included in the Data Collation Exercise

Offshore Wind Farms	Round #	Region	Installed Capacity (MW)	Foundation Type	Status (As of Jan 2010)
Arklow Bank	N/A	Ireland	25	Monopile	Operational
Barrow	1	North West	90	Monopile	Operational
Beatrice	Demonstrator	Scotland	10	Jacket Subsea Structure	Operational
Blyth	Demonstrator	North East	4	Monopile	Operational
Burbo Bank	1	North West	90	Monopile	Operational
Greater Gabbard	2	Thames Estuary	504	Monopile	Under Construction
Gunfleet Sands I	1	East of England	108	Monopile	Under Construction
Gunfleet Sands II	2	East of England	64	Monopile	Under Construction
Horns Rev	N/A	Denmark	160	Monopile	Operational
Kentish Flats	1	South East	90	Monopile	Operational
Lynn & Inner Dowsing	1	East Midlands	194	Monopile	Operational
North Hoyle	1	North Wales	60	Monopile	Operational
Nysted	N/A	Denmark	165.6	Gravity Base	Operational
Princess Amalia (Q7)	N/A	Netherlands	120	Monopile	Under Construction
Rhyl Flats	1	North Wales	90	Monopile	Operational
Robin Rigg	1	North West	180	Monopile	Under Construction
Scroby Sands	1	East of England	60	Monopile	Operational
Thanet	2	Thames Estuary	300	Monopile	Under Construction
Thornton Bank	N/A	Belgium	300	Gravity Base	Under Construction

Monitoring information and data were obtained from offshore wind farm managers/developers, publicly available documents and record archives held by the authors.

As in the SED01 study, relevant data holdings covered the three phases of project development (pre-construction, i.e. baseline, construction and post-construction) for the following three themes:

- Suspended sediment concentrations;
- Seabed morphology; and
- Scour.

The data types which were requested and which are relevant to the sediment monitoring review are:

- Seabed levels (including localised scour development);
- Seabed features (e.g. bedforms);
- Surficial sediment coverage (e.g. PSA);
- Suspended sediment loads;
- Shoreline profiles (where relevant);
- Tidal parameters (water levels and currents); and
- Wave parameters (height, direction, amplitude and period).

Where data had been provided for the SED01 study, only those data collected since that study were requested.

2.2 Evidence Base

Data requests were made for all available relevant monitoring data which had not previously been supplied for the SED01 study. The results of the data collation exercise are summarised in Table 2-2 below.

This table shows all the offshore wind farms (OWF) which were included in this data collation activity. Table 2-2a lists the OWFs which were also included in the SED01 study and Table 2-2b lists all those OWFs which were not included in the SED01 study. For some OWFs, only reports were available, and for others, reports and also the background survey data were available. The tables indicate where reports and data were collated for each development phase of the OWF. Not all of the data collated for this study has been permitted to be made available to the public by the data owners. In these cases (e.g. for Robin Rigg and Princess Amalia OWFs) the data will not be included in the evidence base at this time.

The available digital data outputs were collated into a project database in the form of a sequence of standard project folders (Figure 2-2). The folder structure was amended from that used in the SED01 study, since it was felt that this new structure better reflected the development phases (baseline/pre-construction, construction and post- construction) and themes of new monitoring information which was acquired for each OWF. It was also felt that this structure would aid the process of locating relevant information. A new folder called “Combination” was also added where the information (e.g. monitoring report) covered all three themes in one document. However, this folder structure is only locally relevant and is not visible in the COWRIE database.

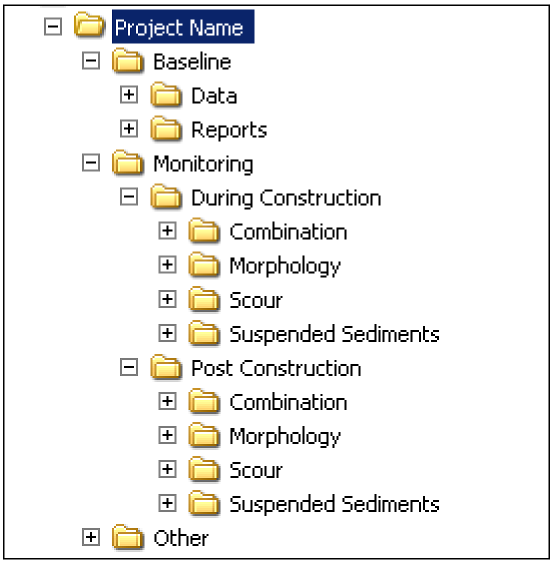
Table 2-2 Results of the Data Collation Exercise

Offshore Wind Farms	Included in SED01	Baseline / Pre-construction	Construction	Post-construction	Suspended Sediment Concentration		Morphology			Scour	
					Data Available	Comments	Data Available	Further Analysis Possible	Comments	Data Available	Comments
Arklow Bank	YES				-		Limited	No	Survey along route and turbine rows	-	
Barrow	YES	Report	Report	Reports & Data	-		Yes	No	Only one SSS plus PSA surveys April 2005	**Updated**	Bathymetric surveys
Blyth	YES	Reports			-		No	No	Built on rocky shoal	-	
Burbo Bank	YES	Reports & Data	Reports	Reports & Data	-		**Yes**	**Yes**	Post-construction swathe surveys available through monitoring reports & data	-	
Horns Rev	YES	Reports		Reports	-		No	No	Considered to be insignificant in ES	-	
Kentish Flats	YES	Report		Reports & Data	-		Yes	No	Pre and post-construction SSS	**Updated**	Bathymetric surveys
North Hoyle	YES	Report		Reports & Data	-		Yes	Yes	Three bathymetric surveys: 2001, 2003 and 2004	**Updated**	Bathymetric surveys
Nysted	YES	Report	Report	Report	-		Limited	No	Monitoring report only	-	
Scroby Sands	YES			Reports & Data	-		Yes	Yes	Six high quality post-construction swathe surveys, plus one pre-construction single beam survey	-	

NB. Bold text refers to Offshore Wind Farm sites with new monitoring data available, as discussed within this report.

Offshore Wind Farms	Included in SED01	Baseline / Pre-construction	Construction	Post-construction	Suspended Sediment Concentration		Morphology			Scour	
					Data Available	Comments	Data Available	Further Analysis Possible	Comments	Data Available	Comments
Beatrice	NO	Reports			-		-			-	
Greater Gabbard	NO	Reports & Data			-		-			-	
Gunfleet Sands	NO	Reports			-		-			-	
Lynn & Inner Dowsing	NO	Reports	Reports & Data		**NEW**	ADCP data available for construction phase	-			-	
Princess Amalia (Q7)	NO		Reports & Data		-		-			**New**	Bathymetric surveys
Rhyl Flats	NO	Reports & Data		Data	-		-			-	
Robin Rigg	NO	Reports	Reports & Data		-		-			**New**	Bathymetric surveys
Thanet	NO	Reports			-		-			-	
Thornton Bank	NO	Reports	Published Paper on scour	Report & Data (Pre-release)	-		**Limited**	**Limited**	Pre-release of first post-construction survey; Gravity Base Foundations	-	

NB. Bold text refers to Offshore Wind Farm sites with new monitoring data available, as discussed within this report.



- Project Name
  - Baseline
    - Data
    - Reports
  - Monitoring
    - During Construction
      - Combination
      - Morphology
      - Scour
      - Suspended Sediments
    - Post Construction
      - Combination
      - Morphology
      - Scour
      - Suspended Sediments
  - Other

Figure 2-2 Standard Folder Structure for Project Database

The evidence base produced during this study was uploaded to the COWRIE Data Catalogue via the COWRIE Data Management System (http://data.offshorewind.co.uk/) along with the corresponding metadata. The full list of data collated for this study is included in Appendix A to this report.

2.3 Structure of Data Review

The technical data review covers the three themes mentioned in Section 2.1 above. These reviews can be found in the following sections of this report:

- Section 3 – Suspended Sediment Concentration (ABPmer);
- Section 4 – Seabed Morphology (Cefas); and
- Section 5 – Scour (HR Wallingford).

This data review provides an advancement and an update to the SED01 review. This study considers wind farms which were not included in the previous review (see Table 2-2b), including Round 2 OWFs and other European OWFs. The lessons learnt and recommendations from this review are summarised in Sections 6 and 7, respectively.

2.3.1 Suspended Sediment Concentration

Following the recommendations made from the review of Round 1 monitoring, suspended sediment concentration (SSC) monitoring is no longer a standard FEPA requirement for monopile OWFs. Where the environmental settings or foundation types differ from Round 1 OWFs (e.g., deeper water sites; gravity base structures, quadropods) or the surrounding environment is sensitive to changes in SSC due to OWF construction, the requirement for SSC monitoring will remain. As such, there was very little new data available for this review.

Lynn and Inner Dowsing is the only OWF for which new data is available for SSC, and this is reviewed in Section 3.2. The Lynn and Inner Dowsing OWF is considered a ‘special’ case where provisions were made to address the consent conditions of the wind farm, due to the on-site disposal of drill arisings (especially chalk).

2.3.2 Seabed Morphology

Only four OWFs had new data which was considered suitable for further analysis: Burbo Bank, North Hoyle, Scroby Sands and Thornton Bank. Burbo Bank and Thornton Bank were selected for this review since they provide new information associated with different foundation types and installation procedures than those reviewed in SED01.

At Burbo Bank OWF (Section 4.3), the seabed was prepared by laying a cobble-size slate filter at the location of each turbine prior to installation, which was intended to prevent/minimise scour from the outset.

Thornton Bank OWF (Section 4.4) comprises gravity base foundations (GBF) which are likely to be the preferred foundation type in Round3. They may also be preferred in Round 2 if the ground and hydrodynamic conditions are suitable and monopile foundations do not offer the most economic solution. In Round 1 all foundations currently favour monopiles (see Table 2-1). Thornton Bank OWF is also in deeper water and in a higher energy environment, as are many of the Round 3 development sites. Therefore, experiences from the Thornton Bank OWF will provide valuable experience and lessons learnt regarding the behaviour of GBFs in exposed settings.

2.3.3 Scour

A total of five OWF sites were considered in this review. Barrow (Section 5.4), Kentish Flats (Section 5.5) and North Hoyle (Section 5.6) were included in SED01 and were updated for this review as these sites had new bathymetric data available. Two new sites, Princess Amalia (Q7) and Robin Rigg are included in this review and provide useful new information to assist the proposed Round 3 sites.

To date Round 1 and Round 2 wind farms have been constructed in relatively shallow water and generally inside Territorial Waters. Since the proposed Round 3 wind farm sites are generally located in deeper water depths, and outside of Territorial Waters, where a wider range of foundation options are likely to be required. Of the monitoring data reported in this review, the Princess Amalia GBF OWF (Section 5.3) represents site conditions that may be more indicative of those likely to be encountered at Round 3 sites.

For a shallow site, the data for Robin Rigg OWF (Section 5.2) represents an extensive monitoring data set and the scour depths attained represent an upper limit on the envelope of values seen to date (the majority are smaller) and support evidence from earlier scour studies (e.g. Breusers and Raudkivi, 1991; den Boon *et al.*, 2004). These data support the view that scour calculations cannot ignore how the seabed soil structure varies with depth. Geotechnical considerations over sufficient depth are therefore also important in the assessment of scour.

2.4 Data Review Issues

As in SED01, the present review considered the following issues:

- What reliability and confidence can be placed on the field data and how might practices be improved?
- How do the observations compare to statements made in the ES (i.e. is the measured data in line with the assessment of effect, or is there a '*surprise*')?
- Has the data addressed the FEPA requirement to provide the additional understanding required to reduce apparent uncertainties?

- Are the methods of survey sufficient and what approaches demonstrate best practice (e.g. if various approaches to monitoring have been applied, then identify which has worked best)?
- Summary of lessons learnt to advise on future requirements (inc. Environmental Impact Assessment (EIA) guidance, regulatory requirements, monitoring provisions, etc).

3. Review of Suspended Sediment Concentration

3.1 Background

In SED01 (DECC, 2008a) it was reported that the assumptions regarding SSC were generally upheld; that is, relative increases in SSC were localised and occurred over short time scales that were connected primarily to construction activities such as drilling and cable laying. Although measurements of SSC have generally been accompanied by poor calibrations (i.e. over limited concentration ranges) or without calibration (i.e. remain in NTU turbidity units), the interpretation has been that relative changes in suspended sediments are typically within the natural range of sediment concentrations due to waves and tidal currents for shallow water sites. As a result it is unlikely that OWFs contribute any significant impacts for such locations.

Key recommendations (from SED01) lessons learnt are:

- *Preferred use of OBS devices calibrated against sufficient water samples spanning the range of monitoring conditions (i.e. peak flow events), ideally a minimum of 20 samples to provide a more robust statistical correlation;*
- *Deployment of sensor at a fixed height above the seabed (notionally at 1m) with an additional vessel deployed sensor sampling through the water column at times of equipment deployment, servicing and recovery;*
- *Water samples analysed for mass concentration, particle size (laser diffraction method), inorganic and organic content;*
- *Consideration for use of sediment traps to monitor fate of drill cuttings;*
- *Associated metocean data and local seabed sediment samples to assess natural sediment disturbance; and*
- *Near-field sampling at no more than 500m from the sediment source.*

However, in shallow settings and where monopile structures are used, the ME1117 report ("Strategic Review of Offshore Wind Farm Monitoring Data Associated with FEPA Licence Conditions") recommends that the condition for measuring SSC in FEPA licences be changed as follows:

> ***Coastal Processes***
> *The results of suspended sediment concentration (SSC) monitoring indicate that, for monopile foundations only, such monitoring need only be requested in locations where sensitivities to increases may be significant. As such, the requirement for SSC monitoring can be determined on a site-specific basis.*

Where the environmental settings or foundation types differ from Round 1 OWFs (e.g., deeper water sites; gravity base structures, subsea jackets) or the surrounding environment is sensitive to changes in SSC due to OWF construction, the requirement for SSC monitoring will remain. For example, in deeper sites where regular resuspension due to waves does not occur, the background SSC may be significantly lower than that experienced in the shallower Round 1 sites. As a result relative changes in SSC during construction are likely to be larger and may require assessment and monitoring.

It was also noted in SED01 that there is very little strategic monitoring and assessment of suspended sediments. Sources of SSC data include the Cefas maintained smart buoy network (seven buoys at present) that measures turbidity (and other parameters), as part of the National Marine Monitoring Programme (NNMP). Other potential sources include ferry boxes (though these are usually uncalibrated), measurements from scientific cruises and satellite imagery. Research into combining such data streams to build up a picture of the natural variability in SSC is currently underway as part of a Cefas project called “Natural Variability of REA regions, their ecological significance and sensitivity” that is funded by the Marine Aggregate Sustainability Levy Fund. Reporting on the first phase of the project, which includes monthly maps of SSC (average, range, variability etc.), is anticipated in March 2010.

Results are presented for the Lynn and Inner Dowsing OWF, the only site since SED01 which has new data useful for updating the suspended sediment concentration ‘lessons learnt’.

3.2 Lynn and Inner Dowsing Offshore Wind Farm

3.2.1 Site Description

Lynn and Inner Dowsing are two adjacent Round 1 offshore wind farms developed by Centrica Renewable Energy Ltd. Together they consist of 54 steel monopile foundations of diameter 4.74m, with each monopile supporting a tower and nacelle containing a 3.6MW Siemens turbine, and three blades. The turbines cover an area of 20km^2 with the closest row of turbines being 5km from the Lincolnshire coast and the furthest being 9km offshore. Installation of the 54 monopile foundations began in April 2007 with the jack-up vessel MV Resolution, using a combination of driving and drilling techniques, due to the presence of a dense chalk substrata encountered at a relatively shallow seabed depth. Those foundations that required drilling used a ‘pile-top’ drilling rig, with the arisings from the drilling process collected at the top of the rig and then deposited into the water column within 150m of each turbine location. The final penetration depths for the monopile foundations ranged from 18.6 to 26.0m below the seabed/water interface.

The installation of the foundations was completed in 2007, with cable laying within the wind farm carried out during 2007 and 2008. The six export cables which were laid to transmit power to shore, were buried up to 2m deep in the seabed using an underwater cable plough weighing 21 tonnes. The array cables, connecting the wind turbine generators, were laid using a Remotely Operated Vehicle (ROV) controlled from MV Resolution and the aforementioned cable plough. Installation of the 3.6MW wind turbine generators, supplied by Siemens Power Generation, commenced in March 2008 and was completed in July 2008. The wind farms became fully operational with the completion of commissioning in March 2009. On this basis, pre-construction is the period pre-April 2007, construction the period April 2007 to July 2008 and post-construction the period after July 2008.

3.2.2 Sediment Properties

The Lincolnshire coast adjacent to the site is underlain by chalk from the Upper Cretaceous era, covered by Quaternary sediments, comprising firstly a sheet of Pleistocene glacial till and finally superficial Holocene sediments. Data published by the British Geological Survey (BGS, 1985) indicates that the thickness of the chalk steadily increases from the extreme south-west boundary of the site, attaining a thickness of more than 100m in the most offshore areas of the site. The overlying glacial till, referred to as the ‘Bolders Bank’ Formation, generally consists of red-brown calcareous, gravelly, sandy clay with erratics that are predominantly of chalk, red-brown sandstone and grey mudstone. Superficial Holocene sediments, are thought to typically cover the Bolders Bank Formation, but generally only to a depth less than 1 or 2 metres, and comprise of sandy and gravelly sediments.

Two detailed geophysical surveys were undertaken by Emu Ltd as part of the Lynn and Inner Dowsing study. The first survey took place over the period 12th to 21st October 2001 and the second between 16th and 20th April 2002. On the basis of a seismic survey, the glacial sediments immediately overlying the chalk typically exhibited no coherent structure, with little or no vertical layering. In many areas a second sediment unit was observed overlying the lower glacial till, typically more uniform in character. The seismic survey also revealed a generally dense, highly reflective seabed with little evidence of mobile surface sediments.

Based on the findings of the geophysical survey and the BGS (1985) data for the area, the ground conditions have been summarised in Table 3-1 (Fugro, 2005).

Table 3-1 Ground conditions of the Lynn and Inner Dowsing Sites

Description	**Lynn**		**Inner Dowsing**	
	Depth to top of stratum (m)	Thickness (m)	Depth to top of stratum (m)	Thickness (m)
Veneer of sandy gravel (Holocene sediments)	0.0	<0.5	0.0	<0.2
Stiff gravelly clay (Bolders Bank Formation)	0.5	3-7	0.0-0.2	6-12
Upper Cretaceous Chalk	3.5-7.5	44-94	6-12	67-116
Lower Cretaceous mudstones and sandstones	47.5-101.5	10	-	-

3.2.3 Hydrodynamic Properties

A tidal amphidrome governs the tidal conditions in the southern North Sea, with the tidal wave rotating anticlockwise, flooding southeast and ebbing northwest twice a day (semi-diurnal tide). The tidal range increases with distance from the amphidrome leading to a tidal range on mean spring tides of 6.0m at Skegness, the nearest standard Admiralty port to the Lynn and Inner Dowsing sites.

The nearest tidal stream points to the OWF sites, SN016P and SN016R (taken from UKHO TotalTide), identify peak currents on an average spring tide of 2.1knots (1.1m/s) and 1.8knots (0.9m/s) for Lynn and Inner Dowsing, respectively.

The dominant wave direction is from the north-northeast and northeast, where for a percentage exceedance of 50% and 10% at the coast, the wave height is 0.5m and 1.0m, respectively.

3.2.4 Monitoring

Pre-Construction Monitoring

Baseline monitoring was recorded by the deployment of oceanographic equipment at four prescribed sites over a 1-month period from the 7th October to 7th and 8th November 2004 by Titan Environmental Surveys Ltd (TES). These positions cover the north-eastern part of the Inner Dowsing site (1), the north-east of the Lynn site (3), a control site to the east of the Lynn site (4, for both of the consented wind farms) and a far-field but near shore site (2, for both of the consented wind farms) to the west.

The monitoring of the suspended sediment load in the water column was undertaken through the deployment of instrument frames comprising of an Acoustic Doppler Current Profiler (ADCP), and an Optical Backscatter Device (OBS).

Three 600kHz RD instruments Workhorse ADCP systems were used at sites 1, 3 and 4. The instrument frame positioned the head of each ADCP 0.9m above the seabed at each site, with readings taken for a 2 minute period, averaged, and then sleep mode activated for 8 minutes before repeating the cycle. At site 2, a Nortek Aquadopp Profiler ADCP was deployed. The unit was set to record a profile over one minute every 10 minutes. Problems were encountered with the instrumentation deployed at Site 4, which may have been deployed on top of an obstruction causing the mooring frame to lie at a highly inclined angle and rock in the currents before overturning after some 19 days in the water with the ADCP ceasing to operate thereafter.

Aquatech Electronics Aqualogger 200TY turbidity loggers were deployed on the instrument frames at a height of 0.45m for sites 1, 3 and 4 (0.3m at site 2), with the sensor facing outwards into open water. All four OBS instruments were configured to sample an average of 8 samples every 5 minutes. On recovery of the data, initial spikes were manually removed and attributed to fish feeding on the instrument frame as well as fouling.

At each site 26 one litre water samples were collected from both 3m above the seabed and below the sea surface between the 31st October and 1st November 2004. These were combined with a further 10 additional samples collected at the time of instrument deployment, and another 10 samples obtained immediately prior to recovery. It is unknown n as to why water samples were collected 3m above the bed, rather than at the same height as the OBS instruments, potentially affecting instrument calibration. A total of 201 water samples were analysed gravimetrically to provide measurements of the concentration of suspended particulate matter present in suspension from which calibration of both the optical and acoustic sensors could take place, providing a baseline against which the derived data could be assessed. The resulting correlation coefficients, R^2, quoted for the period of baseline monitoring for the optical sensors based on water samples collected in the lowest 3 metres of the water column are given as 0.24, 0.32 (far-field), 0.38 and 0.02 (control-site) for all four sites. The R^2 value for the acoustic sensors based on water samples from all water depths are given as 0.26, 0.37 and 0.72 for sites 1 to 3. The R^2 value is a statistical measure of how well the regression line approximates the real data points, with a value <0.49 suggesting there is no clear correlation between the instruments and the water samples.

Both optical and acoustic estimates suggest a variation in the levels of SSC present in suspension over the spring neap cycle from a maximum of 40 mg/l on springs to around 10 mg/l on neaps at sites 1 and 3, with these values agreeing well with gravimetric estimates (Figure 3-1). However, data from the inshore site (2) identifies a wide discrepancy between acoustic and optical estimates of SSC concentration with the OBS data showing a tendency to overestimate SSC values obtained from the water samples and the acoustic methods a tendency to underestimate water sample concentrations (Figure 3-2).

The Environment Agency coastal water monitoring data indicates a SSC range of 5 to 525mg/l, with an average of 129mg/l for the Lynn and Inner Dowsing area. In addition, the Southern North Sea Sediment Transport Study (HR Wallingford, 2002) includes SSC for the area; the SSC was found to vary from 8 to 128mg/l during summer periods and 16 to 128mg/l during winter periods. These SSC values are significantly different to those measured at the sites during the pre-construction monitoring, suggesting that the site is susceptible to a high degree of SSC variation, and the monitored values may not be an accurate representation of the SSC characteristics at both sites.

During Construction Monitoring

Due to a number of the proposed foundation locations requiring drilling of a hard underlying chalk formation, special provisions were made to address the consent conditions of the OWF. As such, monitoring took place during the installation of the monopile foundations.

Following a numerical model assessment of the spoil disposal from foundation installation at Lynn and Inner Dowsing (ABPmer, 2006), Centrica commissioned a survey to monitor the dispersal of drill arisings both in a near-field and far-field environment, with the results being used to verify the findings for the dispersion and spread of drill arisings, rather than mapping out the actual settlement of chalk fines (CREL, 2008).

This was achieved by the deployment of 15 sediment traps, situated 100m (S1a), 1km and 5km from the drilled monopile locations. The purpose of the traps was to capture and retain the passing sediment materials, identifying whether chalk associated with the drilling was present within the water column, rather than measuring a change in SSC. The survey took place from the 10th June 2007 and was carried out in two phases, relating to the suspended materials recovered after 8 days, and the drilling of one monopile foundation (LN02), and a longer 30 day deployment following the combined effects of partially drilling five foundations.

Results from the suspended sediment traps from both Phase 1 and Phase 2 surveys indicated an extremely large natural suspended sediment flux at all sites surveyed. Chalk residues from the discharge of the drill arisings was only recorded at sediment trap S1a (ca. 6.26cm^3), deployed within close proximity (100m) of the LN02 location. However, even here, the settlement of chalk within the sample was minor compared to the natural sediment flux recorded during the 8 day period. The survey revealed that chalk deposits were not recorded in all near and far-field stations (Table 3-2).

Table 3-2 Deployed locations of Sediment Trap Moorings

Location	**Sediment Retained Volume cm^3**	**Sediment Description**	**Chalk**
Phase 1 (8 days deployed)			
S1a (LN02)	16.2	Silts and sands, granular chalk particles in central section of the settlement tube	Yes (6.38cm^3)
S2	279.5	Fine sands and silts over organic silts	Not Seen
S3	228.1	Sandy central layer separating silts	Not Seen
S4	39.74	Homogenous organic silts throughout	Not Seen
S7	895.4	Blockage in tube. Homogenous organic silts throughout	Not Seen
S8	308.4	Mixed sands, silts and shell fragments throughout. Black granules in upper section	Not Seen
S11	1170.1	Mixed course sands and shell throughout	Not Seen
Phase 2 (30 days deployed)			
S4	666.54 (626.8*)	Homogenous sandy silts throughout	Not Seen
S5	177.1	Coarse sands over patchy sands and silts	Not Seen
S7	228.1	Layer of gravelly mixed sands within sandy silts	Not Seen
S8	274.5	Layer of mixed sands separating sandy silts	Not Seen
S9	90.7	Patch sandy silts	Not clear due to light sands
SSCS1	141.8	Homogenous silty sands	Not Seen
SSCS2	228.4	Sandy silts, slight organic layer	Not Seen
SSCS4	188.9	Homogenous sandy silts	Not Seen
* calculation for 22 day deployment			

The deposition of suspended sediments varied across the site and appeared to be dependent upon water depth or proximity to the main channel. Furthermore, even allowing for the variability of these sites, specific events within the deposited sediments could be determined due to similarities in sediment size distributions. This high suspended sediment flux would suggest that all but the largest concentration and sizes of chalk discharges would be dispersed and assimilated into the natural sediments and become indiscernible.

In comparison, results from the spoil disposal assessment (ABPmer, 2006) predicted that drilling operations would enhance SSC, which would be measurable above the ambient conditions; however, these would not be detectable beyond distances of a few kilometres from the monopile drilling locations or after seven days of dispersion, as the plume becomes entrained into ambient sediment loads. Increases in SSC were predicted to be high immediately after the release (120 to 205mg/l), but localised to the release site and for a short duration. Predicted increases in SSC were based on the drilling and sediment disposal at an average site, with the plume dispersion model predicting a further enhancement of SSC if a number of foundations were drilled simultaneously.

Due to the absence of chalk within the sediment samples as predicted in the spoil disposal sediment, a further diver investigation was carried out on one of the discharge spoil piles (LN29) on 26th August 2007.

Dive Survey of Drill Arisings Spoil on 26th August 2007

The diver was lowered to the peak of the spoil pile directly beneath the discharge point, where a sinker weight was deployed. The water depth for the pile height, compared to the natural surrounding sediments was taken, and observations made by the diver in respect to the spoil pile for a distance of 20m from its centre in each of the four compass directions. A summary of the diver observations can be seen in Table 3-3.

Table 3-3 Description of Drill Arisings Spoil Pile Surveyed by Diver, 26th August 2007

Direction	Distance from Centre (m)	Thickness of Spoil (m)	Description
East	20 – 8	<0.02	Light coverage of fine chalks
	6	0.3	Chalk and flint 20-50mm diameter
	4	1.0	Chalk and flint 20-50mm diameter
	2	2.2	Chalk and flint 50-100mm diameter
	0	3.0	Chalk and flint 50-100mm diameter
South	20 – 14	<0.02	Light coverage of fine chalks
	12 – 10	0.3 – 0.4	Coverage of fine chalk
	8	1.0	Chalk and flint 20-50mm diameter
	6	2.0	Chalk and flint 50-100mm diameter
	0	3.0	Chalk and flint 50-100mm diameter
North	20 – 6	0.09 – 0.1	Light coverage of fine chalks
	4	0.6	Chalk and flint 20-50mm diameter
	2	2.0	Chalk and flint 50-100mm diameter
	0	3.0	Chalk and flint 50-100mm diameter
West	Was not surveyed in detail due to deteriorating sea conditions, but the area was identified as being similar to the other three directions.		

In addition to the observations detailed in Table 3-3, a spoil height assessment using a depth sensor was also undertaken. The results from this assessment were broadly interpolated to provide a contour map of the spoil pile, seen in Figure 3-3. The size of the pile observed in August 2007 was much larger than that predicted in the spoil disposal study (ABPmer, 2006). The reason for this is simply due to the fact that the size of the sediments deposited within the main pile, were of much larger diameter (50 to 100mm) than those used within the model (3.2 to 15mm). As such, even though the volume of chalk being discharged would have been similar to that discharged in the model, the majority of the drill arisings were deposited in the form of larger pebbles and cobbles in size, and would have not dispersed over an area as large as the model had predicted, or as quickly. This would account for the lack of chalk found within the sediment traps. The centre of the pile was approximately 3m in depth, with the majority of the outer deposits being of notably finer grade than those at the centre.

Dive Survey of Drill Arisings Spoil on 6th December 2007

The spoil pile around LN29 was surveyed again 4 months after the initial dive survey on 6th December 2007, during which observations were made by the diver in respect to the spoil pile for a distance of 16m from its centre in each of the four compass directions, at 2m intervals. A summary of the diver observations can be seen in Table 3-4.

Table 3-4 Description of Drill Arisings Spoil Pile Surveyed by Diver, 6th December 2007

Direction	Distance from Centre (m)	Thickness of Spoil (m)	Description
East	16	0	Natural seabed
	14	0.15	Slight covering of chalk deposits 10-25mm diameter
	12	0	Natural seabed
	10	0	Natural seabed
	8	0.3	Chalk and flint 45-50mm diameter
	6	0.6	Chalk and flint 45-50mm diameter
	4	0.9	Chalk and flint 45-50mm diameter
	2	1.2	Chalk and flint 45-50mm diameter
	0	1.2	Chalk and flint 50-60mm diameter
South	16	0	Natural seabed
	14	0	Natural seabed
	12	<0.1	Slight deposits of chalk
	10	<0.1	Slight deposits of chalk 25mm diameter
	8	0.3	Chalk deposits 10-30mm diameter
	6	0.9	Chalk deposits 10-30mm diameter
	4	0.9	Chalk and flint 45-50mm diameter
	2	1.2	Chalk and flint 35-40mm diameter
	0	0.9	Chalk and flint 10-35mm diameter
North	Due to diver bottom time restrictions and the deteriorating sea conditions, the survey of the northerly and westerly headings was cut short, but the areas were identified as being similar to those seen in the other two directions.		
West			

Once again, a spoil height assessment using a depth sensor was also undertaken. The results from this assessment were broadly interpolated to provide a contour map of the spoil pile, seen in Figure 3-3. Measured 4 months after deposition, the pile had diminished in size to a maximum height of 1.2m, and ran in the four directions from peak to natural seabed for an average of 10m in length. The deposits had reduced in size from 25mm to 30mm, with the larger being at the top of the pile.

3.3 Discussion and Conclusions

Since SED01, data outputs from OWFs are still confined to shallow water sites and for monopile structures. As mentioned previously in Section 3.1, the ME1117 report ("Strategic Review of Offshore Wind Farm Monitoring Data Associated with FEPA Licence Conditions") recommended that the condition for measuring SSC in FEPA licences be changed for shallow water settings, and where monopile structures are used. As such, SSC monitoring need only be requested in locations where sensitivities to increases may be significant, determined on a site specific basis.

In respect to the Lynn and Inner Dowsing OWF, a number of the proposed monopile locations required additional drilling during installation due to a hard underlying chalk formation. As a result, a survey to monitor the dispersion of drill arisings in a near-field and far-field environment was undertaken in order to meet the FEPA license conditions. The monitoring strategy to observe and quantify the potential spoil plume was coordinated with the spoil disposal assessment (ABPmer, 2006) which predicted that drilling operations would enhance SSC above the ambient conditions, as mentioned previously in Section 3.2.4. However, the absence of chalk within sediment samples, collected via sediment traps during the monitoring period, led to an additional diver survey of a discharged spoil pile.

The diver survey identified that the sediments deposited within the pile, were noticeably larger than those used within the numerical plume model (ABPmer, 2006). As such, the model predictions were conservative, and presented a 'worst-case' scenario. The dimension of drill cuttings will vary in size between sites, determined by the type and density of the underlying strata, the strength of abrasive forces, and the dimensions of the drilling equipment. Furthermore, the survey also identified that the pile itself was much larger than was predicted by the model, due to the reduction in dispersed material.

A second diver survey, approximately 14 weeks after the initial survey, identified that the spoil pile had diminished in size. Lateral spreading of sediments, and the dispersal and assimilation of the chalk into the natural sediments are the main contributing factors to the reduction in the spoil pile height, from 3.0 to 1.2m (as seen in Figure 3-3). Further monitoring of the pile would be beneficial to evaluate the dispersion potential of drill arising under site specific hydrodynamic conditions. The Lynn and Inner Dowsing OWF provides a valuable baseline for future sites, where the disposal of drill arisings will need to be monitored in order to satisfy FEPA licensing conditions.

Furthermore, it would appear no monitoring of SSC took place for the installation of cables through the ploughing technique at the Lynn and Inner Dowsing OWF. Disturbance of the seabed during cable burial may place sediment into suspension, which will contribute to a temporary local increase in SSC. Ploughing is a preferred option, where possible, due to the low disturbance of the sediment, resulting in minimal sediment resuspension. In many cases, the ambient SSC of an OWF site may already be high, and therefore the increase in suspended sediments above background levels will be short-term and generally not significant, but this would need to be confirmed as part of the EIA. Offshore sites tend to experience generally lower ambient levels of SSC but the area affected is relatively small. This being said, some concern does still remain for the method and impact of the landfall part of the cable route (ABPmer, 2009).

Additionally, reporting on SSC for the Thornton Bank (Belgian North Sea) gravity base foundations will provide a useful extension of the knowledge base for SSC. However, this data was not available within the time-scale of this project.

4. Review of Seabed Morphology

4.1 Background

This section provides an update on the review of seabed morphology undertaken in the SED01 report (DECC, 2008a). The aim is to examine morphological changes and lessons learnt at OWF sites in UK and European waters, where sufficient new data has become available (since the publication of the SED01 report). Only new lessons learnt are presented – the points made in SED01 with respect to morphology are not revisited but are listed below.

Key recommendations (from SED01) lessons learnt are:

- *The continued use of multi-beam (swathe) bathymetry equipment is identified as the preferred survey method to reveal the detailed form and features of the seabed which has not always been practical or possible using single beam methods;*
- *For ease of comparison between sequences of surveys it is preferred that as much consistency remains in the execution of surveys and processing of data as possible;*
- *An understanding of relative sediment mobility can be gained from consideration of the exceedence threshold of bed shear stress and be used as a guide for determining monitoring requirements; and*
- *Further investigation is made in relation to the potential risks of secondary scour (e.g,. on inter-array cable burial), especially where new developments are located in areas of high sediment mobility.*

Seabed morphology and changes in seabed morphology are determined from swathe bathymetry surveys conducted as part of the FEPA licence conditions, and in support of the Environmental Statement. The licensing authority requires the developers to undertake a baseline survey and 6-monthly post-construction surveys over a period of three years. Following this period the monitoring conditions are reassessed by the licensing authority using the results of the monitoring reports.

Morphological changes are quantifiable changes in seabed elevation that are determined from comparison of successive surveys and comparison with the baseline survey. These changes include net changes to the sea bed elevation, changes to the type, configuration and dimension of bedforms, and the development of scour and/or wake patterns resulting from the interaction between the flow field and OWF structures such as the turbine foundations, armouring material, filter layers and armoured export cables.

Results are presented from the only two sites, since SED01, that have new data useful for updating the seabed morphology ‘lessons learnt’. These sites are Burbo Bank (UK) and Thornton Bank (Belgium).

4.2 Burbo Bank Offshore Wind Farm

4.2.1 Site Description

The Burbo Bank Offshore Wind Farm, operated by Dong Energy Ltd, consists of 25 steel monopile foundations of diameter 5.0m, with each monopile supporting a tower and nacelle containing a 3.6MW Siemens turbine (90MW maximum output). The wind farm is located in Liverpool Bay, approximately 6km from the Wirral and Liverpool coastlines (Figure 4-1). The water depth ranges from 0 – 8m (below Chart Datum) and the mean neap - spring tidal ranges are 4.4 – 8.0m, respectively. Tidal currents are rectilinear, oriented approximately east-west, have a maximum speed of 1.1m/s and entrain coarse sands into suspension during peak spring tides and fine sands on most tidal cycles. The 1:1 year return wave height is 4–5m. Although the OWF is known as Burbo Bank, it is largely located on the Great Burbo Flats, west of Great Burbo Bank and south of Little Burbo Bank. Both of these banks abut to the training banks of the Queens and Crosby Channels that form the navigation passage into the Mersey Docks.

4.2.2 Monitoring

The OWF site is deepest on its western margin (around 8m CD) and shallowest in the north east near Little Burbo (around 0m CD). The sediments are predominantly medium to fine sands, although silty sands dominate the central section of the OWF (Figure 4-2). The average sand content of grab samples was 95%. In the silty sand samples, silt contents of up to 14% were recorded, suggesting that cohesion is likely to influence the mobility of these sediments. Six turbines were selected for monitoring in the first three years of operation – three in the northern sandy area, and three in the central silty-sand area (see black boxes in Figure 4-2). There is little in the way of bedforms aside from some asymmetric ripples in the south of the survey area.

Construction at Burbo began with the installation of a cobble-size filter layer of slate in May 2006. The filter layer was 25-30m in diameter (e.g., Figure 4-3) and was designed to stabilise bed sediments and reduce the scour that can follow monopile installation. The monopiles were installed in June – August 2006, followed by the placement of additional armouring in September – November 2006. The first (Post-construction) survey was conducted in November 2006, three months following the installation of the monopile foundations. A pre-construction bathymetric survey does not appear to have been undertaken, although data from 2002 (either UKHO chart or Titan (2002) geophysical survey data) were utilised in an historical analysis of seabed levels as presented in the Environmental Statement (SeaScape 2002).

No monitoring was undertaken in the 15 months that followed the first post-construction survey of November 2006. The required six monthly surveys resumed in February 2008, May 2008, ‘Autumn’ 2008 (completed but not reported) and April 2009. Three different contractors were used for surveying bed elevations and this is reflected in reporting – no direct comparisons are made between surveys, except when the same contractor is used (e.g., the Year Two reporting). The timing of morphological monitoring is summarised in Table 4-1.

Table 4-1 Summary of morphological surveys

	Pre-construction	**During Construction (Nov. 2006)**	**Post-construction**		
			Yr 1 (Jan. & May ’08)	**Yr 2 (Autumn ’08 & Apr. ’09)**	**Yr 3**
Type of survey	Single beam?	Swathe	Swathe & sidescan	Swathe & sidescan	n/a
Comments	Data not located. Used for chart analysis?	Three months after foundation installation	Delayed surveys	Autumn ’08 not reported	
Surveyor	Titan Surveys	Osiris Projects	Pelorus	Pelorus	

Scour patterns can be identified in the bathymetric data as (1) distinct depressions in the lee(s) of monopiles and (2) elevation differences in bed level change maps created by subtracting the bathymetric surfaces at two different times from one another. Monitoring reports at Burbo, until the second year reporting, use the former. In some circumstances, where large and deep scour pits develop, this is sufficient. However, at Burbo scour patterns are subtle and less obvious, and bed level change analysis is required to adequately quantify the changes. This is especially relevant in the light of changing contractors. The following discussion derives from the Burbo monitoring reports (CMACS 2008, 2009) and from additional analysis conducted at Cefas within this project.

The combined filter layer and rock armour is around 1.5m high. However, as there appears to be no pre-construction survey it is not possible to map the change in elevation or any initial secondary scour effects as both would already be present in the first swathe bathymetry (November 2006). Likewise, as the first survey was three months after the foundations were completed, the extent of initial scour patterns cannot be quantified through bed level change maps.

Initial scour following monopile installation appears to be in the order of a few tens of centimetres and was noted at 14 of the 25 turbines. Scour appeared to be more prominent in the northern turbines where there is no silt content.

Bathymetric Analysis

Bed level change analysis was undertaken only in the most recent monitoring report (comparing the April 2009 and May 2008 surveys). Annual change, over the 2008 – 2009 period is in the order of centimetres (e.g., Figure 4-4) and in two of the six cases aligns with the tidal ellipse. In general though the bed level changes are variable and scour can be difficult to identify.

In addition, Cefas requested bathymetry data from Seascape Ltd for the most recent survey (April 2009) and the earliest survey (November 2006) to investigate longer-term patterns in scour and morphology (bed level change). This is possible using the November 2006 survey (there is no preconstruction survey) only because the scour pattern is subtle and shallow, and as a rough approximation can be used to represent the pre-installation bed levels. Figure 4-5 shows the bed level change maps for the six monitored turbines. Of the six locations, four show erosive patterns on the east, west or east and west sides, in line with the tidal ellipse. This orientation indicates bed lowering due to scour around the monopiles under tidal flow. The depth changes are small however, and fall within a similar range to the bed level changes adjacent to the monopiles with depths generally not exceeding 1m (erosion). The turbines BB14 and BB24 (Figure 4-5; lower panel left and centre) do not exhibit the tidally aligned patterns observed at the other turbines: at BB14 there are no signs of scour and the bed level is virtually unchanged, whilst at BB24 there is a mild north – south scour pattern (< 0.5m deep). The explanation for reduced bed erosion at these two sites may be related to an increase in fines (silty sands), and therefore cohesion of the bed. As a result, the bed level changes there are likely to be limited due to a combination of scour prevention by the prelaid armouring and a less erodible cohesive surrounding sediment.

If we can assume that negligible change occurred between installation and the November 2006 survey, the absence of any significant scour patterns could be attributed to the preparation of the bed prior to piling. The type and size of armouring material, as well as its extents, would appear to be appropriate for this hydrodynamic setting and may well prove useful at other sites both in terms of minimising the localised impact of turbines on the surrounding bed levels and as a potential cost saving for the developers. Experiences from other silt-free OWFs is needed to validate these observations as cohesion, which could also explain the low level of scour, is difficult to assess (cohesion is a function of silt/clay content, mineralogy, time history of deposition and time history of bed stresses) and may have varied spatially over the life of the OWF to date.

The increases in bed levels extending from all turbines (green shades, Figure 4-5) mark the scour protection placed around the export cables following the November 2006 survey. For cable orientation see the OWF inset that shows the intra-turbine cable route. The cable armouring is stable over the three year period since its deployment. Elsewhere along the export cable route side-scan survey shows that there are no cases of emergent cables. However, no assessment is made of the burial depth after three years. As cable deployment utilised an ROV with active tone detection and a vertical injection system to achieve and confirm the targeted 3m burial depth, an assessment of current burial depth could be undertaken using swathe bathymetry and bed level change maps.

Swathe bathymetry surveys were processed with minimal filtering so that the data were not over-processed and important features removed. Inevitably this can result in tidal busts and other elevation/alignment issues. Whilst this may be an acceptable process it needs to be carefully justified and the survey design should include tie lines as standard practice, which are absent in the results presented to date. Documenting this process carefully is important as it can affect the interpretation of morphology.

4.3 Thornton Bank Offshore Wind Farm

4.3.1 Site Description

The Thornton Bank Offshore Wind Farm, operated by C-Power, consists of 60 five megawatt turbines (300 MW maximum output) that are located on the Thornton Bank, 30km from shore in the Belgian southern North Sea. The site is of special interest as it is the first GBF OWF that is in relatively deep water, offshore (previous GBF OWFs are close to shore and mostly < 10m deep) and exposed to high wave energy and strong tidal currents (> 0.8m/s; Van den Eynde, 2005). The experiences from the Thornton OWF will provide the first field evidence to guide GBF developments in settings such as the UK's Round 2 and 3 sites. Design and stability of the scour protection system was undertaken using a mobility analysis (Shields curve) and physical models for a design condition of 6.32 m significant wave height (equates to 1:100 year return period), peak period 11.06 seconds, storm duration 3 hours, surge of 1 m and a maximum depth averaged velocity of 1.2 m/s. The size of the scour material that remains immobile under these conditions was calculated using the Shields parameter and equated to stones with a diameter > 0.25 m, and > 0.35 m on the edges of the filter where the slope rises. Breaking waves were not considered.

Tests were also conducted in DHI's 35 – 5.5 m re-circulating flume (DHI, 2007). They showed that scour was more likely to develop under storms rather than tidal currents alone, and that development of 5-10 m long pits occurred during storms (Hs = 3.5 m, Tp=9s, mean current = 1.2 m/s) that occur for just one hour in 10 years. The armouring around the GBF remained stable in these tests. These calculations and physical model runs will be put to the test when the post-construction data are collected and reported, which is due to be in June 2010.

4.3.2 Monitoring

Thornton Bank comprises medium – coarse sands (d_{50} = 250 – 400μm) and experiences a mean spring tidal range of 4m and in extreme storms wave heights >6m. The bank features large linear and bifurcating sand waves (up to 7 m high) overlain by 15 – 30cm (wavelength) ripples. Historical analysis of charts reveals that on average the bank is lowering by 2cm/year, which translates to 60 – 75cm over the 30 year life time of the OWF. The turbine support structures have a 6 m design wave height, 11m maximum wave height, and a design current of around 1.2m/s. There are some concerns regarding the additional forces due to breaking waves, which were not considered in Shields calculations and physical model runs, which has led to discussion on the use of video camera monitor presence of breakers at some of the shallower turbines.

The Gravity Base Foundations have a 23m diameter and weigh 2800 – 3000 tonnes (Figures 4-6 and 4-7). Once deployed on the seafloor, these concrete caisson structures are designed to be infilled with sediments dredged as part of the bed preparation process. The bed preparation process took 1-2 weeks for each turbine. At each turbine site a pit measuring 50 x 80 m was dredged to a depth of 7m below the surrounding seabed. The dredged material was placed 300 m from the pit and used later as backfill around the GBF and as ballast infill within the GBF. The foundation beds were carefully prepared to ensure the towers were vertical and that the GBF weight was correctly transferred to the subsoil. Two filter layers (sand then gravel) were placed using a Dynamically Positioned Fall Pipe and ROV (equipped with cameras and multibeam echosounders) and subsequently levelled. Each GBF was lowered into position using specialist transport and lowering equipment, and four echosounders mounted on the GBF base plate itself. The dredge pit was then backfilled and capped by a filter/armouring layer (green in Figure 4-8; d_{50} = 350mm) of at least 1.3m thickness. Each GBF is then hydraulically infilled using the remaining dredged material from the bed preparation pit.

Bed preparation is an essential component of the GBF deployment technique. It is both a precise and time consuming effort. With respect to morphology, pit dredging to 7m represents a significant disruption to local sediment transport. However, the first post-construction survey results, made available by the Management Unit of the North Sea Mathematical Models (MUMM), indicate that bedload sediment transport patterns are reasserting themselves via the reformation of individual sand wave crests (Figure 4-9; bedform crests in the blue dredge pit area). Use of the same dredged materials as backfill has probably aided the natural recovery of the bedforms.

The circular region around the turbine is the scour protection that has a diameter of 48m and is around 2m higher than the surrounding bed. This layer is reported to be stable. There appears to be some secondary scour stemming from armouring, retained within the dredge/backfilled area and extending around 30m. The scour patterns evident may evolve further, and will no doubt be discussed in the first post-construction annual report, which is due for release in June 2010.

4.4 Discussion and Conclusions

As the shift to deeper water sites with greater wave exposure occurs, new foundation types will be used (Carbon Trust, 2009). To date there is no guidance and very little field experience for the range of different types of foundations proposed (e.g. Figure 4-10). A monitoring approach similar to that used in Round 1 is required as new structures are introduced and until the knowledge base and guidance can be developed for each structure type. As many of the proto-type structures require seabed preparation, experience and guidance on different techniques and any resulting secondary scour will also be needed. For example, it will be necessary to determine the horizontal scales of scour and wake patterns for differing structures (including armouring) in differing hydrodynamic regimes. Until guidance can be developed, swathe bathymetry baseline and monitoring survey should cover 100% of the OWF. Scroby Sands OWF (see SED01), where large wake features developed, is a good example of bed changes that occurred further from the turbines than was expected and of the utility of full coverage survey. In that case, the length scale of the wake was sufficient to interact with adjacent foundations, scour and wake, however the orientation meant that the interaction of bed effects was avoided. Appropriate design regarding the layout of the large scale round 3 OWFs, including knowledge of the length scales of scour and wake patterns for the particular foundations in use, will be essential to avoid interactions between the bed effects of two or more foundations, the effects of which are unknown. The 100% coverage condition may be relaxed for individual OWFs once the scour and wake patterns are apparent and stable, and once the knowledge base is sufficiently robust to predict the affects of new foundation types.

Experiences from the Burbo OWF suggest that filter layers and armouring deployed prior to piling (or deployment of other non-piled foundations) is an effective means of scour prevention. Despite currents of up to 0.8m/s, the scour patterns were limited in extent and depth, and in some cases were undetectable. Bed cohesion may have played a role in minimising the scour at some sites. Further research on the behaviour of the bed to prelaid armouring is required to validate these observations. If utilised in a successful manner, preparation of the bed can minimise scour and may have operational advantages by avoiding the need for emergency post-construction scour protection.

5. Review of Scour

5.1 Background

This section deals with those aspects of sediment monitoring related to scouring around wind turbine foundations for sites evaluated by HR Wallingford (2010) and is an extension of the work reported in SED01 (DECC, 2008a) and SED02, Dynamics of Scour Pits and Scour Protection – Synthesis Report and Recommendations (Milestones 2 and 3) (DECC, 2008b). The aim is to examine scour patterns and lessons learnt at OWF sites in UK and European waters, where sufficient new data has become available.

Key recommendations (from SED01) lessons learnt are:

- *All local scour surveys from Round 1 sites remain related to mono-pile foundations and do not yet include cable routes or cable crossings;*
- *Present swathe surveys have not resolved small scale features which may be attributable to J-tubes;*
- *Scour features are resolved well by the use of high resolution swathe systems, but the post-processing of the data often looses the location of the mono-pile through interpolation of 'holes';*
- *The footprint of the scour survey remains local to the foundation and generally extends up to 50m around each structure, which is sufficient to encompass the anticipated scour width dimension for monopiles. The presence of any secondary scour is unlikely to be revealed from this process and must depend on the more general morphological survey which extends over larger distances;*
- *Further reporting of scour monitoring needs consideration of the metocean conditions in the lead up to the survey to enable a view of any potential "recovery" phase which may contribute to partial in-filling of a scour hole;*
- *Future monitoring is most important around new foundation types that differ in scale to mono-piles; and*
- *The time period for data collection may depend on site specific circumstances, but to understand better the time evolution of scour then an initial survey immediately after construction (e.g. within the first two weeks) and then soon after (e.g. within the next 3-months) would expand the scientific understanding of scour development.*

A total of five sites are considered in this section, with their locations identified in Figure 2-1. The current study has extended the data reviewed in SED01 by including two new sites, Robin Rigg and Princess Amalia, and other sites are included where an update of the available data has been obtained. Information on sites previously reviewed can be found in DECC (2008a; b).

5.2 Robin Rigg Offshore Wind Farm

5.2.1 Site Description

The Robin Rigg Offshore Wind Farm is currently being developed by E.ON UK. The wind farm site is located in the outer Solway Firth, on the sandbank known as Robin Rigg (Figure 5-1). The Solway Firth is situated on the north-west coast of the UK and separates England and Scotland. The seabed in the area of the wind farm consists of a series of banks (Dumroof Bank, Robin Rigg, Two Feet Bank and Three Fathoms Bank) orientated in a northeast – southwest direction moving from north to south across the estuary. The Robin Rigg and nearby Dumroof Banks are partially drying and seabed levels across this area of sandbanks vary from about 1.5m above Chart Datum (CD) to deeper than -16.5m CD in some locations. The water depth varies across the site from shallow, the depth just north of turbines A1 and A2 is 1m, to deep, west of K1 the water depth is 10.5m (2008 data). Robin Rigg consists of 60 steel monopile foundations of diameter 4.3m, supporting a tower and nacelle containing a 3.0MW turbine (180MW maximum output). All sixty of the monopile turbine foundation structures and the offshore substation, consisting of two monopiles, have been installed, with the initial installation of eight of the turbine foundations completed between December 2007 and January 2008. The layout of the wind farm with turbine locations and the substation location is shown in Figure 5-2.

The Solway Firth is a large shallow water estuary system consisting of extensive areas of saltmarsh, intertidal mud and sand flats, and sub-tidal and drying sandbanks. The sub-tidal sandbanks are separated by channels which are continually changing their form through erosion and accretion of the sediments. The banks are also a source and sink for sediments in the estuary helping to maintain a sediment balance.

5.2.2 Sediment Properties

The Solway Firth Basin, occupies a northeast - southwest geological syncline which is infilled largely with Permo-Triassic sediments. The Carboniferous rocks within the area are many kilometres thick (Bullen Consultants Ltd, 1998).

The Shoreline Management Plan (SMP) for the region (Bullen Consultants Ltd, 1998) describes the primary and major source of sediment in the region to be derived from glaciogenic material deposited in the Irish Sea by the retreating Scottish ice sheet. The movement of this ice sheet, along with others flowing from surrounding hills, resulted in the deposition of a complex sequence of sediments on the seabed.

The sandbanks in the Solway Firth have mobile superficial deposits with much denser more compact cores, which were formed during periods of lower sea levels (Bullen Consultants Ltd, 1998).

The seabed material is varied consisting of fine to medium sand and sandy muds overlying tills, fluvio-glacial and glacio-marine sediments (Bullen Consultants Ltd, 1998). Such extensive areas, covered by fluvio-glacial sands and gravel are thought to be the major source for the accumulation of material on the sandbanks and flats within the region. A south-west to north-east channel is present off Allonby Bay following from the course of the locally named English Channel. The grading of material in this channel varies from coarse at the south-west end becoming finer to the north-east, and indicates the influence of stronger currents associated with the presence of a flood channel resulting in little inshore-offshore movement of material in this region.

Seabed grab-sampling was carried out further up the Firth near Annan and Bowness in 1991 as well as from the deeper main channels in the Solway Firth. The results from analysis of the collected samples indicate that the bed material becomes progressively coarser in the outer firth and in the deeper water off Silloth and Maryport (Ove Arup & Partners, 1993). On the saltmarshes and intertidal sand flats, sediments are predominantly fine to coarse sands.

The site investigation work undertaken for the wind farm (Osiris Projects, 2004) identified several distinct soil types present; these include finer grained granular sediments, a variable series of glacial till deposits and intermediate strata of a variable nature ranging from laminated sands, silts and clays to organic silts and clays.

The lower flanks of Robin Rigg bank are characterised by the presence of sediment bedforms, which have been classified as mega-ripples (Osiris Projects, 2004). These mega-ripples are up to 1m high, with variable orientation and wavelengths between 6m and 20m. The side scan sonar data indicate that granular sediments are present at seabed level across the whole of the turbine array area and generally comprise mobile, shelly fine to medium grained sands.

From the soil profiles taken during the 2004 site investigation local to the wind farm turbine structures the seabed comprises of sands inter-bedded with silts and clays overlying Glacial Till. The thickness of the deposits overlying the Glacial Till were reported to be in the range 17.0m – 21.0m, although at boreholes A1 and A9 thicknesses of 23.1m and 28.8m were reported, respectively (Osiris Projects, 2004).

The sand identified at bed level was typically reported as being fine or fine to medium. From the borehole records the sand is described as typically medium dense to dense; in contrast the cone penetration tests indicate that the sand is typically dense to very dense.

The silt and clay layers found within the sands were considered to be alluvial deposits formed from a reworking of the underlying Glacial Till. These deposits are generally described as being fine sandy silt or soft to firm clay.

5.2.3 Hydrodynamic Properties

The shallow nature of the estuary system and its orientation to the open sea means that tidal currents are moderately strong and wave energy can be significant.

In the Solway Firth the spring tide flood lasts for approximately 5 hours at Silloth, with a range of approximately 8 metres, but decreases with distance into the Firth. Similarly the spring tide ebb lasts for approximately 7 hours at Silloth. Off Dubmill Point the flood tide achieves a mean flow rate of 1.0m/s with a mean ebb flow rate of 0.9m/s (Bullen Consultants Ltd, 1998).

Previous studies within the Solway Firth have shown that the estuary is an area of high tidal energy and strong tidal currents. Ove Arup & Partners (1993) undertook near-bed current measurements (1m above the seabed) at two relatively deep water sites within the upper Solway Firth, just offshore of Silloth and opposite the Annan Estuary. In the channel off Skinburness, mean flows reached 1.8m/s, whilst further into the firth just downstream of Annan mean flows of 2.5m/s were recorded (spring flood tide). From the NERC (1992) marine atlas, tidal current speeds over mean spring tides are shown to be around 1.9m/s between Dubmill Point and Southerness Point and around 2.4m/s at Annan to Bowness. These sites are up-estuary of the Robin Rigg site and of the UKHO chart 2013 tidal stream points, diamond B and C (see Figure 5-1 for locations) which have peak currents on an average spring tide of 2.1 knots (1.1m/s) and 3.9 knots (2.0m/s) respectively. It is likely that the mean spring tidal currents in the vicinity of the wind farm on Robin Rigg Sandbank will also be of a similar order.

During neap tides the tide periods for Silloth are approximately the same as for springs (i.e. 7 hours ebb, 5 hours flood) but the range is reduced to approximately 3 metres.

The passage of the tide in and out of the Solway Firth mainly follows an east-west route to the north of the Isle of Man and sustained residual currents at the seabed have been estimated at 0.015 to 0.05m/s in an easterly direction (Perkins *et al.*, 1964).

Information on near-bed currents at Silloth and Annan indicate that the flood tide exhibits higher velocities than the ebb, the maximum recorded flood and ebb velocities being 2.0m/s and 1.5m/s, respectively (Ove Arup & Partners, 1993), creating greater opportunity for sediment transport during the flood tide and hence sediment transport into the estuary.

5.2.4 Monitoring

A number of surveys have been completed during the construction phase of the Robin Rigg OWF. The results of these surveys are presented in this section of the report.

March - April 2008 Survey

Several bathymetric surveys have been undertaken at the Robin Rigg OWF site since installation of the foundation piles. The first of these was undertaken between March and April 2008 (Osiris Projects, 2008). This survey covered the eight foundations installed at that time, E3, G3 – G7, H1 and H2; Figure 5-2 shows the position of these turbine structures relative to each other. Table 5-1 shows the results from an analysis of the seabed depths from the Digital Terrain Model (DTM) of the survey data at the eight turbine foundation positions and the corresponding scour depths, together with scour depths obtained directly from the Osiris survey charts.

Table 5-1 Scour depths estimated from March - April 2008 bathymetric dataset

Turbine Position	Maximum depth (m OD(N))	Estimated local undisturbed seabed level (m OD(N))	Estimated scour depth from DTM (m)	Scour depth estimated directly from Osiris charts (m)
E3	-13.9	-8.6	5.3	6.0 to 7.0
G3	-14.9	-9.5	5.4	5.5 to 6.0
G4	-14.9	-9.5	5.4	5.5 to 6.0
G5	-14.7	-10.2	4.5	4.0 to 5.5
G6	-14.8	-10.2	4.6	5.5 to 6.5
G7	-13.6	-8.7	4.9	5.5 to 6.0
H1	-14.0	-9.5	4.5	4.5 to 6.0
H2	-15.7	-10.3	5.4	6.0 to 6.5

December 2008 – January 2009 Survey

During December 2008 to January 2009, Osiris undertook a repeat bathymetric survey across the Robin Rigg site (Osiris Projects, 2009). As previously, a DTM of the new survey data was created using software within the DHI Mike21 modelling suite at a grid 5m x 5m grid spacing. Figure 5-2 shows the position of the 8 previously installed foundations and scouring around the adjacent recently installed foundations. Figure 5-3 shows the same bathymetric survey but as a 3-dimensional image. Again, an analysis of the seabed depths from the new DTM at the eight installed foundations, E3, G3 – G7, H1 and H2 was carried out. The results of this analysis are shown in Table 5-2.

Table 5-2 Scour depths estimated from December 2008 – January 2009 bathymetric dataset

Turbine Position	Maximum depth (m OD(N))	Estimated local undisturbed seabed level (m OD(N))	Estimated scour depth from DTM (m)	Difference between DTM scour depths (value in Table 4 minus value in Table 3) (m)	Scour depth estimated directly from Osiris charts (m)
E3	-13.0	-8.4	4.6	-0.7*	5.5 to 5.8
G3	-13.8	-9.1	4.7	-0.7*	5.5 to 5.8
G4	-14.3	-9.3	5.0	-0.4*	6.5 to 6.8
G5	-15.4	-10.0	5.4	0.9	6.1 to 6.8
G6	-15.6	-10.1	5.5	0.9	7.5 to 7.7
G7	-14.0	-8.6	5.4	0.5	7.0 to 7.4
H1	-13.1	-9.2	3.9	-0.6*	5.0 to 5.3
H2	-14.4	-10.3	4.1	-1.3*	5.0 to 5.5
* Negative value identifies infilling of the scour hole.					

In addition to the seabed depths determined from the new DTM at the eight turbine foundation positions and the corresponding scour depths, a difference in the estimated scour depth between the March-April 2008 survey and the December 2008-January 2009 survey was calculated. Also shown in Table 5-2 are the scour depths at the same eight locations determined directly from the Osiris survey images.

Based on the comparison of the results in Tables 5-1 and 5-2 the general inference is that the majority of the eight previously installed piles have undertaken a certain amount of infilling, although at some of the foundation positions the depth of the lowest level within the scour hole has increased (i.e. become deeper). This apparent contradiction is due to a general lowering of the seabed. This general lowering of the seabed may well be a function of winter storms reducing the upper volume of the sandbank, although this effect has not been investigated further here.

The results presented in the tables also show an inconsistency between the scour depths estimated from the DTM and those determined directly from the Osiris images and report. The values determined directly from the Osiris report generally identify much larger scour values for the initial monitoring period (March – April 2008), with a maximum scour depth of up to 7.0m at E3, compared with 5.3m estimated from the DTM. This inconsistency can also be seen in the second monitoring period (December 2008 – January 2009), with a maximum scour depth of up to 7.7m taken directly from the Osiris report for G6, compared with 5.5m estimated from the DTM.

The numbers quoted in Table 5-3 were taken from Osiris Projects reports (2008; 2009). From the table the results suggest that at some locations the scour has developed further between the March-April 2008 survey and the December 2008 and January 2009 survey. At some of the locations the data shows that backfilling has occurred. Survey data for all the turbine locations is shown in Table 5-4. At the time of this survey, foundation installation was ongoing.

Table 5-3 Natural seabed levels and scour depths for installed foundations E3, G3 – G7, H1 and H2 (Osiris Projects, 2008; 2009)

Turbine Position	Natural seabed level June 2007 (m CD)	Natural seabed level March/April 2008 (m CD)	Deepest seabed level March/April 2008 (m CD)	Natural seabed level Dec 2008 – Jan 2009 (m CD)	Deepest seabed level Dec 2008 – Jan 2009 (m CD)
E3	-4.0	-4.0	-10.0	-3.7 to -4.0	-9.5
G3	-5.0	-5.0	-11.0	-4.7 to -5.0	-10.5
G4	-5.0	-5.0	-11.5	-4.7 to -5.0	-11.5
G5	-5.5	-5.5 to -6.0	-11.0	-5.5 to -6.2	-12.3
G6	-5.0 to -5.5	-5.5	-11.5	-5.3 to -5.5	-13.0
G7	-3.5 to -4.0	-4.5	-10.0	-3.85 to -4.2	-11.2
H1	-5.0	-5.0	-11.0	-4.7 to -5.0	-10.0
H2	-6.0	-6.0	-12.5	-5.5 to -6.05	-11.0

Part of the differences between the DTM results and the Osiris results may be due to differences in accuracy between the DTMs (5m x 5m grid) and the Osiris charts, as the Osiris charts may be based on higher resolution data and, therefore, be capable of picking up more of the detail adjacent to the foundations. The other possible reason for the difference is the calculation of the natural seabed level at each foundation location.

Spatial Variation around the eight foundations

Figures 5-4 to 5-13 show the bathymetry local to the individual structures for the March-April 2008 survey and Figures 5-14 to 5-21 show the equivalent images for the December 2008-January 2009 survey. These images were obtained from the DTMs constructed from the raw XYZ data. The differences between these two surveys are shown in Figures 5-22 to 5-29. The differencing was carried out as the ‘Dec-Jan survey’ minus the ‘Mar-Apr survey’, therefore, positive values indicate accretion of sediment whilst negative values indicate erosion.

At position E3 the difference between the surveys shows a deepening around the sides of the foundation (relative to the apparent principal flow axis) and back-filling within the scour hole adjacent to the pile location. There has also been a general lowering of the seabed upstream and downstream of the foundation position. This general lowering may be related to the pile, or part of a more general background lowering in seabed.

At position G3, there has been back-filling of the scour hole immediately adjacent to the pile location and general scouring downstream of the pile (relative to the dominant tidal flow direction) suggesting a relaxation of the slope of the hole. Again there has been a general lowering of the seabed along the principal flow axis passing through the pile location.

The differencing shows a similar pattern of change at foundation G4 to that at foundation G3, with back-filling adjacent to the pile location, general lowering of the seabed along the principal flow axis passing through the pile location and further scouring downstream of the pile.

At foundation G5 there has been back-filling of the scour hole immediately adjacent to the pile location. Downstream of the pile (relative to the dominant tidal flow direction) there has been further scouring and also a general lowering of the seabed along the principal flow axis passing through the pile location. How much of this general lowering is a function of normal seabed movement and how much is related to the presence of the pile is not obvious from the data.

At foundation G6 the difference plot indicates a deepening adjacent to the front face of the pile (relative to the dominant tidal flow direction) and back-filling along one side and at the rear of the pile. There is also a lowering of the seabed along the principal flow axis through the pile.

At position G7 there is some accretion and erosion at the front and sides of the pile, as well as general lowering of the seabed along the principal flow axis through the pile. There is less coherence with respect to the general seabed differences at this location suggesting that much of the difference observed here from comparison of the two survey datasets is due to general bed movement rather than due to the presence of the pile.

At foundation H1 the difference plot indicates accretion adjacent to the front face of the pile (relative to the dominant tidal flow direction) and erosion at the rear of the pile. The plot also indicates general bed movement around the pile location.

At position H2 the analysis shows erosion to the sides of the pile location and accretion at the rear of the pile (relative to the dominant tidal flow direction). There is also a general lowering of the seabed along the principal flow axis passing through the pile location. There is also a localised 'mound' of accretion to the north-east of the pile. This spot of accretion may be associated with installation works relating to the remaining foundations and jack-up operations.

In addition to the spatial plots, cross-sections were taken along the principal axis of scour based upon the December 2008 – January 2009 survey (Figures 5-30 to 5-37). In some instances, the principal axis of scour may have a different orientation at a foundation in the earlier March-April 2008 survey. There is, therefore, room for some error in the comparison due to this misalignment, however, this is not considered to be a significant factor at this stage given the vertical accuracy of the bathymetry surveys (typically ±0.25m).

Table 5-4 Seabed levels obtained from Osiris December 2008 – January 2009 survey report

Turbine Position	Natural se0abed level Dec 2008 – Jan 2009 (m CD)	Deepest seabed level Dec 2008 – Jan 2009 (m CD)	Foundation installation status
A1	-1.2 to -1.4	No scour yet	Not installed
A2	-2.00 to -2.30	-7.50	Installed
B1	-1.50 to -1.80	No scour yet	Not installed
B2	-2.50 to -2.80	No scour yet	Not installed
B3	-3.00 to -3.20	-9.50	Installed
B4	-2.20 to -2.50	-9.00	Installed
B5	-1.00 to -1.60	-8.50	Installed
C1	-3.00 to -3.40	No scour yet	Not installed
C2	-2.20 to -2.50	-4.00	Installed
C3	-3.50	-5.00	Installed
C4	-3.20 to -3.50	-9.00	Installed
C5	-1.50 to -2.00	-8.00	Installed
C6	-0.75 to -1.25	-8.00	Installed
D1	-4.70 to -5.50	No scour yet	Not installed
D2	-2.75 to -3.00	No scour yet	Installed
D3	-3.50 to -3.80	-6.50	Installed
D4	-4.00 to -4.25	-4.75	Installed
D5	-2.50 to -3.00	No scour yet	Installed
D6	-1.25 to -2.00	-6.50	Installed
D7	-0.95 to -1.20	-8.50	Installed
E1	-5.40 to -6.30	No scour yet	Not installed
E2	-3.95 to -4.30	No scour yet	Not installed
E3	-3.70 to -4.00	-9.50	Installed
E4	-4.25 to -4.50	-9.50	Installed
E5	-3.50 to -3.80	-9.00	Installed

Turbine Position	Natural se0abed level Dec 2008 – Jan 2009 (m CD)	Deepest seabed level Dec 2008 – Jan 2009 (m CD)	Foundation installation status
E6	-3.00 to -3.80	-9.00	Installed
E7	-1.50 to -1.80	No scour yet	Installed
E8	-1.20 to -1.80	-8.00	Installed
F1	-5.45 to -6.30	No scour yet	Installed
F2	-3.75 to -4.25	-9.00	Installed
F3	-4.70 to -5.20	-11.00	Installed
F4	-4.95 to -5.30	-10.00	Installed
F5	-3.95 to -4.30	-10.20	Installed
F6	-3.70 to -4.20	-10.50	Installed
F7	-1.75 to -2.50	-9.00	Installed
F8	-1.50 to -2.00	-2.30	Installed
G1	-5.20 to -5.50	-9.50	Installed
G2	-4.60 to -4.80	-9.00	Installed
G3	-4.70 to -5.00	-10.50	Installed
G4	-4.70 to -5.00	-11.50	Installed
G5	-5.50 to -6.20	-12.30	Installed
G6	-5.30 to -5.50	-13.00	Installed
G7	-3.85 to -4.20	-11.20	Installed
G8	-2.25 to -3.20	-10.20	Installed
H1	-4.70 to -5.00	-10.00	Installed
H2	-5.50 to -6.05	-11.00	Installed
H3	-6.40 to -7.00	-13.00	Installed
H4	-7.05 to -7.40	-13.80	Installed
H5	-5.45 to -6.00	-12.00	Installed
H6	-4.00 to -4.30	-11.00	Installed
H7	-3.40 to -3.70	-10.70	Installed
J1	-7.70 to -9.30	-13.70	Installed
J2	-8.20 to -8.60	-11.70	Installed
J3	-7.15 to -7.55	-13.20	Installed
J4	-5.80 to -6.30	-12.00	Installed
J5	-4.10 to -4.50	-10.50	Installed
J6	-3.10 to -3.50	-10.50	Installed
K1	-8.70 to -9.30	-14.00	Installed
K2	-7.65 to -8.10	-13.70	Installed
K3	-6.60 to -7.10	-13.50	Installed

5.3 Princess Amalia (Q7) Offshore Wind Farm

5.3.1 Site Description

The Princess Amalia (Q7) OWF is the second offshore wind farm in the Dutch sector of the North Sea and the first to be located outside the 12 nautical mile limit (Figure 2-1). The 4m diameter monopile turbine foundations are located in water depths of between 19m and 24m and the wind farm is located approximately 23km from IJmuiden, The Netherlands. The wind farm consists of 60 steel monopile foundations, with an overall generating capacity of 120MW, comprising 60 Vestas V80 2MW wind turbines. It has been operational since June 2008.

5.3.2 Sediment Properties

The Southern North Sea has been significantly influenced by the glacial and interglacial periods. During much of these stages of ice retreat and advance, much of this area remained as dry land and subject to sub-aerial erosion and deposition. Over the Pleistocene Epoch, the accumulation of glacial, marine and fluvial sediments, as a result of the sequence of ice sheet advance and retreat, has created a complex geology, which has been modified by periglacial activity and marine reworking. Eisma (1987) has stated that there is little sand supplied to the North Sea and predominantly the sedimentary processes consist of the re-working of existing sediments which were deposited during the last glacial period. This process is primarily governed by tidal currents and van der Molen (2002) suggests that tides in the Southern Bight are strong enough to transport considerable quantities of sand close to the bed (within 1m). In the southern North Sea the re-working of the sediments result in the formation of mobile sandwaves, which can achieve heights of 2 to 3m in the area off Egmond aan Zee (McCave, 1971).

Fugro (2003) undertook a detailed geophysical survey of the Princess Amalia wind farm site and their report provides an overview of the local geology. To the east of the site is a sandbank and sandwaves are found to the west of the site. The sandbank has a maximum height of 5m and a width of around 2km. It lies along a north-northeast to south-southwest line. Small sandwaves have been recorded on the sandbank (height < 1m). The sandwaves to the west of the site have heights of around 2m and may be the remains of a relic sandbank. The general orientation of the sandwave crests is along a northwest to southeast line and their asymmetry suggests a southwest to northeast sediment transport direction. Fugro (2003) state that the fine to medium sands of the sandbank and sandwaves are Holocene deposits of the Bligh Bank Formation and are found at a depth of approximately 0 to 3m.

From the borehole information the indication is that the sediments underlying the Bligh Bank Formation are a soft to firm organic-rich clay and this clay layer and underlying silty sand layer have been interpreted as the Holocene Elbow Formation (Fugro, 2003). These deposits are found between 3m to 5m. The indication from the boreholes is that the Elbow Formation is only found underneath the eastern sandbank and the sandwave features to the west of the site.

Underlying the Holocene Elbow Formation are shallow marine sand deposits of the Eem Formation at depths of between 5m to 25m. These sands are from the Pleistocene period and consist of fine to medium grained dense to very dense sands. The Yarmouth Roads Formation underlies the Eem deposits and these comprise medium dense to dense fine to medium grained sands with some clay layers.

Sediments tend to be fine to medium sands (0.125 – 0.500mm) with low organic carbon content due to the relatively strong current speeds that lead to a winnowing out of the fine grained sedimentary and organic particles. This is supported by the geophysical studies which describe the surficial sands as generally consisting of poorly graded fine to medium sand or medium sands. The silt/clay content is generally low within these sediments. The Holocene sand layer is typically loose to medium dense, whilst the cohesive sediment making up the Elbow formation are comprised of soft to stiff peat clays.

From a benthic study of the Q7 site (Jarvis *et al.*, 2004) the median sediment characteristics have been quoted as 0.578mm with a maximum grain size of 0.642mm and a minimum of 0.470 mm. This would suggest the surficial sediments to be coarse grade sand rather than fine to medium grade.

5.3.3 Hydrodynamic Properties

The tides along the Dutch coast are semi-diurnal and residual surface tidal currents run along a northeast axis, approximately parallel to the coastline. Eisma (1987) has described the currents along this section of coast to be some of the strongest in the North Sea, and according to van der Molen (2002) currents can reach 1.4m/s. Van der Giessen *et al.* (1990) have reported that a residual onshore movement (around 0.03m/s) exists here in the lower portion of the water column. This is generally a tidally dominated environment, except during storms when storm waves and wind-driven currents can become important and be sufficient to move seabed sediments at considerable depth. Van der Molen (2002) stated that erosional effects have been detected down to 45m in other areas of the North Sea.

Den Boon *et al.* (2004) describe the 50 year design conditions for the Princess Amalia OWF. The local depth-averaged current for both tidal and wind-driven current is 1.3m/s, whilst the wave conditions in block Q7 of the Dutch North Sea are a significant wave height of 7.7m with a mean wave period of 9.7s.

5.3.4 Monitoring

The data obtained for the Princess Amalia OWF relates to surveys undertaken prior to scour protection being placed. Trenching related to the inter-array cable laying is evident in some of the surveys. Figure 5-38 shows the layout of the foundations relative to the bathymetry. Table 5-5 gives the scour depth prior to placement of the scour protection; we do not know how close to equilibrium depths these holes were. The values are estimated from a Digital Terrain Model (DTM) of the survey data. The interval between the installation of the monopiles and the survey is also given in days in Column 6 of Table 5-5. Installation took place between October 2006 and April 2007.

Table 5-5 Estimated scour depth pre-scour protection at Princess Amalia Wind Farm

Turbine Position	Mean depth (m)	Minimum depth (m)	Scour depth, S (m)	S/D (Scour Depth/Foundation Diameter)	Interval between foundation installation and survey (Days)
WTG01	-24.106	-26.694	2.6	0.647	324
WTG02	-24.139	-26.355	2.2	0.554	270
WTG03	-24.226	-27.090	2.9	0.716	303
WTG04	-24.226	-27.135	2.9	0.727	301
WTG05	-24.037	-26.088	2.1	0.513	unknown
WTG06	-24.032	-26.021	2.0	0.497	318
WTG07	-23.882	-25.979	2.1	0.524	300
WTG08	-24.357	-26.428	2.1	0.518	270
WTG09	-24.285	-26.702	2.4	0.604	267
WTG10	-24.069	-26.445	2.4	0.594	267
WTG14	-23.263	-26.119	2.9	0.714	330
WTG15	-23.736	-25.957	2.2	0.555	291
WTG16	-25.531	-27.807	2.3	0.569	268
WTG17	-24.581	-27.006	2.4	0.606	263
WTG18	-24.454	-26.330	1.9	0.469	263
WTG19	-25.069	-27.639	2.6	0.643	294
WTG23	-23.926	-25.681	1.8	0.439	294
WTG24	-23.928	-26.039	2.1	0.528	263
WTG24_off	-23.933	-26.031	2.1	0.525	263

Turbine Position	Mean depth (m)	Minimum depth (m)	Scour depth, S (m)	S/D (Scour Depth/Foundation Diameter)	Interval between foundation installation and survey (Days)
WTG25	-25.452	-27.150	1.7	0.424	259
WTG26	-25.636	-27.696	2.1	0.515	258
WTG27	-25.726	-28.608	2.9	0.721	298
WTG28	-26.113	-28.265	2.2	0.538	295
WTG31	-20.863	-23.710	2.8	0.712	unknown
WTG32	-22.805	-25.344	2.5	0.635	242
WTG33	-23.361	-25.382	2.0	0.505	252
WTG35	-25.922	-29.143	3.2	0.805	292
WTG36	-26.391	-27.625	1.2	0.309	296
WTG38	-22.935	-24.417	1.5	0.371	329
WTG40	-20.991	-25.609	4.6	1.155	unknown
WTG41	-24.386	-26.699	2.3	0.578	313

From the analysis of the data, scouring at the majority of the turbines foundation appears to be limited. The geophysical report of Fugro (2003) states that the fine to medium sands of the sandbank and sandwaves are Holocene deposits and are found at a depth of between 0 to 3m, approximately. Underneath the eastern sandbank and the sandwave features to the west of the site, the sediments are a soft to firm organic-rich clay. These deposits are found at depths of between 3m to 5m. It is possible that these clay deposits are acting to limit scouring at many of the foundation locations as given the time-scale between installation and the survey (7 - 11 months, approximately) it is expected that equilibrium scour conditions would have been achieved for a mobile, unconstrained sand bed. However, we note that data for a piled foundation on the Dutch shelf (N7 site reported in DECC, 2008b) experienced progressively deepening scour over a number of years. Turbine WTG40 is one of the few sites for which survey data has been obtained that achieves a scour depth that would be considered close to the expected equilibrium condition (for a mobile unconstrained sand bed).

Figures 5-39 to 5-45 show a sample of the survey sites including Turbine WTG40 (Figure 5-43). The survey data for the foundations WTG 14 and 26 is also presented in both 2D (Figures 5-39 and 5-40) and 3D formats (Figures 5-44 and 5-45). At WTG14 there is a circular depression adjacent to the foundation associated scour. This is likely to be caused by one of the legs of the jack-up platform used to construct the wind farm. At WTG26 the seabed impression of trenching associated with the cable laying is clearly visible. Similar marks are also visible at WTG38 (Figure 5-42).

Since (we understand) scour protection was installed after these surveys were undertaken it is not possible to assess the longer-term development of the unconstrained scour to determine whether the scour development would have continued but at a slower rate than predicted for a uniform sand.

5.4 Barrow Offshore Wind Farm

5.4.1 Site Description

Barrow Offshore Wind Farm is situated about 8km southwest of Walney Island in the Irish Sea (Figure 2-1). Thirty monopile foundations have been placed within the site, each of 4.75m diameter, D.

5.4.2 Sediment Properties

British Geological Survey (BGS, 1987) shows the seabed comprises muddy sands and sandy gravels across the entrance to Morecambe Bay, with exposures of Quaternary till. Titan Environment (2002) undertook a geophysical survey of the wind farm site that provided further detail, showing the site as comprising mainly sand with concretions overlying tillite and clays, except in the shallower south east corner of the site where exposures of tillite and clays dominate and the surface sand becomes patchy. The depth of surface sediment reaches 10m in the northwest but this depth includes bedded muddy sands as well as the surface layer of sand. A pre-construction geophysical survey was carried out in 2005 by Osiris Projects (Report C5002, May 2005) which confirmed the earlier distribution of sediment.

Seacore (2004) undertook further geophysical surveys, including borehole sampling. At the western side of the wind farm, the bed material at the top of the borehole sample consists of medium dense becoming very dense brown silty fine SAND with occasional shell fragments. This layer extends to 10.8m beneath the surface, with patches of very dense sand and occasional other material, such as coal fragments and quartz granite fine to coarse gravel. The sand at this location is very fine at 1.75m below the surface, with a significant fraction smaller than 0.06mm (the boundary between sand and silt). The sand increases in size on going down through the layer. Beneath the sandy layer is a thick layer of “stiff becoming very stiff slightly gravelly CLAY with occasional cobbles” (Seacore 2004).

At the southernmost borehole the top 3m of seabed consisted of very silty, fine SAND. Beneath the top layer of sand is a 6m deep layer of slightly laminated, slightly sandy CLAY. Within the clay dominant area of the site some of the borehole data shows a sand veneer extending only around 0.1m below the surface. Beneath this veneer of sand is another 0.1m deep layer of very gravelly, sandy CLAY and underlying this layer is a 6.1m thick layer, also of very gravelly, sandy CLAY. Underneath this are alternate layers of sand and clay.

5.4.3 Hydrodynamic Properties

Calibrated numerical modelling (HR Wallingford, 2002) showed that the tidal currents run in an approximately east to west alignment over the wind farm. Peak spring and neap current speeds at the site were reported to be 0.67m/s and 0.34m/s (HR Wallingford, 2004). The 1-year return period significant wave height, H_s, is 4.8m at the western edge of the wind farm, with a corresponding peak wave period of T_p = 9.8 s. Based on the analysis of wave statistics a significant wave height of 0.5m is only exceeded 25% of the time.

5.4.4 Monitoring

Since the Barrow OWF became operational in July 2006, several post construction bathymetric surveys have been carried out as required by the FEPA Licence. Results for July 2005 and September 2006 were used in DECC (2008b). The early bathymetric surveys of the site have shown the general seabed levels to have remained similar to those surveyed pre-construction. Scour surveys were carried out around nine of the turbines in November 2006 and April 2007. Scouring was found to have taken place around 7 of the turbines to varying degrees, with recorded depths of scour between 1m and 6m. These early surveys also revealed faint remains of the inter-turbine cable installation around many of the turbines.

Further surveys were carried out in November 2007 and May 2008. Table 5-6 shows the results of the monitoring surveys between November 2006 and May 2008. It should be noted that the depths have been estimated from the contour plots provided within BOWind (2008a, 2008b) and may be subject to some error in estimating the lowest depth local to the turbine foundation. Comparisons with predicted scour depths were made in DECC (2008b).

Observable in some of the earlier surveys are several jack-up leg depressions. These depressions have tended to infill over time. The surveys also reveal that there has been some exposure of the cables. This may be associated with the natural movement of sediment across the area. Work was carried out in May 2007 to secure the protection and burial of exposed or vulnerable inter-array and transmission cables (BOWind, 2008a).

Table 5-6 Scour Monitoring Data taken from BOWind (2008a; b)

Turbine No.	**Survey Date**			
	November 2006		April 2007	
	Background levels (m ODN)	Scour depth (m)	Background levels (m ODN)	Scour depth (m)
A3	-17.00 to -18.5	No scour	-16.75 to -18.25	No scour
A6	-20.75 to -21.25	No scour	-20.75 to -21.05	0.70 to 1.00
B2	-19.75 to -20.55	No scour	-19.75 to -20.25	No scour
B5	-20.25 to -20.50	1.50 to 1.75	-20.25 to -20.50	1.50 to 1.75
B8	-20.40 to -20.75	2.50 to 2.75	-20.40 to -20.75	2.50 to 2.85
C3	-20.40 to -20.75	2.75 to 3.10	-20.45 to -20.65	2.60 to 2.80
C6	-21.00 to -21.30	4.95 to 5.25	-21.00 to -21.25	4.50 to 4.75
D2	-20.45 to -20.65	1.60 to 1.80	-20.75 to -20.65	1.60 to 1.80
D5	-21.25 to -21.50	5.75 to 6.00	-21.00 to -21.25	4.75 to 5.00
Turbine No.	**Survey Date**			
	November 2007		May 2008	
	Background levels (m ODN)	Scour depth (m)	Background levels (m ODN)	Scour depth (m)
A3	-16.75 to -18.25	No scour	-16.45 to -18.25	No scour
A6	-20.75 to -21.00	0.25 to 0.50	-20.25 to -21.00	No scour
B2	-19.75 to -20.25	No scour	-19.50 to -20.25	No scour
B5	-19.75 to -20.25	1.50 to 2.50	-20.00 to -20.25	1.00 to 1.25
B8	-20.25 to -20.50	2.50 to 2.75	-20.30 to -20.75	2.50 to 2.95
C3	-20.25 to -20.75	1.75 to 2.25	-20.45 to -20.75	1.50 to 1.80
C6	-21.00 to -21.25	4.25 to 4.50	-21.05 to -21.25	3.75 to 3.95
D2	-20.45 to -20.75	1.25 to 1.55	-20.45 to -20.75	1.00 to 1.30
D5	-21.00 to -21.25	4.25 to 4.50	-21.00 to -21.25	3.50 to 3.75

Analysis of this table suggests background levels throughout the wind farm have been generally stable between November 2006 and May 2008, with little variation between summer and winter conditions. The November 2006 survey showed sites where no scour occurred and others where up to 6m occurred. In general terms however, there has been a trend for the scour holes to backfill at most locations.

5.5 Kentish Flats Offshore Wind Farm

5.5.1 Site Description

Kentish Flats OWF is located in the outer Thames Estuary, approximately 9km off the North Kent Coast and north of Herne Bay and Whitstable (Figure 2-1). The area lies to the south of the main Thames shipping channels and is bounded to the west by East Middle Sand and East Spaniard Banks and to the east by the Pan Sands Bank. The main export cables have a landfall at Hampton Pier, Herne Bay from where they run inland to a substation and connection with the National Grid.

Construction of the wind farm was started in August 2004 and work was completed at the end of August 2005. The wind farm is composed of 30 turbines placed within a 10km^2 area of the seabed and the foundations consist of 4.3m diameter monopile foundations. The monopiles were piled into the seabed with penetration depths of between 28 and 34m below existing seabed levels. The seabed over the site has a general depth of between -3.0m CD and -4.5m CD. Kentish Flats OWF became operational in September 2005.

5.5.2 Sediment Properties

The bathymetry of the Outer Thames Estuary comprises sandbanks and channels that are coast aligned, approximately. The channels are generally shallower than -20m CD and many of the banks dry on the lower low waters. In addition to the sandbanks there are mobile sandwaves with amplitudes of several metres. The banks also shift their position and the depths change over time.

The seabed at Kentish Flats is generally flat and subtly varied, comprising mainly coarse sand, but with varying amounts of shell gravel, whole dead shells, occasional pebbles and stacks of slipper limpets, very occasional cobbles and small exposures of the underlying clay. The sand is smooth or slightly rippled in places, but elsewhere are broadly spaced ridges and hollows. Geotechnical surveys at Kentish Flats show that the seabed consists of variable thickness of sand, underlain by soft to firm clays, on top of the London clay formation. The surficial sediment comprises muddy sands with shells and seaweed.

5.5.3 Hydrodynamic Properties

Tidal currents within the Outer Thames Estuary are complex as a result of the various banks and channels. Flows are generally rectilinear following the Queens and Princes Channels to the east and then separating around the Pan and Middle Sands. Peak currents to the north and south of Kentish Flats run east-northeast to west-southwest, with stronger flows on the ebb but longer duration on the flood due to tidal asymmetry. Tidal currents are strongest to the southeast where mean-spring tidal speeds are of the order of 0.7m/s on the flood and 0.9m/s on the ebb (HR Wallingford, 2002). These rates will increase slightly under larger spring tidal events.

The predicted mean spring tidal range across the wind farm site is approximately 4.7m. With bed elevations across the site of between -3.0m CD and -4.5m CD, the maximum water depths under typical tidal conditions will be around 8m to 10m (HR Wallingford, 2002).

Waves in the Outer Thames Estuary are heavily influenced by the complex system of banks and channels. Waves from all sectors will be subject to shoaling, refraction and/or breaking due to the bathymetry and tidal currents, particularly at mid- to low tidal states. Waves of up 4.0m have been recorded at the site, but these are infrequent, and wave conditions vary considerably along the coast with the 0.1% exceedence level for H_{max} around 2.7m (HR Wallingford, 2002). However, the site will be depth limited and assuming a breaking ratio (wave height to water depth) of between 0.55 and 0.8, then potentially waves with a significant height (H_s) of 1.65m or higher may break.

5.5.4 Monitoring

Scour monitoring has been carried out at Kentish Flats on a six-monthly basis since the foundations were installed in November 2004 for a period of three years. The monitoring was undertaken at four turbine foundation locations, which were selected on the basis of being representative of the various sedimentary environments present (Vattenfall, 2009). The results from these surveys are shown in Table 5-7. Data in DECC (2008b) included results from surveys to April 2006.

Table 5-7 Recorded scour depths at Kentish Flats Offshore Wind Farm (Vatenfall, 2009)

Survey Date#	Scour Depth (m)			
	WT E2	WT F2	WT F3	WT F4
January 2005	0.8	1.1*	1.4	1.1
November 2005	1.2	2.3	2.1	1.8
April 2006	1.4	1.6	1.7	1.7
October 2006	1.4	1.7	1.7	1.5
March 2007	1.5	1.9	1.7	1.7
November 2007	1.5	1.9	1.7	1.9

Note: # Foundations were installed in November 2004
* Value used in DECC (2008b) was 1.2m

The turbine foundations have a diameter of 4.3m. Also observable in the monitoring surveys were six regular depressions caused by the jack-up vessel at the time of installation of the foundations. Immediately post-construction, these depressions were recorded to have depths of between 0.5m and 2.0m. At the time of the final survey in November 2007 these depressions had reduced, on average, by 0.6m. This would suggest that there has been some infilling of these depressions by the mobile sandy sediments.

The data in Table 5.7 generally indicates that maximum scour rates occurred during the first year from installation and then rapidly slowed with near stability occurring by the third anniversary of the works, with scour depths ranging from 1.5 – 1.9m at the monitoring locations. The area comprises of non-cohesive sands over London Clay. The results possibly indicate that the scour depth is restricted by the cohesive underlying clay formation.

5.6 North Hoyle Offshore Wind Farm

5.6.1 Site Description

North Hoyle OWF is situated approximately 7.5km from the North Wales coast offshore of Prestatyn and Rhyl (Figure 2-1). The wind farm consists of thirty turbines in water depths varying between around 7m to 11m (LAT) which were installed by Seacore Ltd. over the period April to July 2003. The foundation units each comprise of 4.0m diameter monopiles and are arranged within a 10km^2 area of seabed licensed from The Crown Estate. The turbine array configuration is 5 columns and 6 rows, with respective separations of 800m and 350m, approximately, between foundations.

The coastline is generally flat and predominantly sandy, although there are rocky islands at the mouth of the Dee Estuary (Hilbre, Little Hilbre and Little Eye), and there are also low-standing red sandstone cliffs along the western shoreline of the Dee between Heswall and West Kirby.

5.6.2 Sediment Properties

During the Pleistocene period, the whole Irish Sea area was covered in an ice sheet which led to the deposition of glacial tills. As sea level rose due to the melting ice sheet the Irish Sea was formed, separating Ireland from mainland Britain. As the sediments became progressively submerged by rising sea levels, the erosive action of waves and the sorting action of the tide created the sediment distribution that exists today forming the Holocene deposits.

The British Geological Survey (BGS) publish broad-scale maps of the coastal geology across Liverpool Bay, but detailed data of the coastal geology is less readily available. In general, Pleistocene and Holocene sediments overlie older bedrock (Permio-Triassic) and/or glacial till (Late Devensian), with sediment depths typically around 10m. These sediments tend to be mainly sands and gravels with a varying degree of mud content. There are few bedrock outcrops with Hilbre Island and Red Rocks being the principal local formations.

The oldest of the sedimentary structures within Liverpool Bay date from the Ordovician and Silurian period whilst the youngest consist of Pleistocene and Holocene material. The surficial seabed sediments are made up of fine to medium sand overlying a partly eroded surface of boulder clay with local occurrences of gravel. This boulder clay layer is considered to be the principal source of sediments within the inner Liverpool Bay area transported by the general current and wave action within the Irish Sea.

Within the North Hoyle OWF site the seabed sediments generally consist of sandy gravel or gravelly sand. Further offshore are larger patches of gravel most likely formed through the winnowing action of the waves combined with the tidal currents. Within these areas the gravels tend to exist as a thin layer overlying sand or boulder clay (BGS, 1992). The data from project specific sampling campaigns identify the site as being strongly heterogeneous, with variability over very short distances, as well as being composed of very poorly sorted sediments with varying contributions of sands and gravels.

There is a net eastward transport of silt and sand in the Irish Sea and in Liverpool Bay as a result of the combined action of wave stirring and tidal currents. From analysis of bedforms (BGS, 1992) there are extensive sandwave fields in the southern part of the Irish Sea with heights of between 2m and 20m. The large sandwaves have smaller bedforms (ripples, mega-ripples and even small sandwaves) superimposed, indicating a range of hydrodynamic conditions under which sediment transport takes place. Within Liverpool Bay there are small patches of low-amplitude sandwaves with pronounced north-south trending crest lines. The sandwave profiles are typically asymmetric with the lee slope eastward facing in the direction of net transport. This is also the direction of peak tidal velocities. BGS (1992) also note that the sediment size trends tend to fine in an eastward direction.

5.6.3 Hydrodynamic Properties

Ramster and Hill (1969) studied water movements within Liverpool Bay using Woodhead drifters and revealed a predominantly northward drift of surface water towards the Solway Firth and a predominantly eastward drift at the near-bed towards the North Wales and Lancashire coasts. These flows are dependent on various factors including the strength of inflow from the Atlantic, the density distribution across the bay and variability of the wind.

The tidal properties along the shoreline of Liverpool Bay vary with location with differences in the spring tidal range of around 1.5m between the Sefton coastline and Llandudno, with differences of up to 30 minutes in the phasing of the corresponding high and low waters within the same area. The tide gauge at Hilbre Island is the closest long-term dataset to the wind farm site, with records dating back to the 1850's, although not continuously.

Within Liverpool Bay, the currents are strongly rectilinear and peak tidal flows on both the ebb and flood occur on a west to east axis. There is some asymmetry in the tidal propagation leading to stronger currents on the flood than the ebb tide. Inshore along the North Wales coast, the tide flows parallel to the coast with peak mean-spring speeds of around 0.75m/s to 1.0m/s.

Waves in Liverpool Bay are generally wind generated although longer period swell waves propagate into the Irish Sea from the Atlantic Ocean via St. Georges Channel in the south and from the channel between Northern Ireland and Scotland in the north. The predominant wind direction is from the west with around 70% of wind occurring from the southeast to northwest sectors.

Data from one of the met masts deployed as part of the wind farm construction showed measured flow speeds in excess of 0.8m/s, with a maximum peak flow rate measured on 5 November 2002 of 1.17m/s. This event occurred on a flood tide.

5.6.4 Monitoring

To assess the development of scour around the monopile foundations at North Hoyle a series of surveys have been carried out (NPower Renewables, 2006; 2007). The first survey conducted was an as-built survey carried out by the main contractor over the period August to October 2004. In addition to this bathymetric survey a diver inspection at each foundation was undertaken between April and May 2004 by the main contractor.

Following on from these surveys Osiris Projects Ltd were commissioned to undertake scour monitoring surveys on all turbine foundations at the site in Autumn 2004 and subsequently again in Spring 2005. The Autumn 2004 survey was used previously, DECC (2008b), as part of a review of scouring at constructed Round 1 wind farms where data were available. The 12 August to 12 October 2004 (Osiris, 2005) high-resolution swathe bathymetry scour survey was used to assess scouring around the foundation structures at North Hoyle. This survey represented a 16 to 18 month post-construction period and each of the surveys was carried out over 100m square boxes, centred at each mono-pile location. In addition, 68 grab samples were also taken at specific locations around each foundation.

During 2004, a decision was made to place rock protection to all J-tubes and along the section of cable running from the J-tube at seabed level to full burial depth (cable bight) to a distance of up to 12m from each turbine as a precautionary measure against mechanical damage to the J-tubes and to protect the shallow-laid cables on their approach to the J-tubes. Therefore, at the time of the Autumn 2004 survey, rock dumping would have been taking place.

Within DECC (2008b) the presence of drill cutting mounds to the south of each pile, and some minor scouring to the north of piles, was reported. The mounds were assumed to be related to armouring around the J-tubes and were observed to have variable volume and form. In fact these mounds, whilst providing armouring around the J-tubes and cabling, are now considered to be the placed rock protection. However, it was also noted within DECC (2008b) that rock dumping (armouring) operations were underway during the Autumn 2004 survey period that related to further protection around J-tubes.

From the annual FEPA monitoring reports, NPower Renewables (2006; 2007) the results for the as-built survey carried out between August and October 2003 (Report no. HBC-750-NH-R002) showed no appreciable scour holes formed around the turbine foundations. At the time of the survey all foundations had been installed for at least 30 days. As part of the design assumption it was thought that if scour was to develop it would most likely do so within 14 days of installation.

The scour monitoring surveys, undertaken as part of the FEPA Licence requirements, were originally planned on a sixth monthly basis, but only the 2004 surveys were carried out for the Spring and Autumn (12 August to 12 October, 2004) periods. These surveys were undertaken over a 100m by 100m box area by the high-resolution swathe method. A further survey was carried out in Spring 2005, between 26 April and 2 May. Localised seabed changes, as a result of the rock protection placement, were observed in this survey but scour was minimal (DECC, 2008b).

The survey showed minor scouring (< 0.5m depth) to have occurred around a few turbine foundations (4, 7, 14 and possibly 20). Secondary scour, as a result of the rock placement at the cable J-Tubes, appeared to have taken place at Turbines 11 to 19, 21 to 23, 27 and 28, although no values are given in the monitoring reports.

Based on the results from the various surveys, Defra confirmed that scour monitoring would only be required on an annual basis, so no further survey was carried out in 2005.

The Spring 2006 survey was carried out between 5 April and 16 April. Whilst this survey suggested that there is a general movement of sediment taking place across most of the turbine survey boxes it is considered that this movement is part of the natural sediment transport processes.

Results from the 2007 survey show no scour development at the turbine monopiles or J-Tube rock protection. At Turbines 3 and 5 and possibly to some degree at Turbines 12 and 28 there is some indication that settlement of the rock armour has occurred since the previous survey, although no secondary scour was observed. Sediment accretion around the rock armour at Turbines 10 and 14 was also noted.

5.7 Discussion and Conclusions

The scour data that has been made available to this project from the built wind farm sites has been analysed and brought together to show how the scour depths from the different sites compare in terms of scour depth and ambient water depth (Figure 5-46). The evidence database on scour relates to monopile foundations in different sediment and hydrodynamic environments. The new insights from this data are discussed with data presented in the standard parameters of scour depth (S) non-dimensionalised with foundation diameter (D), and the water depth (h) also non-dimensionalised by foundation diameter.

In the previous study (DECC 2008a; b) for sites without scour protection the deepest scour recorded was at the Scroby Sands site (S/D = 1.38). In this update, the new data from Robin Rigg shows foundation averaged scour depths up to S/D = 1.77, with the majority of locations being less, in a similar range of water depths. The main clusters of data for Scroby Sands and Robin Rigg are deeper than the single value for Arklow Bank. However, there is scatter in the S/D values for Robin Rigg such that the observations cover the range of existing predictive equations, i.e. 1.3D to 1.75D, and some foundations have lower periods of time between installation and survey, which limits the scour development at the time the survey was taken. The most recent data for Kentish Flats in a clay environment has values of S/D up to 0.4. There is some evidence (Table 5-7) for fluctuations in scour with time at Kentish Flats, with two foundations apparently experiencing progressive scour depth increase with time. The data for Barrow (Table 5-6, May 2008) is plotted showing low (no) scour in the clay sites, as previously quoted (DECC, 2008b), and scour at D5 has reduced at the time of this most recently included survey to around 0.8D, from a peak of 1.24D in November 2006 (Figure 5-47). The newest data from North Hoyle shows evidence of little (no) scour around the foundations. The new data from Princess Amalia in a cluster up to scour depths of S/D = 0.81, with one value deeper at S/D = 1.15.

To date Round 1 and Round 2 wind farms have been constructed in relatively shallow water. For the proposed Round 3 wind farm sites the water depths are generally deeper and, therefore, a wider range of foundation options are likely to be required. Of the monitoring data reported here, the data for the Princess Amalia OWF, in the Dutch Sector of the North Sea, represents site conditions that may be more indicative of those likely to be encountered at Round 3 sites.

At the shallow sites, the data for the Robin Rigg Wind Farm site represents an extensive monitoring data set and at this location the scour depths attained tend to represent an upper limit to the envelope of values seen to date. The observed values cover the predicted range of scour that might be expected up to around 2D. When these data are compared with those for the other built wind farms the results support a conclusion that scour calculations cannot ignore how the seabed soil structure varies with depth, i.e. limiting effects of complex soils. Therefore, geotechnical considerations are also important in the assessment of scour.

The time variation with respect to the period between installation of the foundation structure and the monitoring survey or surveys is important as there will be a general increase in scour depth to some equilibrium condition over a time-frame that will vary with site conditions. Under steady flow conditions the scour process will take some time to develop a scour hole and the development of the depth of scour with time, $S(t)$, can be defined by the following formula (Whitehouse, 1998) – where S_e is the equilibrium scour depth, Ts the characteristic time scale of scour and n an exponent generally taken to be equal to 1:

$$S(t) = S_e\left[1-\exp\left(-\frac{t}{T_s}\right)^n\right] \qquad [1]$$

The monitoring data for Barrow demonstrates this general exponential growth in scour (Figure 5-47), although as noted above some deeper values have reduced more recently. Caution should be taken though in inferring a general reduction in scour depth with time, as this may just be a function of the prevailing conditions at the time of the survey rather than a general trend. Recent studies by Harris *et al.* (2010) suggest that the scour depth can vary significantly under combined current and wave conditions through time as demonstrated in Figure 5-48.

The data from the Princess Amalia Wind Farm (Figure 5-49) suggests that at the time of the monitoring the scour development had reached an equilibrium state for the conditions that existed at site. The variation in S/D is considered primarily to reflect the difference in geotechnical conditions across the site.

Round 3 wind farm sites will be constructed in water depths of around 30m to 60m, typically. The deeper sites will require different foundation options to that of the monopile solution used in UK Round 1 and 2 wind farm sites to date.

There is currently uncertainty in the scouring potential around more complex foundation options such as gravity bases, jacket structures and multi-leg structures. Whilst tidal currents may be of lower magnitude in the deeper water sites than experienced in many of the coastal sites of the Round 1 and 2 wind farms, wave exposure may be more significant. In addition to issues related to foundation stability, the construction of foundations in deeper water will also entail their own complex issues some of which may also be related to scour issues depending on construction methods employed (for example, the use of jack-up vessels).

In addition to those issues related directly to scour in response to the presence of the foundations, there are also issues of scouring related to cabling and in particular the I-Tube/J-Tube connections.

From the analysis of the scour data available for the built wind farms to date, the main conclusions are given below:

1) As has been noted previously in DECC (2008b) the data analysed supports the view that scour is a progressive process where the seabed sediment is naturally mobile and there is an adequate thickness of that sediment for scouring to occur. Where the seabed is comprised of stiff clay, there is only a superficial layer of sediment overlying clay or the wave and current conditions are not generally strong enough to cause the seabed sediment to be naturally mobile, the scour will be slower or limited in depth.

2) In comparison with the existing predictive formulae in guidance (DNV, 2007) and the Opti-Pile method (den Boon *et al.*, 2004) DNV guidance suggests that with current-induced scour the scour depth S in relation to the foundation diameter D can be taken as S/D = 1.3 and the Opti-Pile method assumes the greatest scour depth that can be achieved is S/D = 1.75. However, many of the early studies into scouring at structures suggested higher values of equilibrium scour depth. Melville and Sutherland (1988) adopted a value of S/D = 2.4 for live-bed scour accounting for sediment gradation, whilst Breusers and Raudkivi (1991) suggested a value of S/D = 2.3 when the flow velocity was four times the sediment threshold velocity. Below this condition they adopted a graphical approach to determining the multiplier based on experimental evidence. For mean spring tide conditions at the Robin Rigg site the flow regime is in the live-bed condition and this would suggest predicted values in the order of S/D = 1.7 to 2.0. The data available to the DECC (2008b) study for other sites indicated the maximum depth of scour observed was S/D = 1.38. This is slightly larger than the value provided in DNV guidance but it was not clear whether this value (observed at Scroby Sands prior to placement of scour protection) was fully developed and what range of wave and current forcing had been experienced prior to the measurement being made. In the current study, the data from Robin Rigg Offshore Wind Farm indicates a single maximum observed scour depth in the order of S/D = 1.77 and this is consistent with many of the studies undertaken into scouring around single pile structures. It should be noted that the approach recommended in DNV guidance is only a mean value, and omits the standard deviation term of 0.7, which would give an upper value of S/D = 2.0 (Sumer and Fredsoe, 2002).

3) Scour will arise from a continuously operating combination of tidal currents, either with negligible or a moderate amount of wave stirring, on a day by day basis. Based on laboratory experience the stronger currents occurring under spring tides can be expected to produce deeper scour than under neap tides. Under more extreme conditions, e.g. storm surges, larger currents may be generated and wave action can become significantly more energetic. Under these conditions the seabed sediment will be naturally more mobile. However, it is not clear whether the scour in an unlimited thickness of sandy sediment will be deeper or shallower during a storm with strong wave action. Research undertaken by Harris *et al.* (2010) suggests that from model results waves suppress the scour development, consistent with the equations used within the model. The range of tidal, seasonal (including storm events) and longer term variations in currents, wave action and water levels can be expected to influence the way in which scour develops at a foundation, and this has an influence on foundation stability. The detailed time behaviour of scour in a varying wave and current environment remains to be measured.

4) It is considered good practice for scour evaluation that, during the design process of the foundation, an appropriate analysis is made for local scour arising from the influence of waves and currents taking account of spring and neap conditions and the influence of storm events, as well as the relative magnitude of waves and currents which will vary from location to location. In those locations where a strong reversing tidal flow exists, it would be advisable to evaluate the influence of that current pattern on scour development. The potential for scour interaction between adjacent foundations needs to be assessed. Finally, the influence of variation in bed level over the design life of the wind farm needs to be considered; this may arise from regional changes or local changes due to migration of seabed features such as banks, sandwaves or channels.

Whilst the data in this report has not dealt with data for sites at which foundation scour protection is placed, results with foundation scour protection were presented in DECC (2008b). At those sites where scour countermeasures have been employed, the scour protection that has been placed appears to be effective in preventing bed lowering adjacent to the foundations. The interaction of the placed scour protection with the surrounding seabed levels has been examined from the available data. Where material has been placed in the scour hole formed around the foundation and the top level of the protection is above the level of the surrounding seabed level it is evident that the mound of protection material has produced a secondary scour response. The data that was available in DECC (2008b) does not presently have the resolution to evaluate whether there has been any displacement of the protection material itself by wave and current action.

6. Lessons Learnt

6.1 Data Management

There are similar issues with data management as reported in SED01 (Section 3.1). However, for this study many reports were located on the developers' websites. Also, a large number of reports for most of the UK OWFs included in this study were found via the COWRIE Data Management System. Obtaining background survey or modelled data proved to be difficult, with these data being supplied directly from the developers, where possible.

6.2 Evidence Base

As in SED01 (Section 3.2) this update provides an important and valuable evidence base of sediment process monitoring data. The database developed in this study covers fifteen OWFs including three sites outside of the UK. Once again it is strongly recommended that this evidence base is maintained, developed and expanded on with further data when this becomes available from further completed OWFs (including those outside of the UK), especially from those sites which will be of particular benefit to Round 3 OWF development projects and where there are currently gaps in scientific understanding.

6.3 Suspended Sediment Concentrations

Only the Lynn and Inner Dowsing OWF offers new data for lessons learnt in this update of SED01. A key recommendation from the previous study – "*consideration for use of sediment traps to monitor fate of drill cuttings*" was implemented at Lynn and Inner Dowsing, and through the absence of chalk in the sediment samples identified the non-existence of a disposal plume predicted in a numerical plume dispersion model. This led to further diver surveys, which may prove beneficial in the monitoring of the morphological changes of a spoil disposal mound under site specific hydrodynamic conditions. It must be further mentioned, that the Lynn and Inner Dowsing OWF was a 'special' case, with the SSC monitoring requirement meeting specific provisions made within the FEPA Licence conditions due to the presence and local disposal of chalk in the drill arisings.

6.4 Morphology

Two sites offer new data for lessons learnt in this update of SED01. They are Burbo Bank and Thornton Bank. Data from both sites has been released during the running of this project which includes sufficient information to examine changes in morphology. Other projects are under construction or only recently constructed (Rhyl Flats, Robin Rigg, Lynn and Inner Dowsing, Gunfleet Sands and Greater Gabbard) and are yet to produce post-construction surveys that can be used to investigate seabed changes.

New lessons learnt pertain to monopile deployment technique and foundation type as follows:

- **New deployment technique:** At Burbo Bank the developers used a prelaid filter/armouring layer, comprising cobble-sized slate material, in an attempt to minimise scour around monopile foundations. This technique appears to have been successful, however the site does contain cohesive sediments that may be partly responsible for the low levels of scour observed. Further experience from a non-cohesive environment is needed to confirm the success of this technique.

- **Gravity Base Foundations (GBFs; sometimes referred to as Gravity Base Structures):** Monopiles were used extensively in Round 1 OWFs, however, they are only suitable in depths of less than 20-30 m. GBFs are one option for deployments at the larger depths found in Round 3 (c. 70% > 30 m), however they are still being developed (e.g., Brook-Hart *et al.*, 2009) and have traditionally been deployed in shallow (< c. 10 m), sheltered near-shore settings (Peire *et al.*, 2009). To date there is only one relatively deep water GBF OWF (depths of 12 – 27 m), which is the recently completed Thornton Bank in the Belgian North Sea.

6.5 Scour

There are three distinct but related areas in which further research will lead to benefits in understanding and predicting scour response. The first relates to the scour potential and scour development with time in complex soils (gravel-sand-silt-clay mixtures); the second relates to complex foundation structures (gravity base, jacket and multi-leg foundations), and the third relates to the optimisation of scour protection performance for monopile and complex foundation structures.

Dealing with the latter topic first, there is a lack of evidence as to the performance of installed scour protection around existing OWF sites (other than DECC, 2008b), therefore, if field measurements are available of foundations where protection has been used then:

- Carry out an ongoing analysis of the performance of the scour protection placed at operational sites and on new projects. As well as measurements of scour protection level and profile it would be useful to have sample visual information to show how the surface of the scour protection material varies with time. This could be obtained from a video camera lowered to the seafloor, or controlled by a diver or from a Remotely Operated Vehicle (ROV).

- It would be useful to distil further guidance on the role of placement methodology in the evolution of the scour protection and the interaction of the protection with the surrounding seabed. In the longer term it will be useful to have data with which to evaluate the scour protection performance under the influence of regional changes in bed level, which can be especially important on sandbanks, or due to the movement of bedforms such as sandwaves and channels.

There is also an issue of time development of scour holes in a varying wave and current environment and this can have implications for placement of scour protection.

With respect to complex foundations, any uncertainties are primarily related to design and impact on operational conditions. For foundation structures, other than monopiles, it is necessary to use a combination of approaches to estimate likely scour around the foundation. The general suitability of these approaches acts as an uncertainty in the design process. Further, the representation of more complex foundation types in the typical shallow water coastal modelling systems that are used in the environment assessments is a large uncertainty. This uncertainty can be reduced through a programme of detailed laboratory experiments combined with numerical modelling.

There is also uncertainty of scouring around foundations in complex soils (clay or sand-clay mixtures). There is currently no specific guidance as to how to assess scour potential in such situations. Therefore, there is a requirement for a review of available methods and recommendations made to the most appropriate approaches to adopt.

7. Recommendations

There is an over arching need for the further interpretation and analysis of monitoring data for individual sites, in order to allow the improvement and continued calibration of numerical models. Such improvements should help provide an accurate representation of OWF schemes, and is achievable by looking at the long-term trends in scour/morphology around foundation installations at individual sites. Additional recommendations for suspended sediment concentrations, morphology and scour can be seen below.

7.1 Suspended Sediment Concentrations

The recommendations made in SED01 still hold (as mentioned in Section 3.1), but with the addition of the following:

- More accurate calibration of instruments from water samples is required, in which samples should be taken at the same depth as the deployed instrument(s);
- Further analysis of reporting on SSC for the Thornton Bank gravity base foundations will provide a useful extension of the knowledge base for SSC for this type of structure.

7.2 Morphology

The recommendations made in SED01 still hold (as mentioned in Section 4.1), but with re-emphasise on two of them:

- Swathe bathymetry remains a key technique for monitoring seabed morphology in and around the foundations of wind turbines. It is an essential tool for quantifying scour, secondary scour, wakes, bedform movement (sediment transport) and the natural variability of the bed levels adjacent to turbine foundations. However, the survey timing, extent and consistency with regard to equipment, survey contractor and processing techniques can still be an issue.
    - Up to date baseline survey combined with construction (e.g., within 2 weeks of completion) and initial post-construction (e.g., within 3 months) survey is recommended to aid understanding of scour evolution and for operational purposes, especially around new foundation types;
    - The extent of survey around new structures, and in new settings, needs to be sufficiently large to encompass the development of any unexpected scour or wake patterns. For example, the Scroby Sands monopiles, with their relatively slender 4 m diameter and rock armour scour protection (c.f. Thornton Bank 23m diameter), cast scour and wake patterns 400m long, which is of the scale where inter-turbine scour could occur. Thus, the survey extents for new structures and/or settings should be beyond the expected scour zone – we suggest the inter-turbine distance as an appropriate scale - at least until the scale of initial scour has been shown in the post-construction 3 month survey. The baseline survey should have 100% coverage of the OWF.

- Also noted in SED01, and still very relevant, is the need to maintain consistency of the survey (vessel, hardware, survey contractor and processing techniques) in order that robust comparisons can be made between monitoring periods.

Use of adaptive monitoring regimes in addition to the current monitoring conditions (i.e. preset sampling intervals) should be considered for new structures in new settings, especially where the exposure to more severe wave conditions occurs. For example, at Thornton Bank a regular monitoring program is supplemented by responsive monitoring following storms with wave heights exceeding the 1:5 year return interval. The rationale behind this is that there is no knowledge base on seabed responses to these structures in the deeper more exposed setting. There are also operational reasons for measurement after severe storms pertaining to stability of the bed and the integrity of the structure.

7.3 Scour

The recommendations made in SED01 still hold (as mentioned in Section 5.1), but with the addition of the following:

- The need for geotechnical interpretation of the bed, in order to assess the scour potential of the surficial sediments and underlying cohesive formations;

- Scour should be defined using both bathymetric maps (where scour depressions and wake patterns can be seen) and using bed level change maps (i.e., subtracting one bathymetric surface from another). Consistency in survey execution, analysis software and method throughout the monitoring program can be critical for the latter. Bed level change maps are a useful tool as they quantify changes in depth and how this evolves through time until equilibrium is reached. In the case of Burbo Bank OWF, the scour patterns were sufficiently subtle (< 1m) that they were not easily identified in the bathymetry maps, but were revealed in the bed level change analysis (presented in Section 5.7); and

- Further analysis of scour rates at the various sites in relation to the sediment type is required for better quantification of scour potential.

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Figures

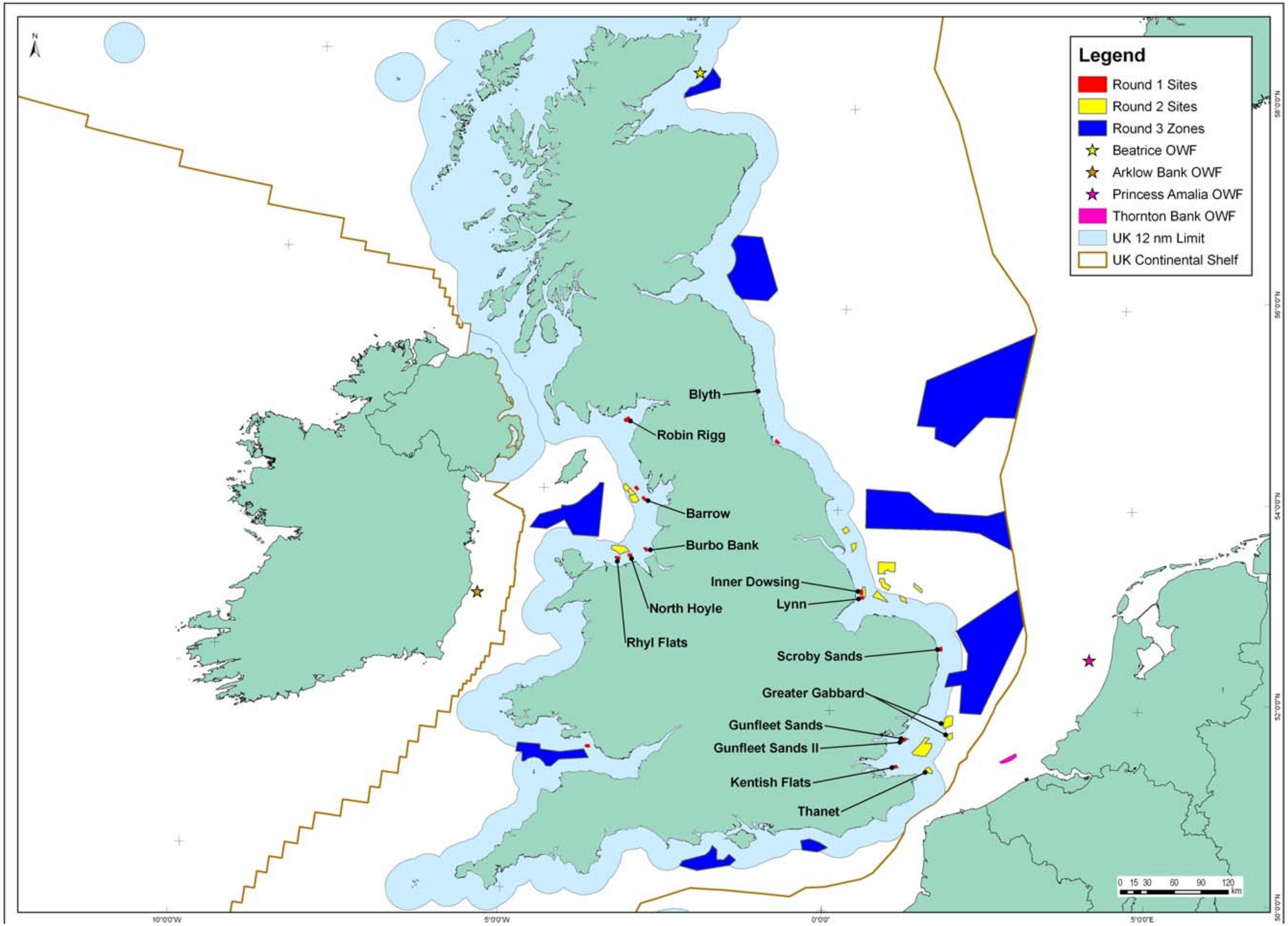
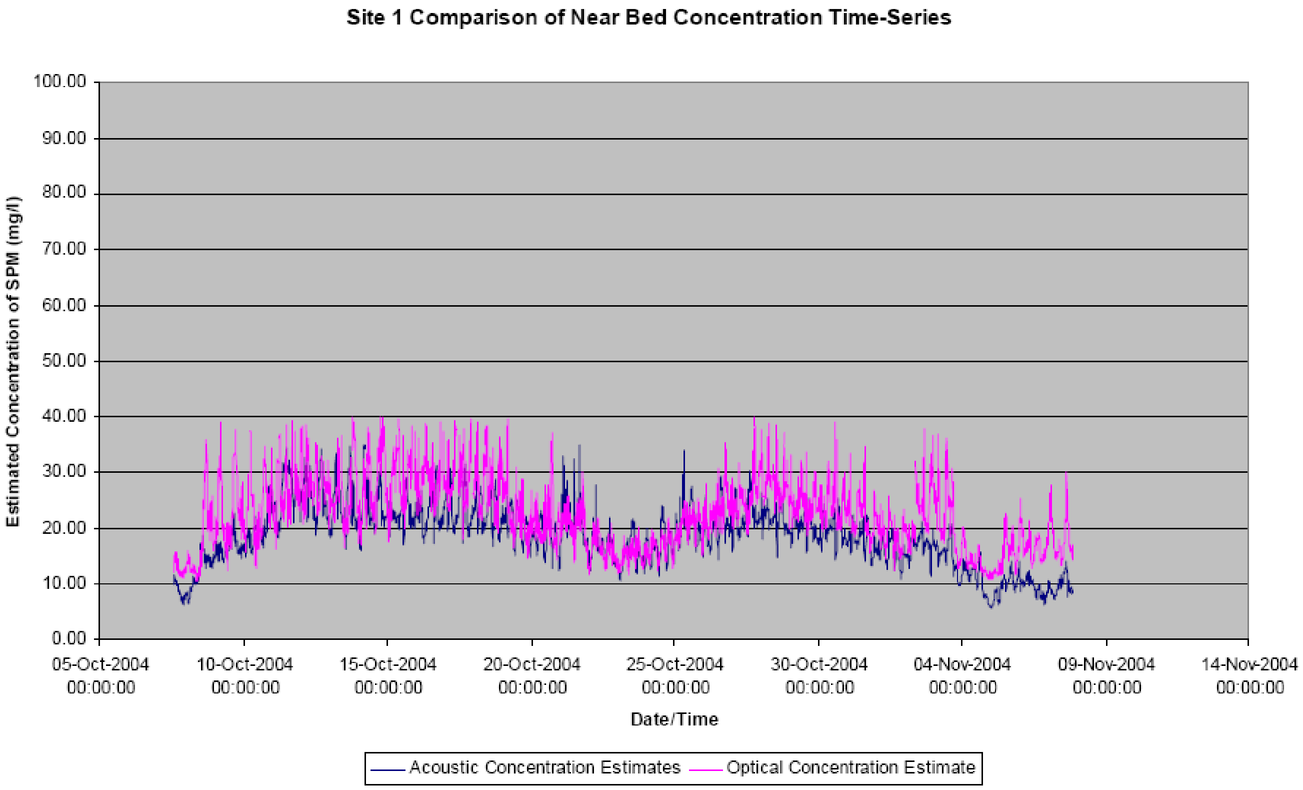


Figure 2-1 Offshore Wind Farm Location Map



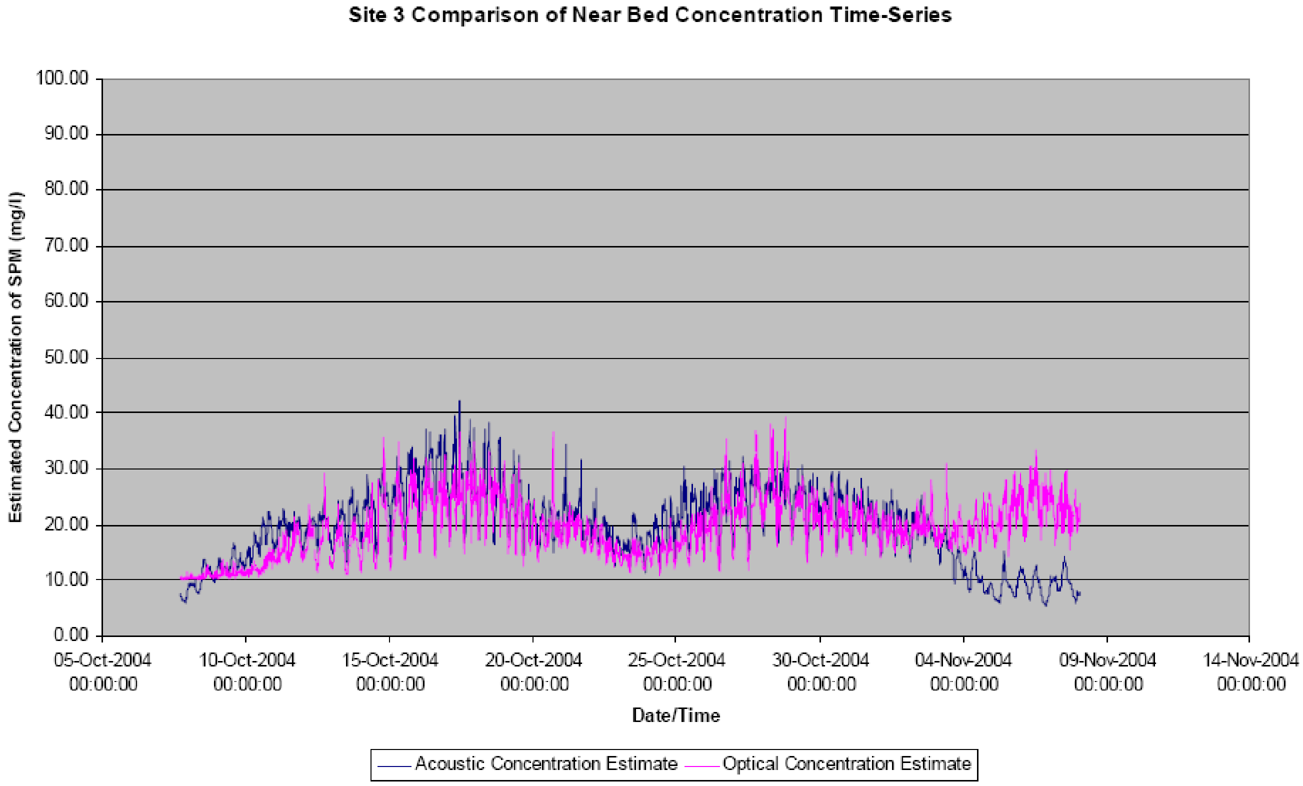


Figure 3-1 Time series of Near Bed SPM Concentration (SSC) determined by Optical Backscatter Sensor and Inversion of the Acoustic Backscatter Recorded by the Doppler Current Profiler at Sites 1 and 3 (TES Ltd, 2004)

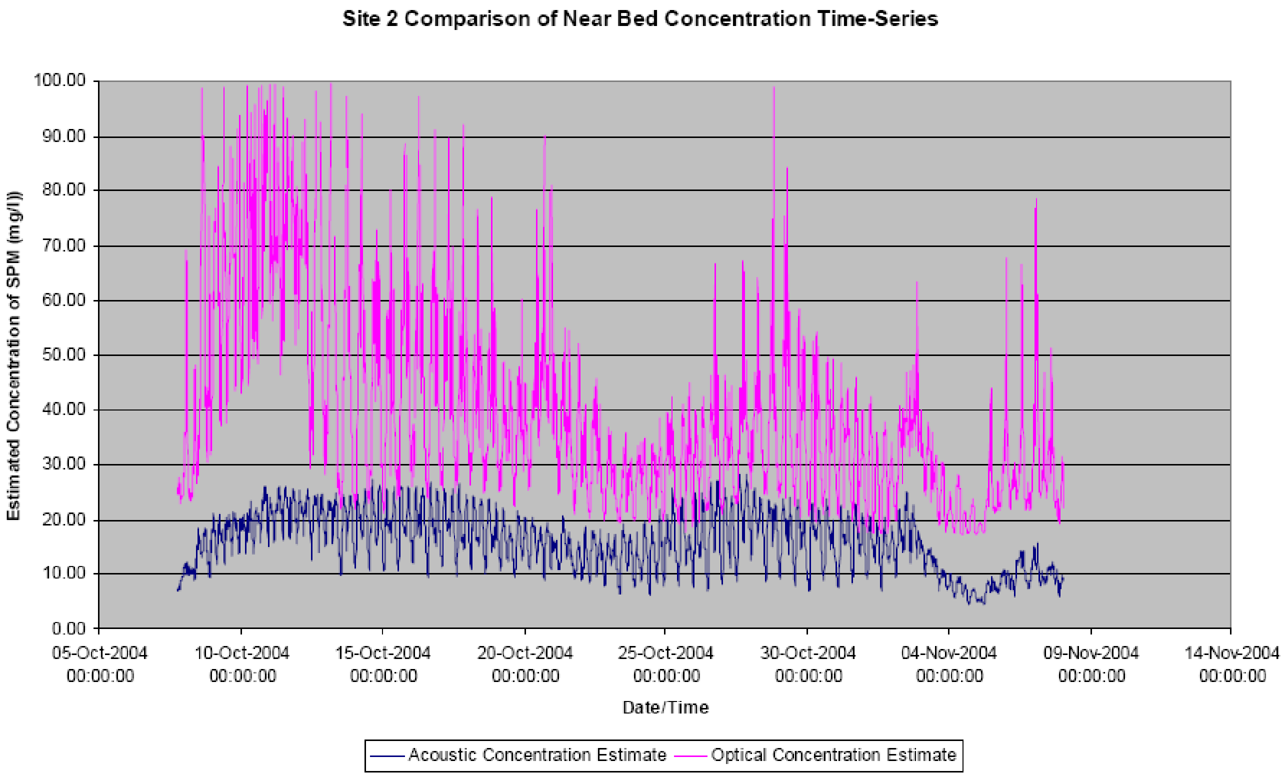
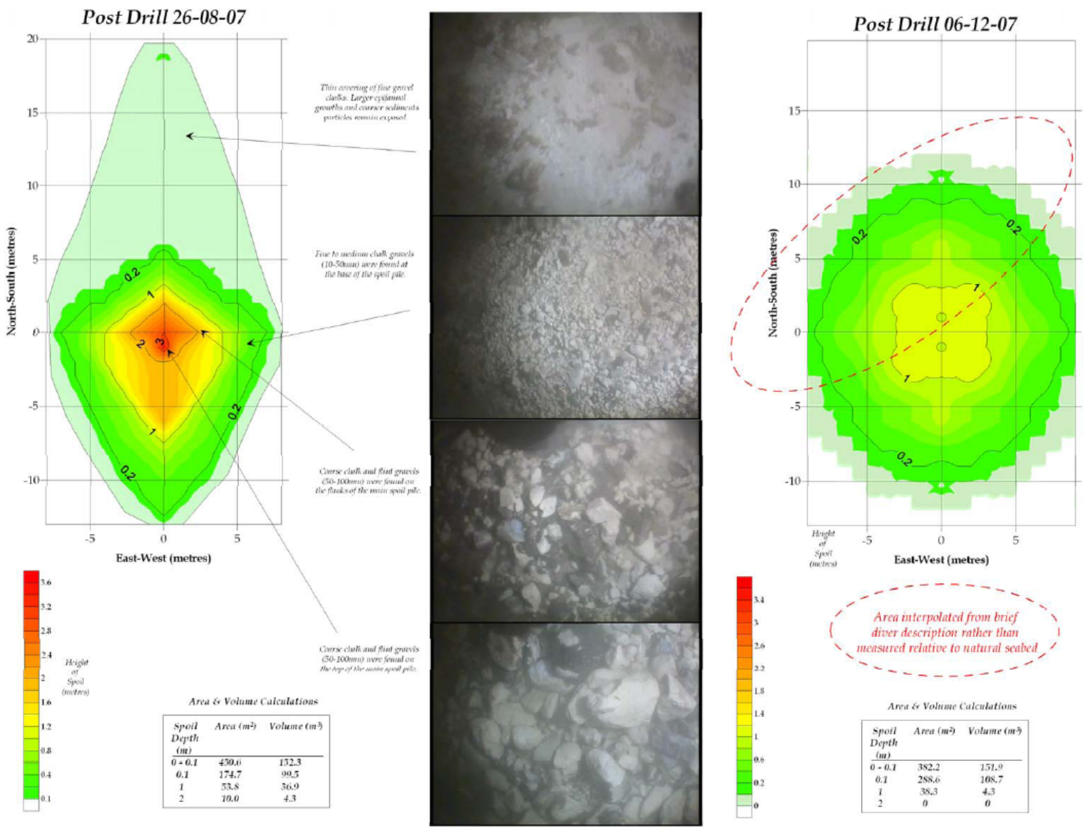


Figure 3-2 Time series of Near Bed SPM Concentration (SSC) determined by Optical Backscatter Sensor and Inversion of the Acoustic Backscatter Recorded by the Doppler Current Profiler at Site 2 (TES Ltd, 2004)



Thin covering of fine gravel chalks. Larger epifaunal growths and coarser sediments particles remain exposed.

Fine to medium chalk gravels (10-50mm) were found at the base of the spoil pile.

Corse chalk and flint gravels (50-100mm) were found on the flanks of the main spoil pile.

Corse chalk and flint gravels (50-100mm) were found on the top of the main spoil pile.

Area interpolated from brief diver description rather than measured relative to natural seabed

Area & Volume Calculations

Spoil Depth (m)	Area (m²)	Volume (m³)
0 - 0.1	450.0	152.3
0.1	174.7	99.5
1	53.8	36.9
2	10.0	4.3

Area & Volume Calculations

Spoil Depth (m)	Area (m²)	Volume (m³)
0 - 0.1	382.2	151.9
0.1	288.6	108.7
1	38.3	4.3
2	0	0

Figure 3-3 Contour maps of the disposal spoil pile, for the dive surveys on the 26th August and 6th December 2007

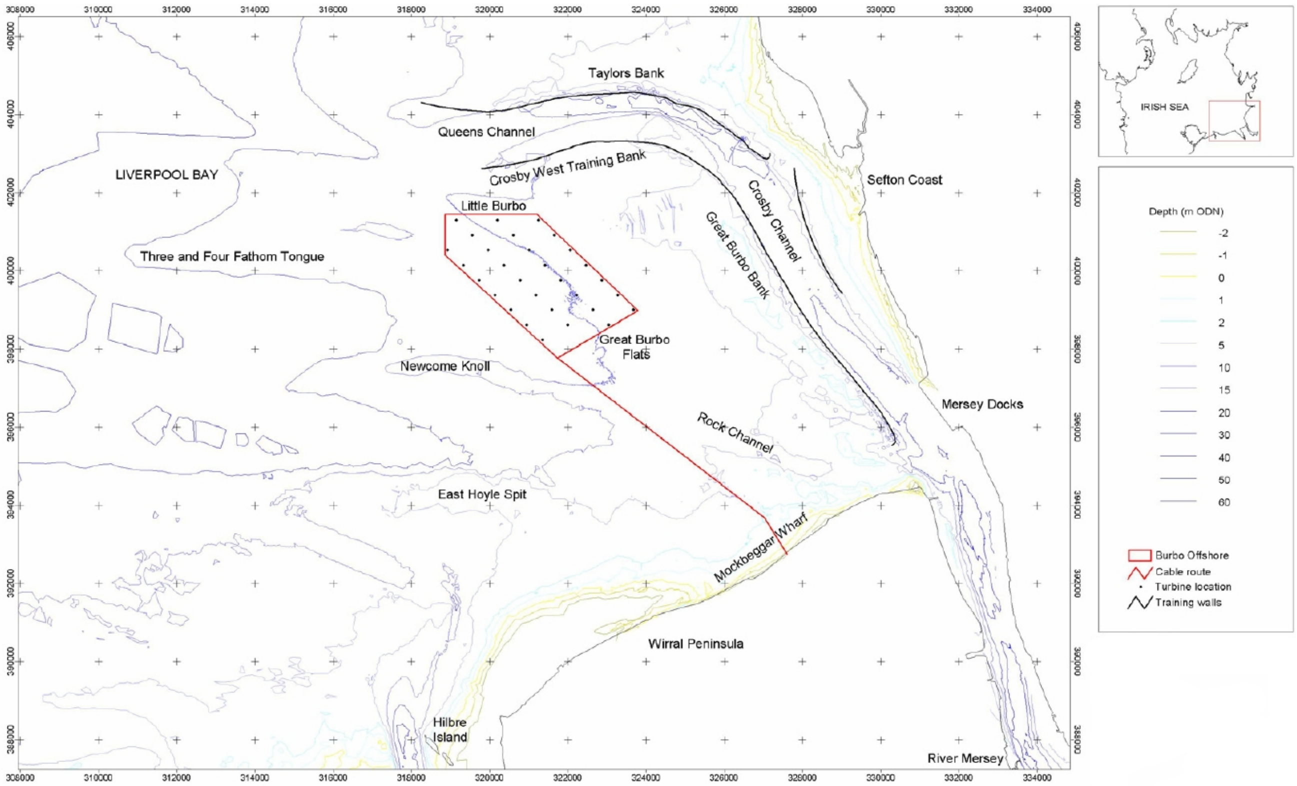


Figure 4-1 Location map of the Burbo OWF. Modified from SeaScape Ltd (2002)

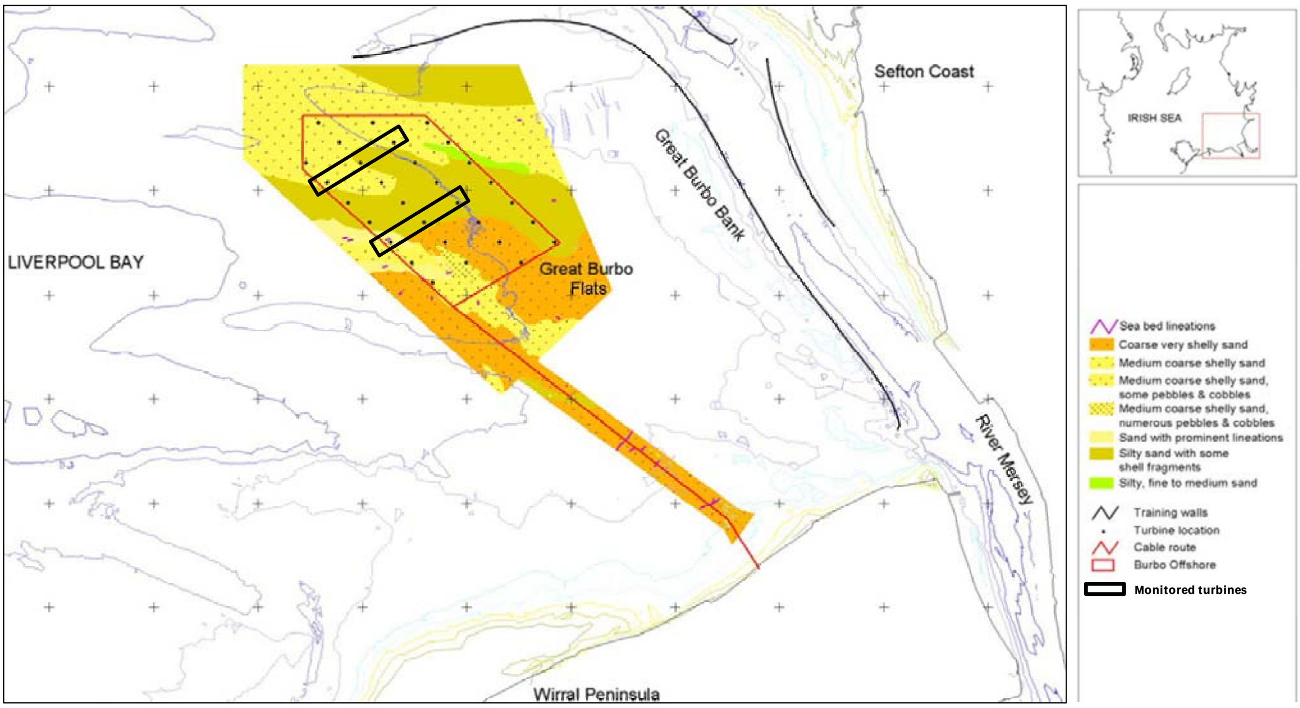


Figure 4-2 Burbo sediment map showing the turbines used in monitoring reports. Modified from SeaScape Ltd (2002) and CMACS Ltd (2009)

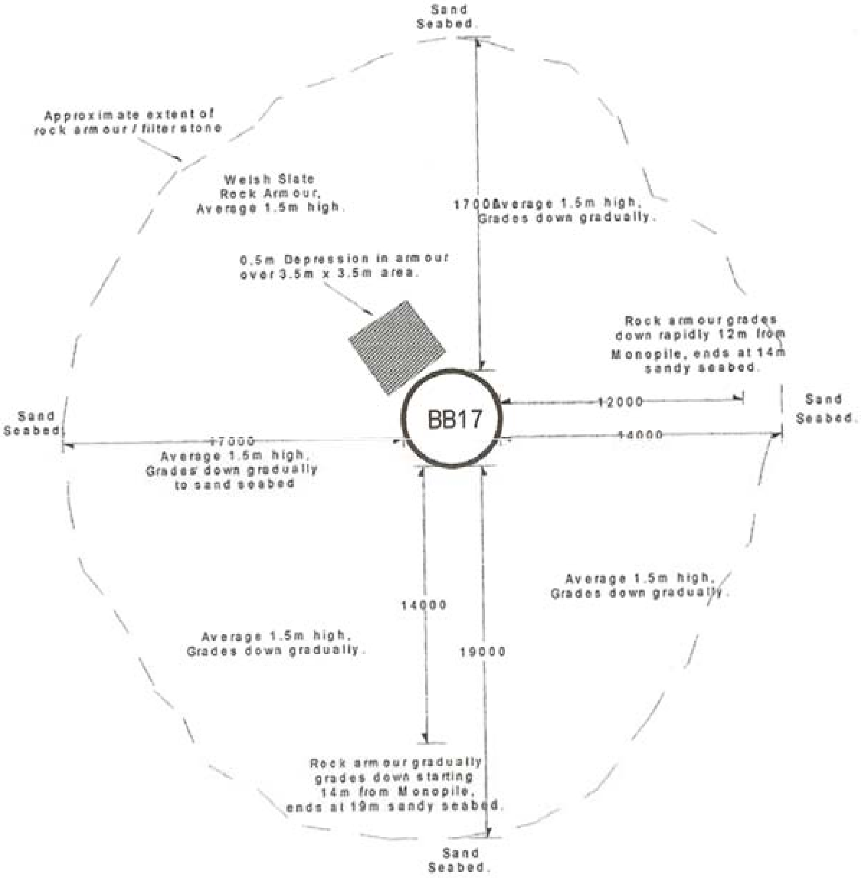


Figure 4-3 Scour protection extent at turbine BB17

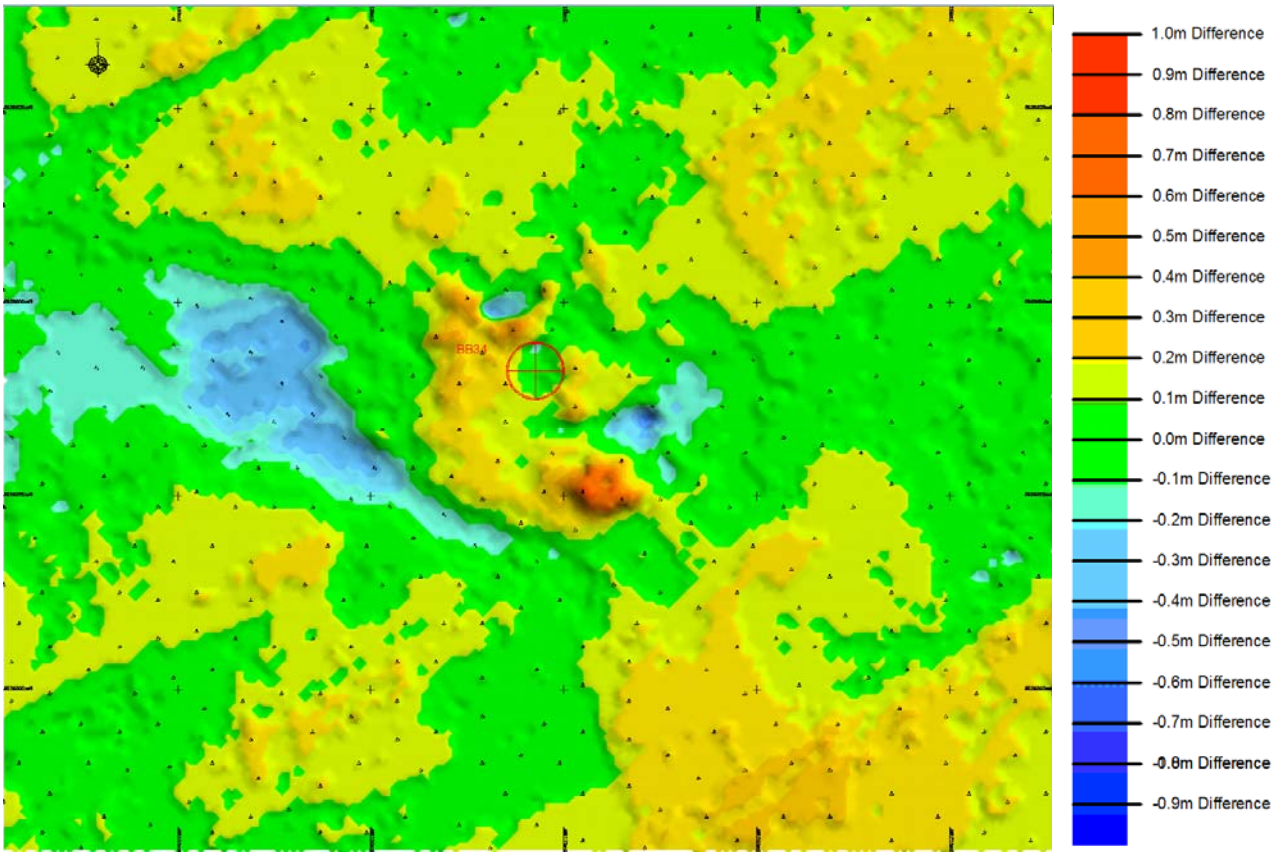


Figure 4-4 Bed level change around turbine BB34

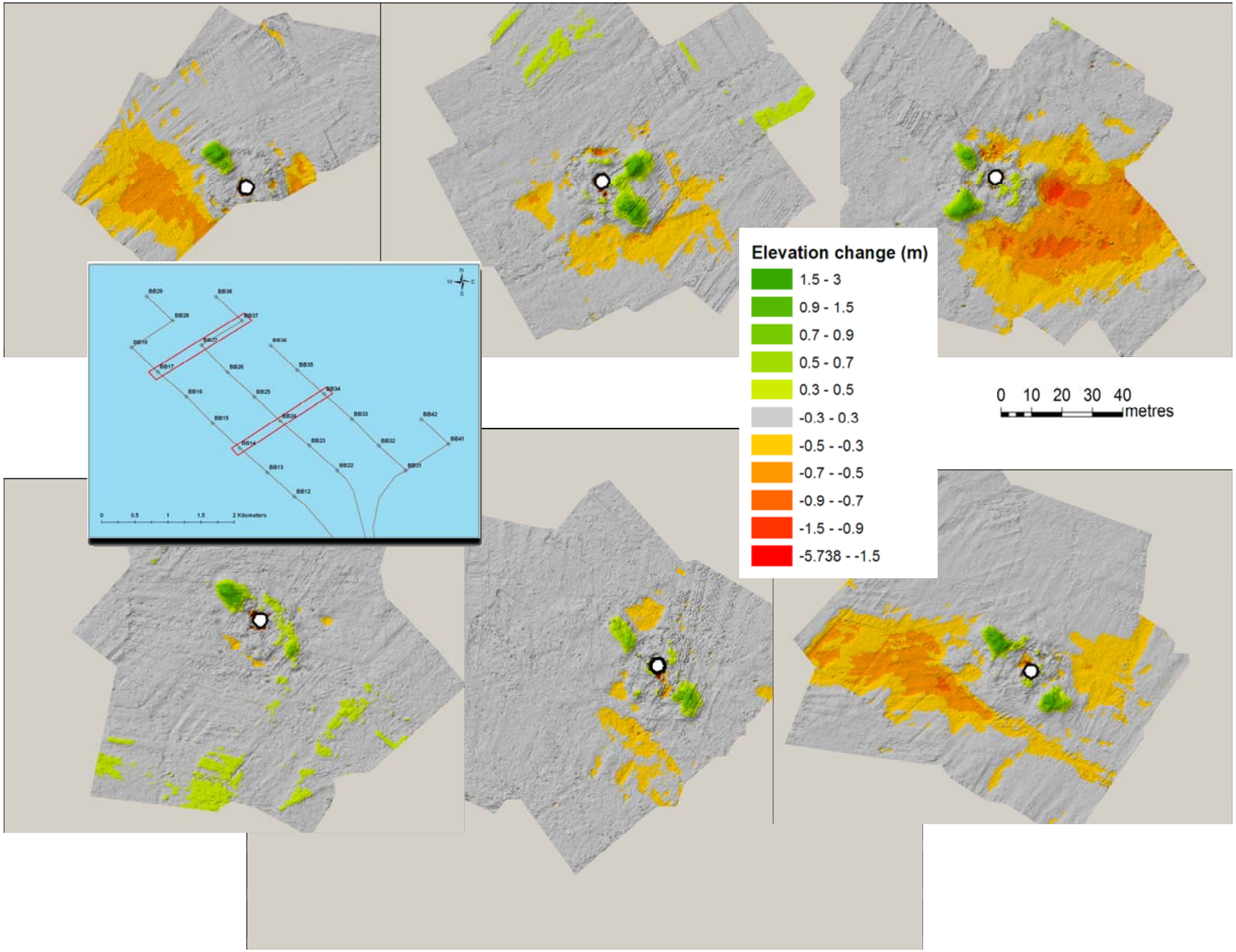


Figure 4-5 Long term (April 2009 – November 2006) bed level change at Burbo. The top panel equates to the top left three turbines in the OWF map inset (blue background). The turbine centre is marked by the white filled circle

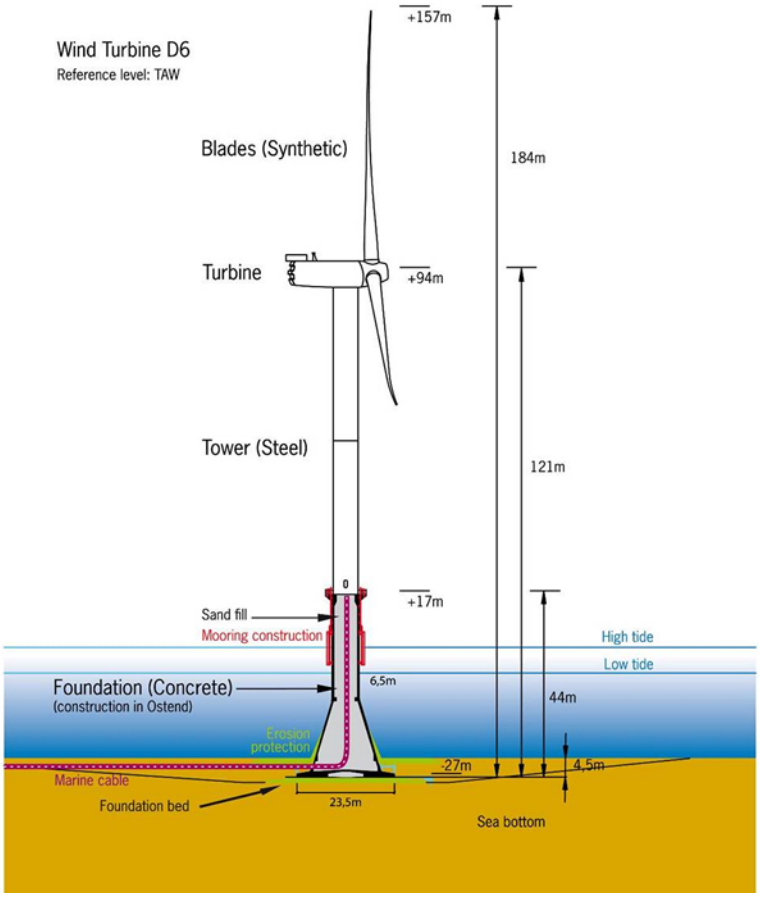


Figure 4-6 **Schematic of the Thornton Bank GBF wind turbine design**

Figure 4-7 **Gravity base foundation being prepared for lift-off from the quay (Source: Peire *et al.*, 2009)**

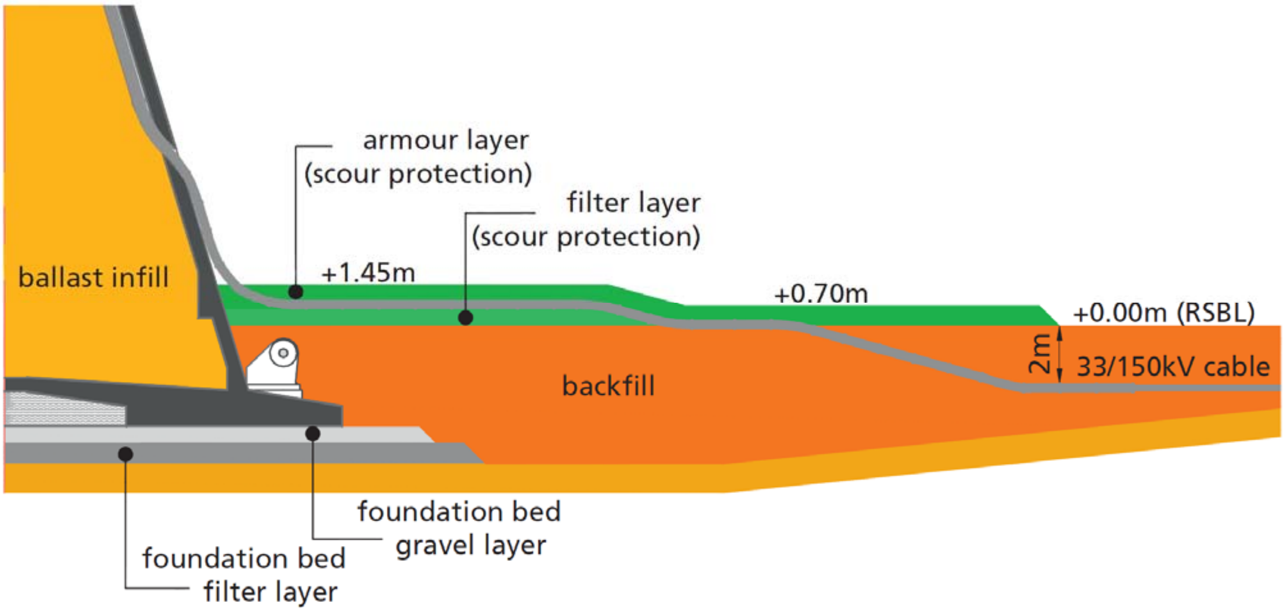


Figure 4-8 Schematic of filter and foundation layers, and scour protection around a Thornton Bank GBF. The export cable exits the GBF near the bed elevation and runs directly into the scour protection layers. (Source: Peire *et al.*, 2009)

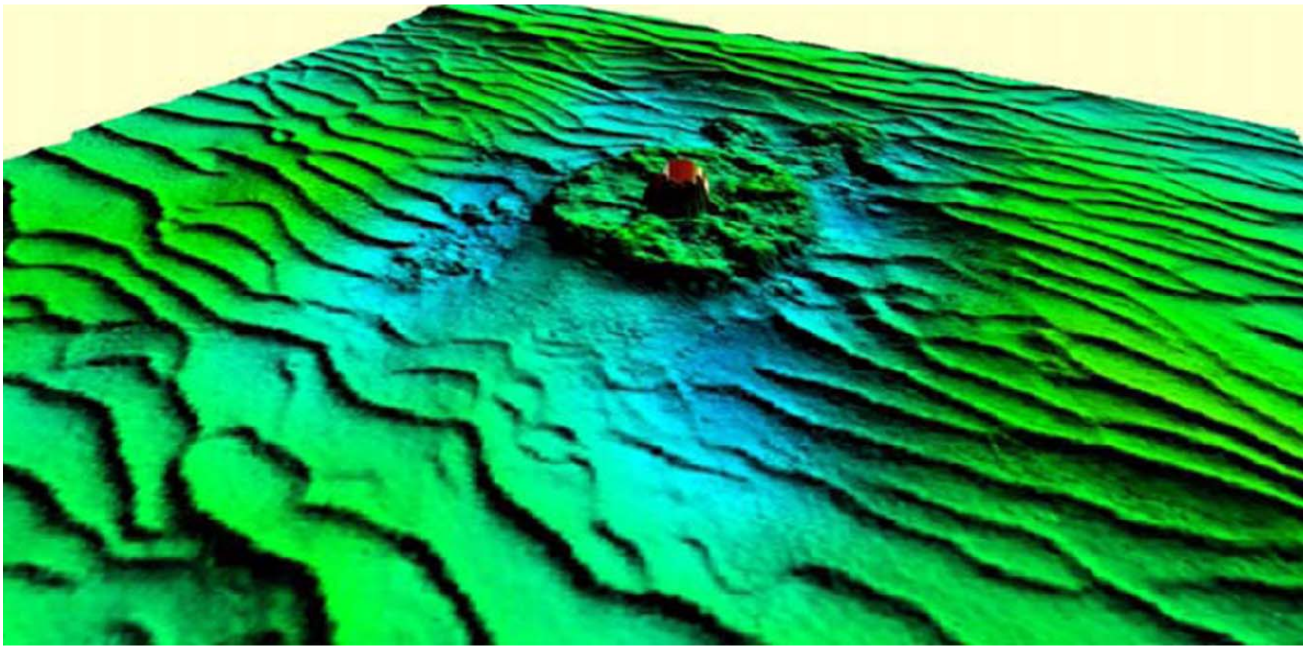


Figure 4-9 Perspective view of bathymetry at a Thornton OWF turbine (red)

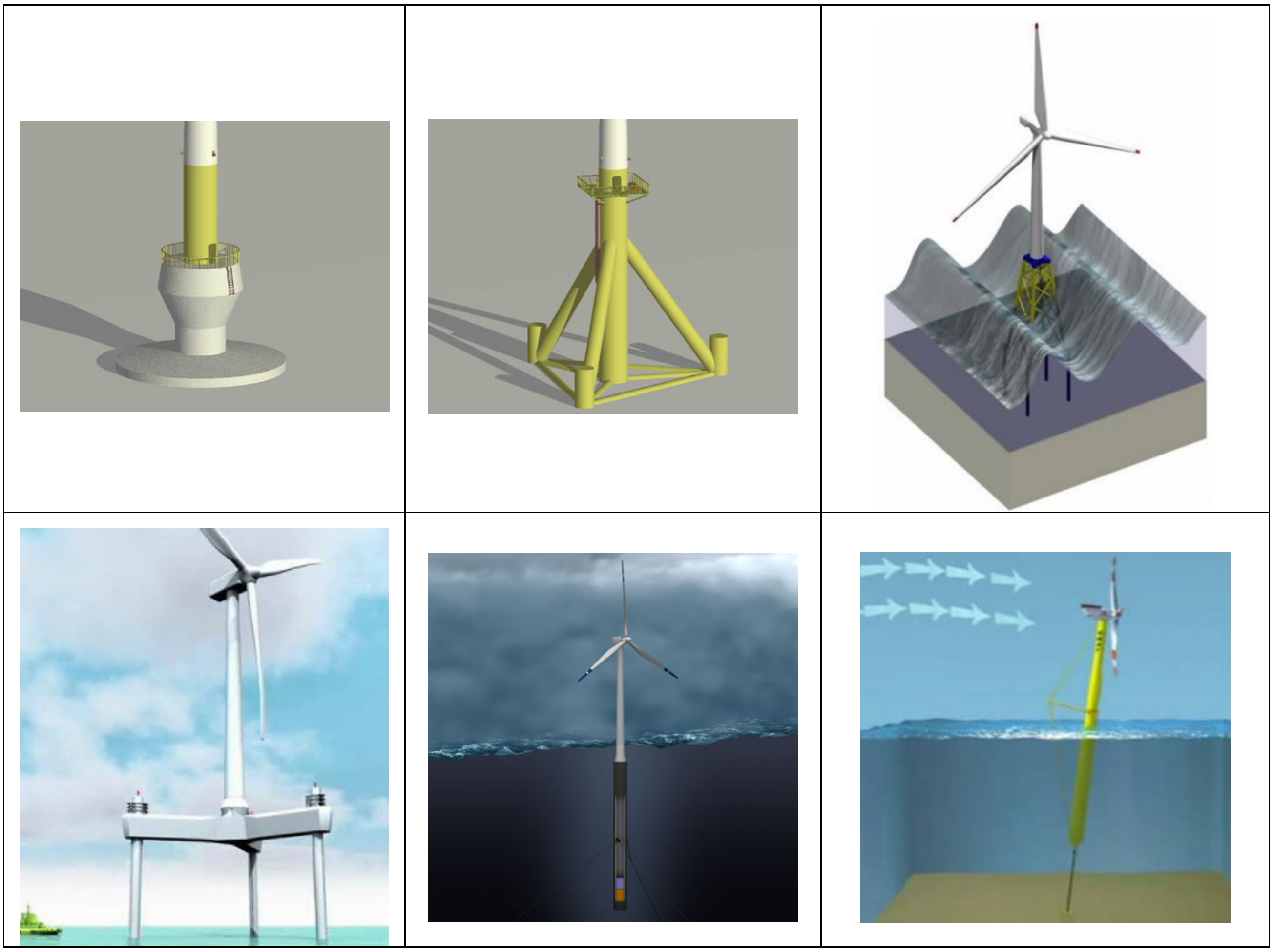


Figure 4-10 Examples of foundation designs for deep water settings: gravity base, tripod, jacket, Titan, floating and Sway (reverse mounted turbine) floating structures (horizontally, top left to bottom right)

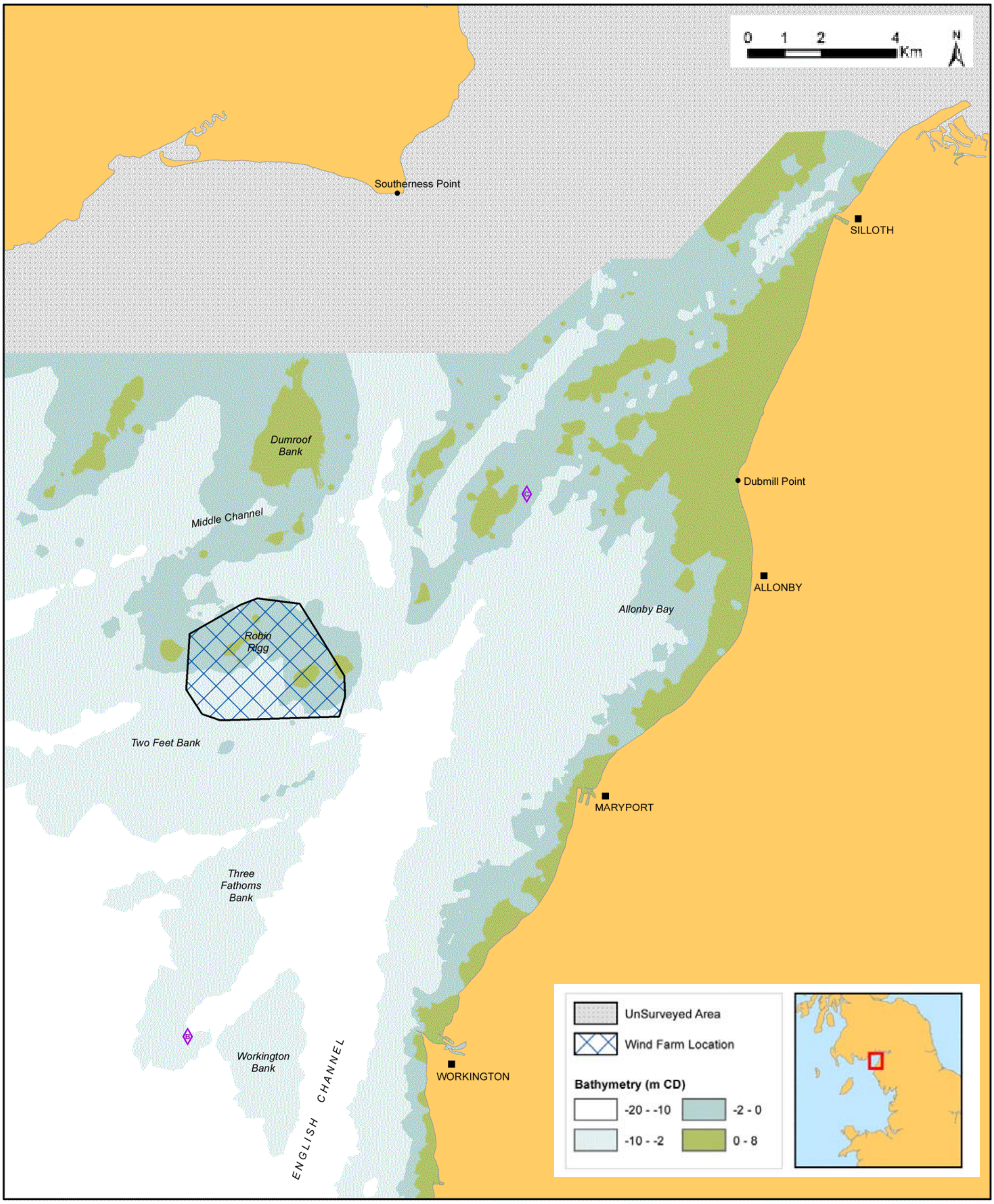


Figure 5-1 Location map for Robin Rigg Offshore Wind Farm (HR Wallingford, 2010)

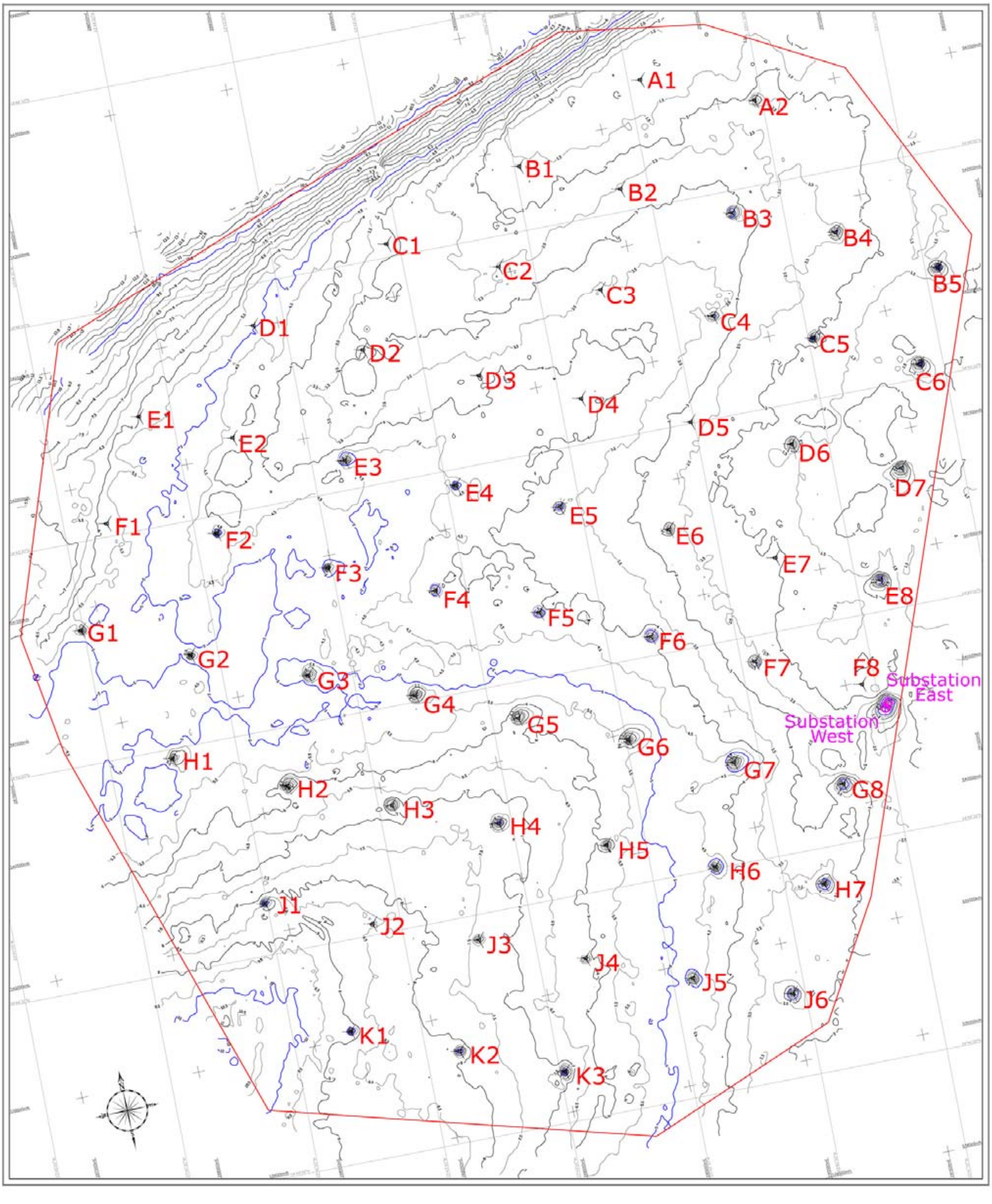


Figure 5-2 Robin Rigg Offshore Wind Farm turbine and substation positions; water deepens from 1.0m below CD in the top right (northeast) to 10.5m below CD in the bottom left (source: E.ON, 2008 data)

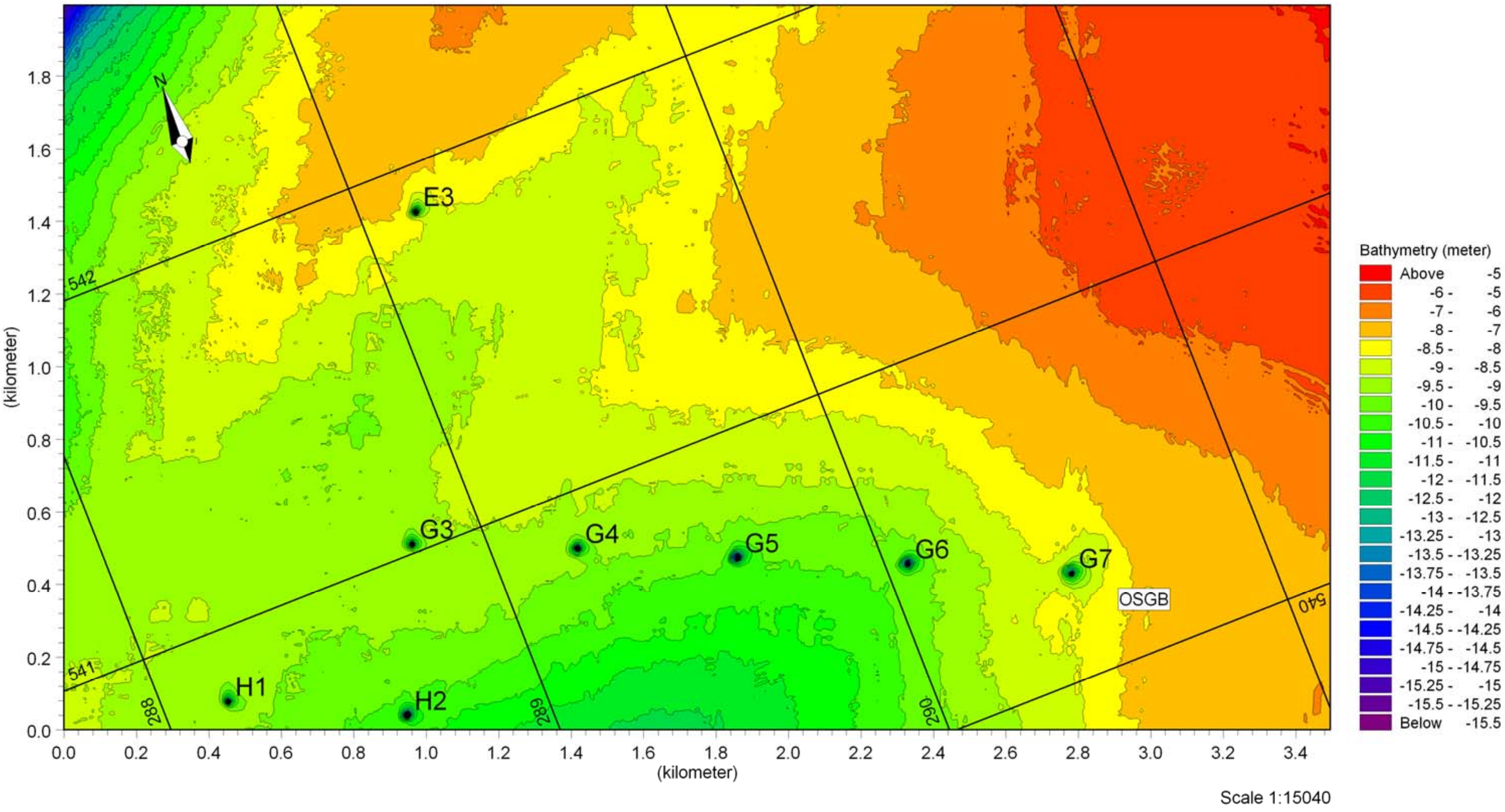


Figure 5-3 **Location of eight piled turbine foundation structures at Robin Rigg Offshore Wind Farm in 2008. Figure also shows March - April 2008 bathymetric survey data**

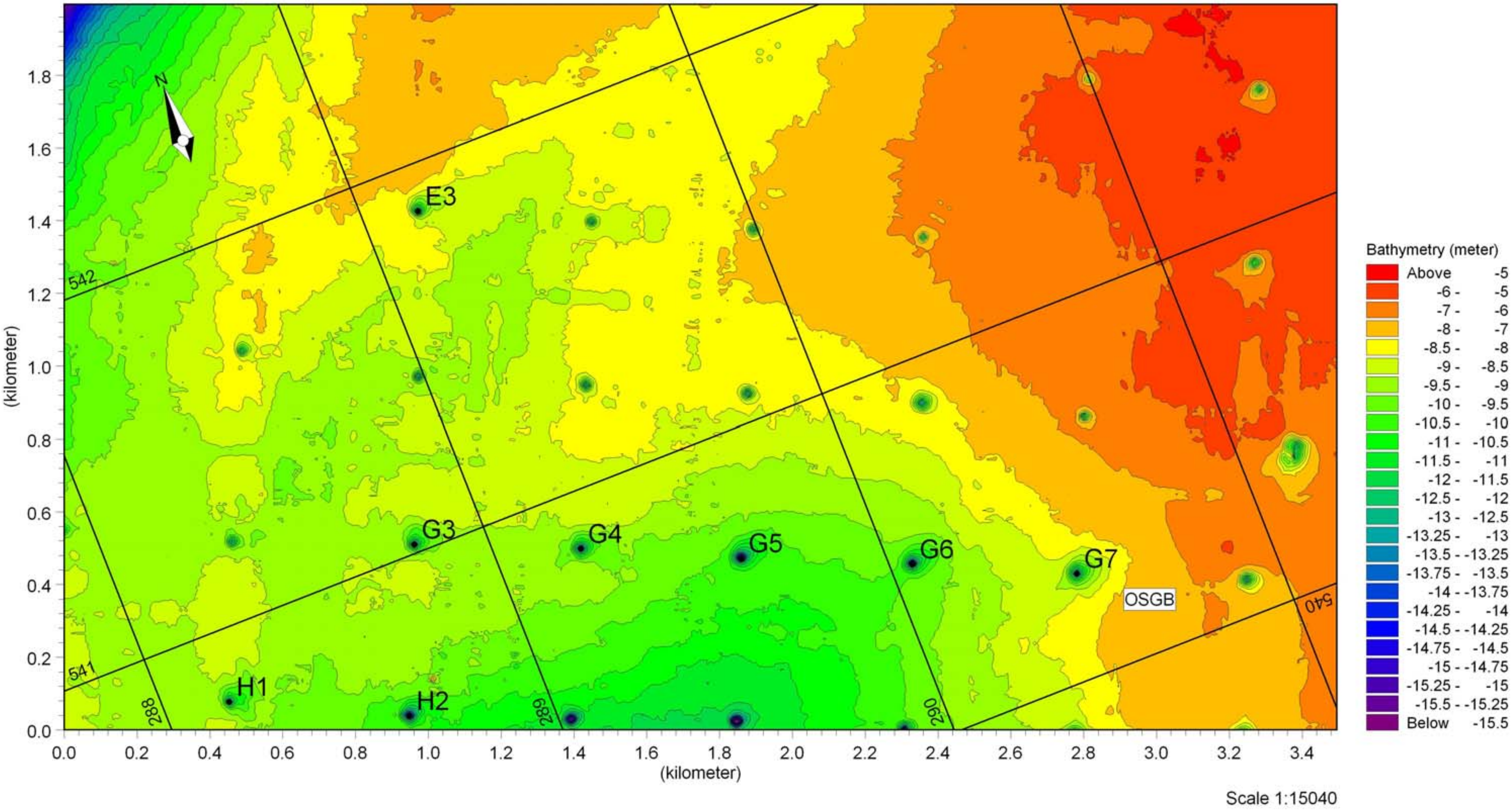


Figure 5-4 Location of the eight piled turbine foundation structures at Robin Rigg Offshore Wind Farm (Figure 4) with further adjacent foundation installations based on December 2008 - January 2009 bathymetric survey data

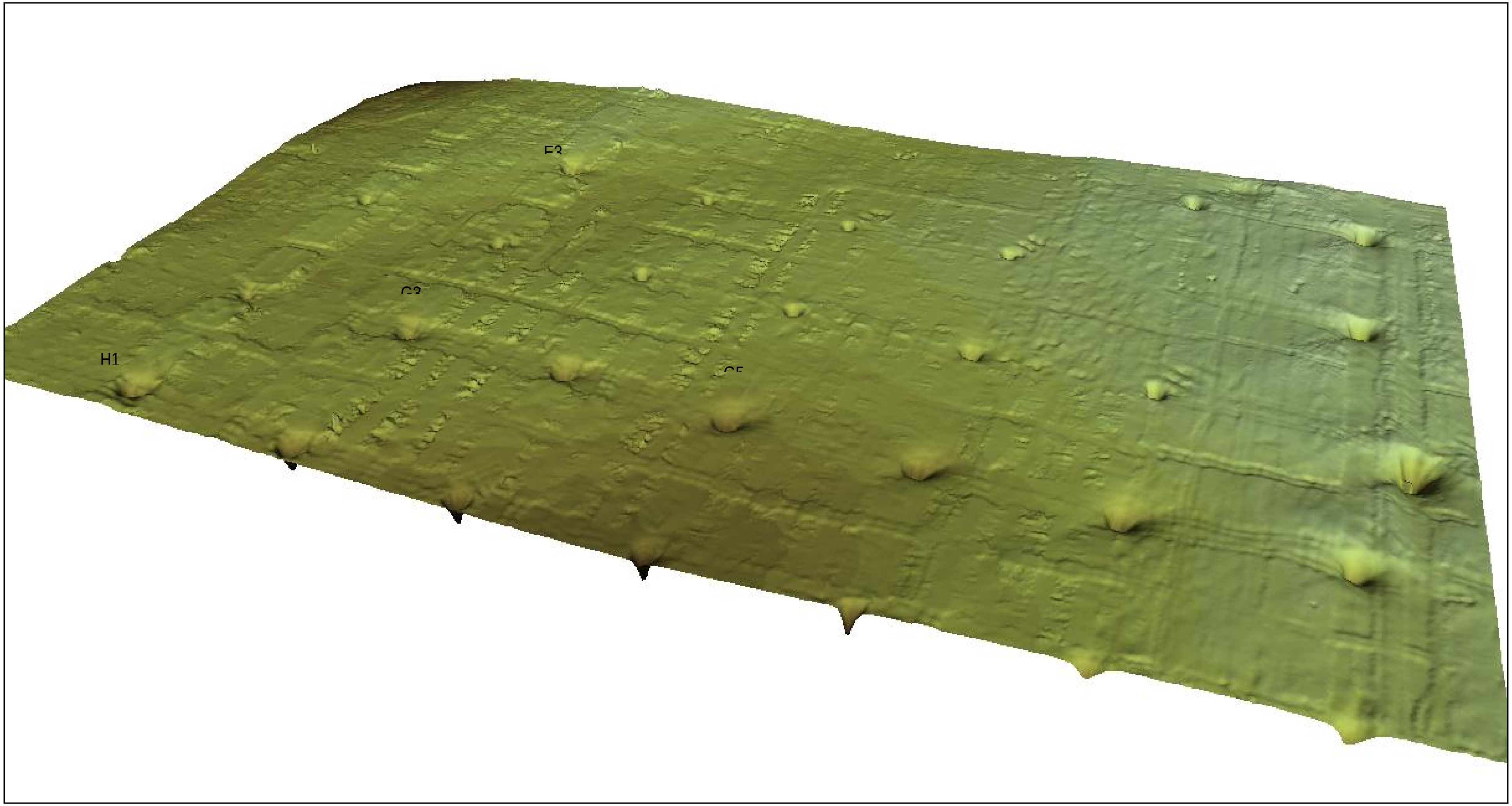


Figure 5-5 Image showing scouring around the eight installed turbine foundation structures and additional adjacent foundation installations at Robin Rigg Offshore Wind Farm based on December 2008 - January 2009 bathymetric survey data

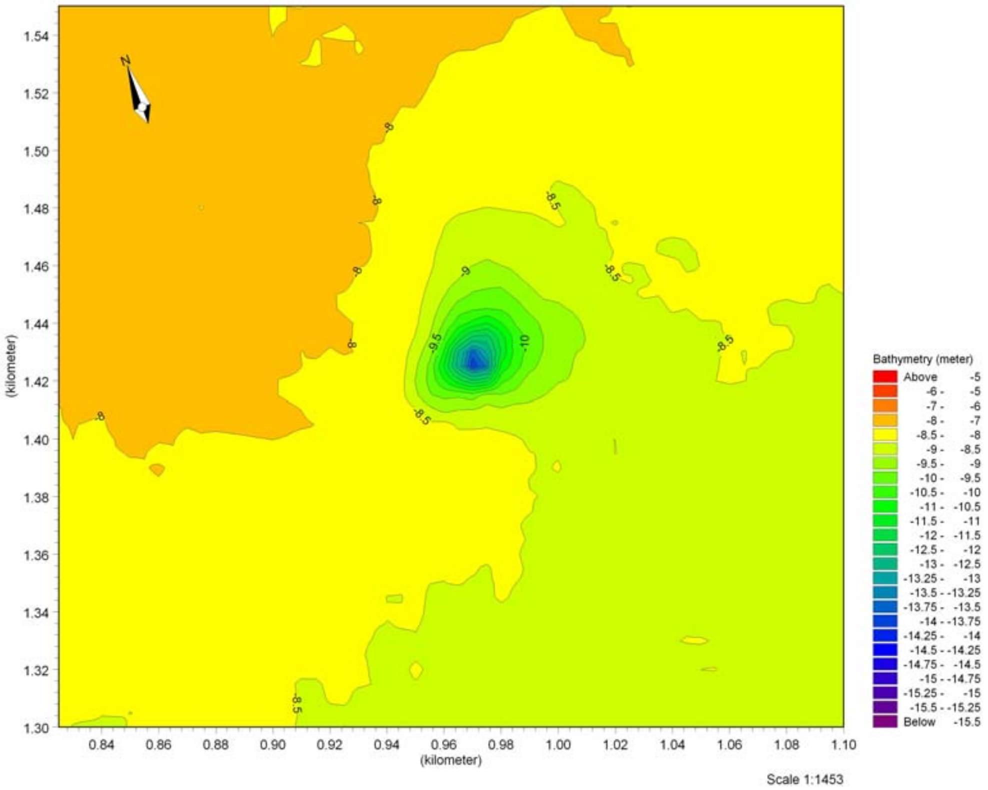


Figure 5-6 Scour hole formation around turbine foundation E3 (Robin Rigg), 2008 survey (26 March – 27 April 2008)

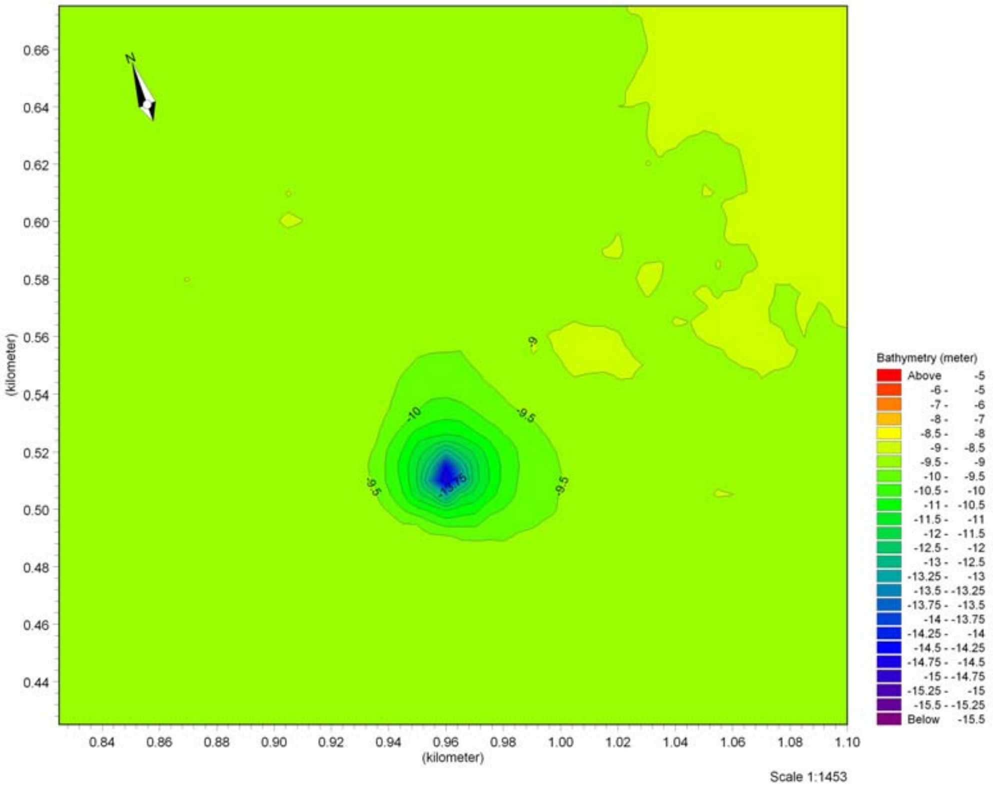


Figure 5-7 Scour hole formation around turbine foundation G3 (Robin Rigg), 2008 survey (26 March – 27 April 2008)

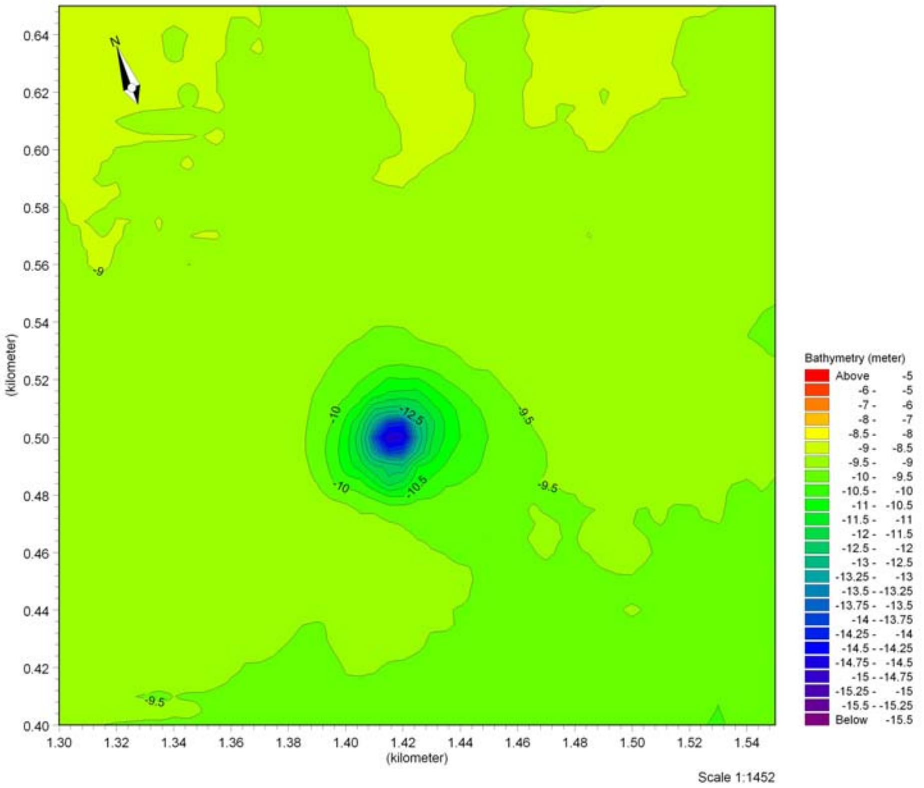


Figure 5-8 Scour hole formation around turbine foundation G4 (Robin Rigg), 2008 survey (26 March – 27 April 2008)

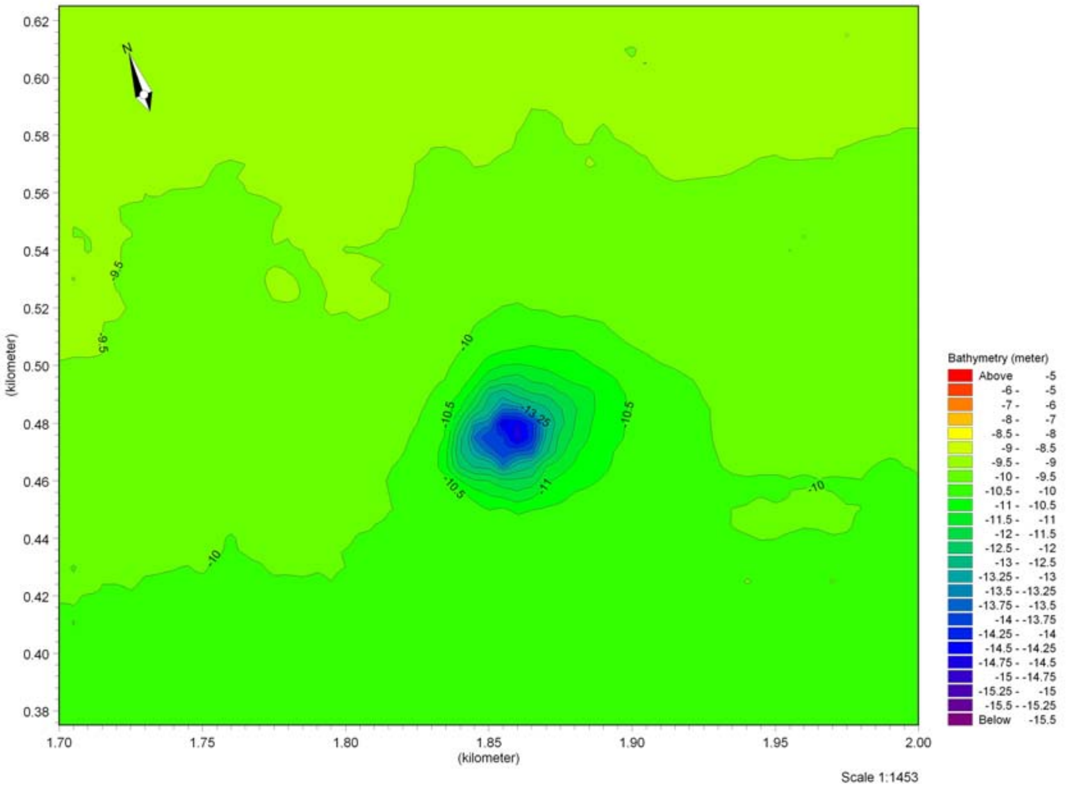


Figure 5-9 Scour hole formation around turbine foundation G5 (Robin Rigg), 2008 survey (26 March – 27 April 2008)

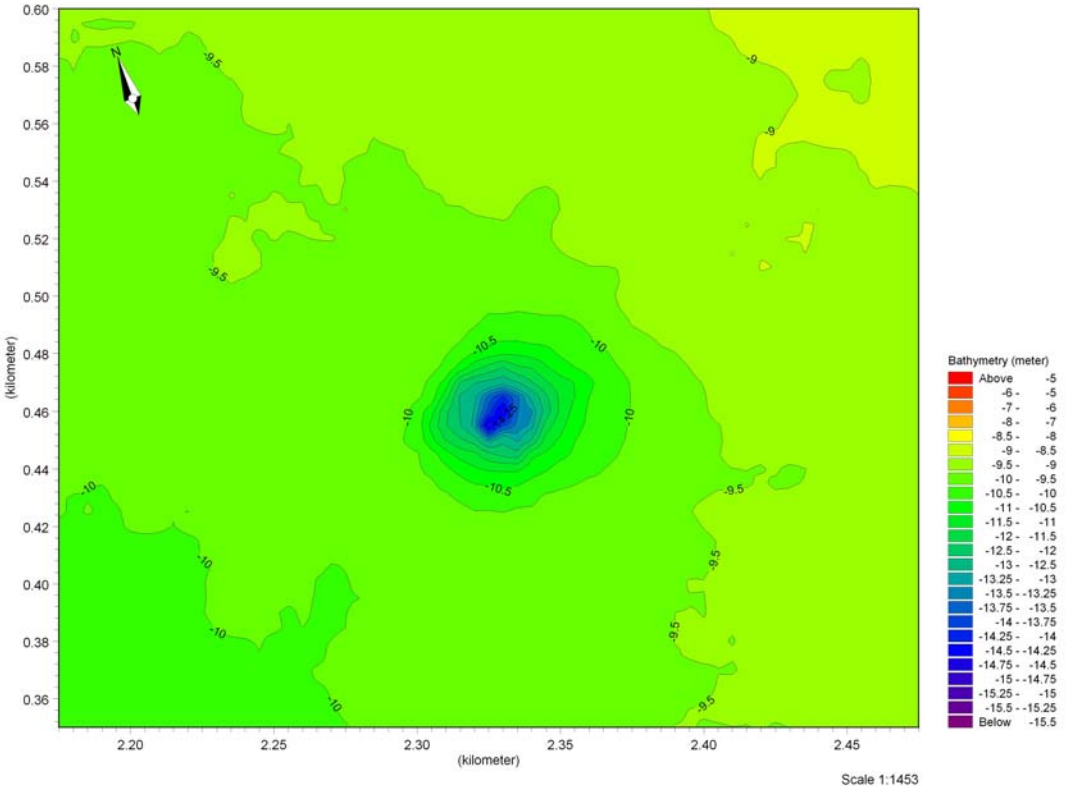


Figure 5-10 Scour hole formation around turbine foundation G6 (Robin Rigg), 2008 survey (26 March – 27 April 2008)

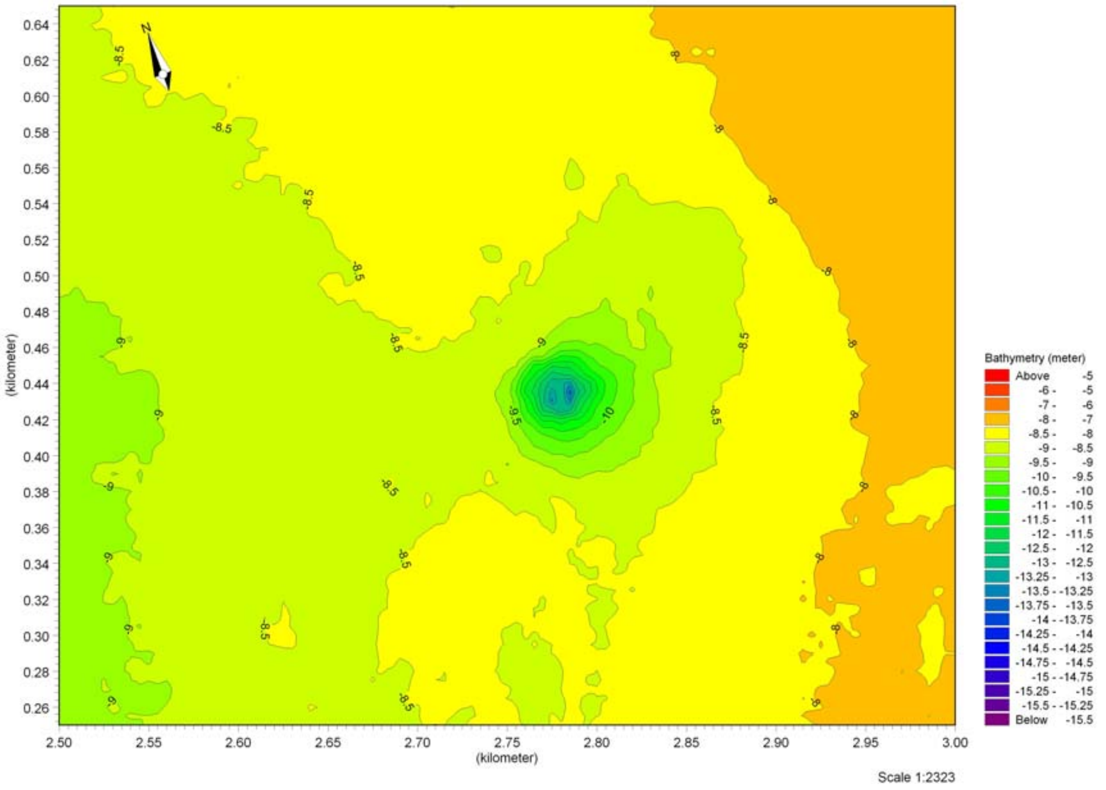


Figure 5-11 Scour hole formation around turbine foundation G7 (Robin Rigg), 2008 survey (26 March – 27 April 2008)

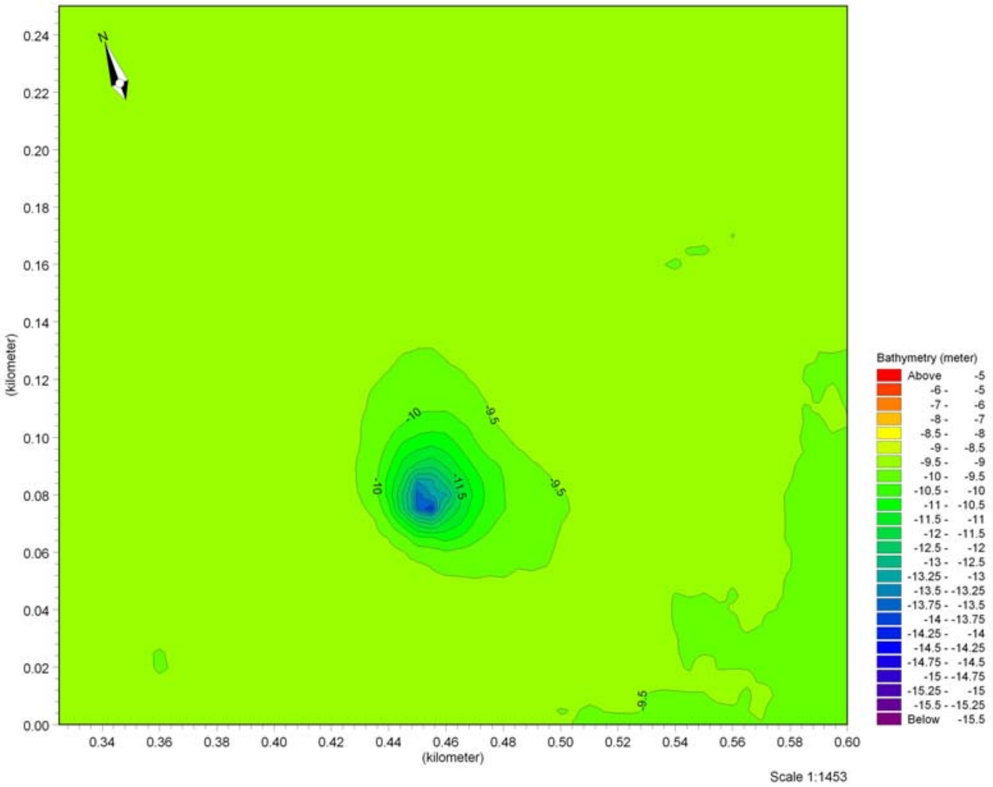


Figure 5-12 Scour hole formation around turbine foundation H1 (Robin Rigg), 2008 survey (26 March – 27 April 2008)

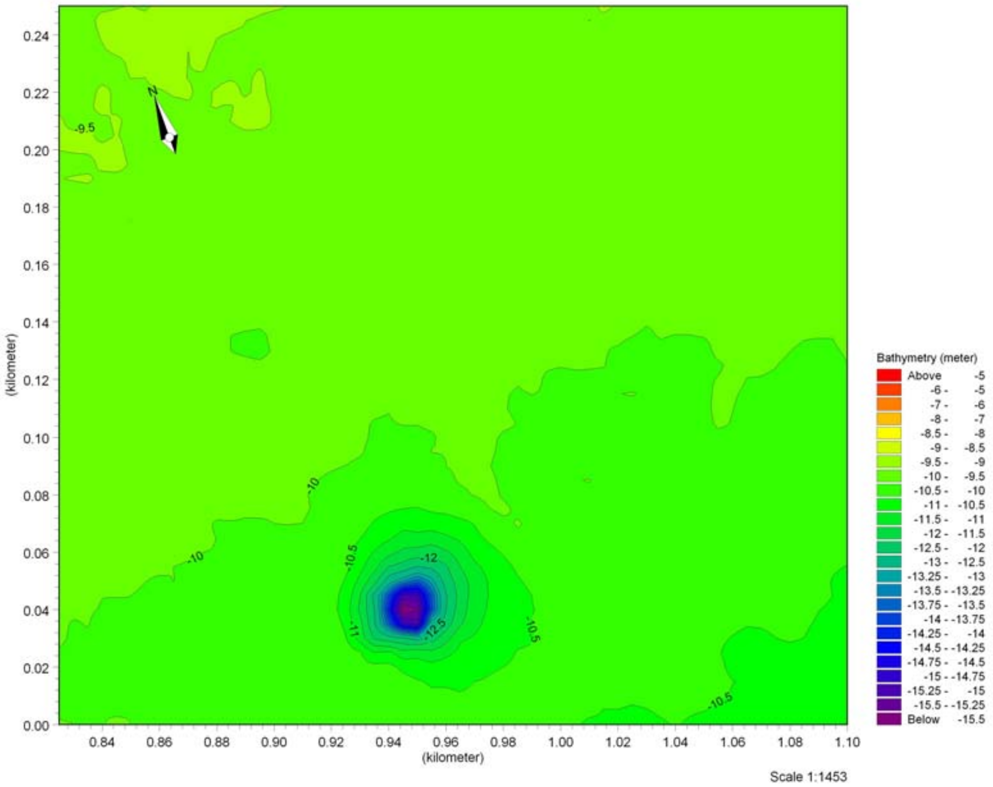


Figure 5-13 Scour hole formation around turbine foundation H2 (Robin Rigg), 2008 survey (26 March – 27 April 2008)

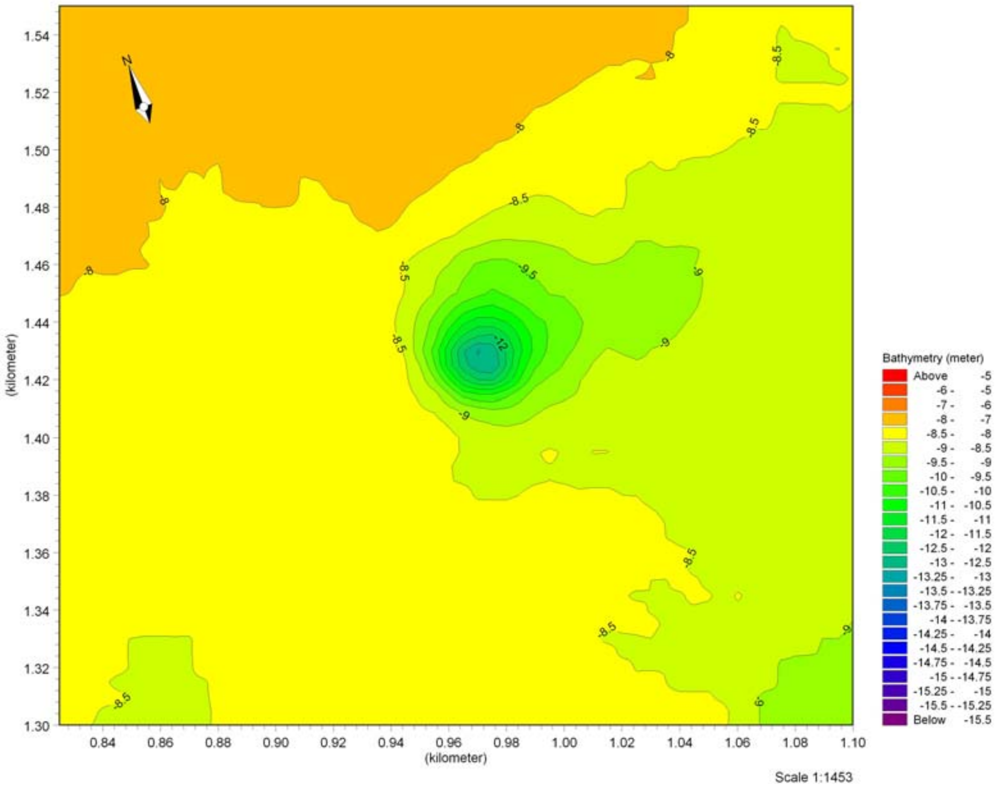


Figure 5-14 Scour hole formation around turbine foundation E3 (Robin Rigg), 2008-2009 survey (December 2008 – January 2009)

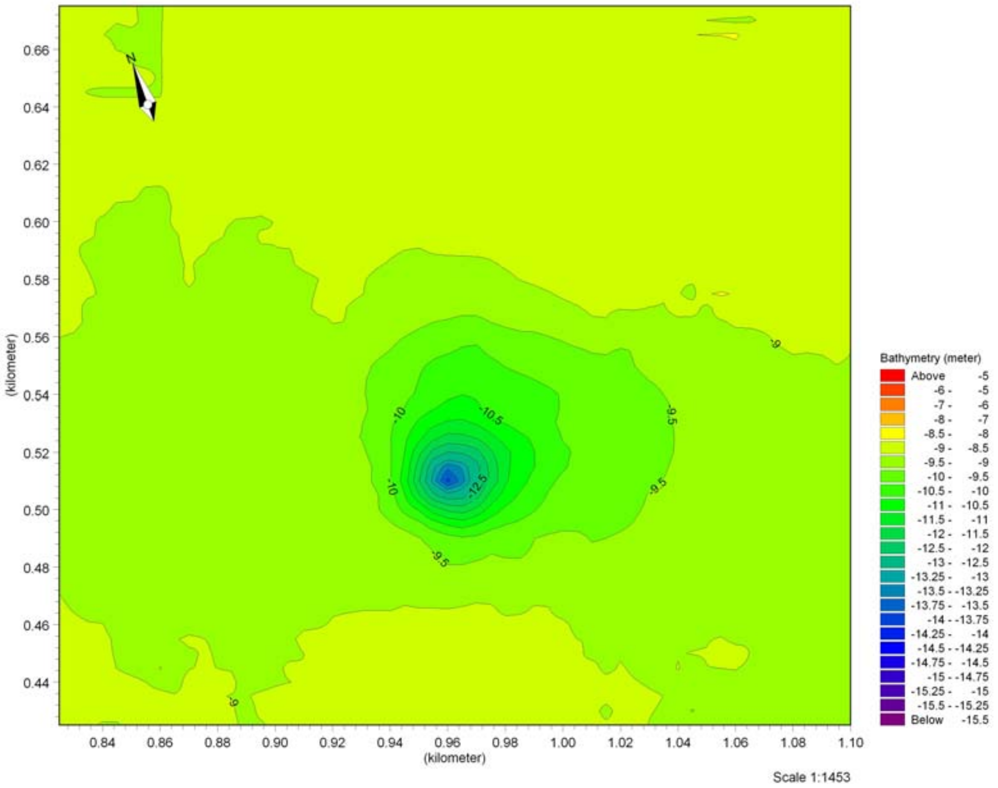


Figure 5-15 Scour hole formation around turbine foundation G3 (Robin Rigg), 2008-2009 survey (December 2008 – January 2009)

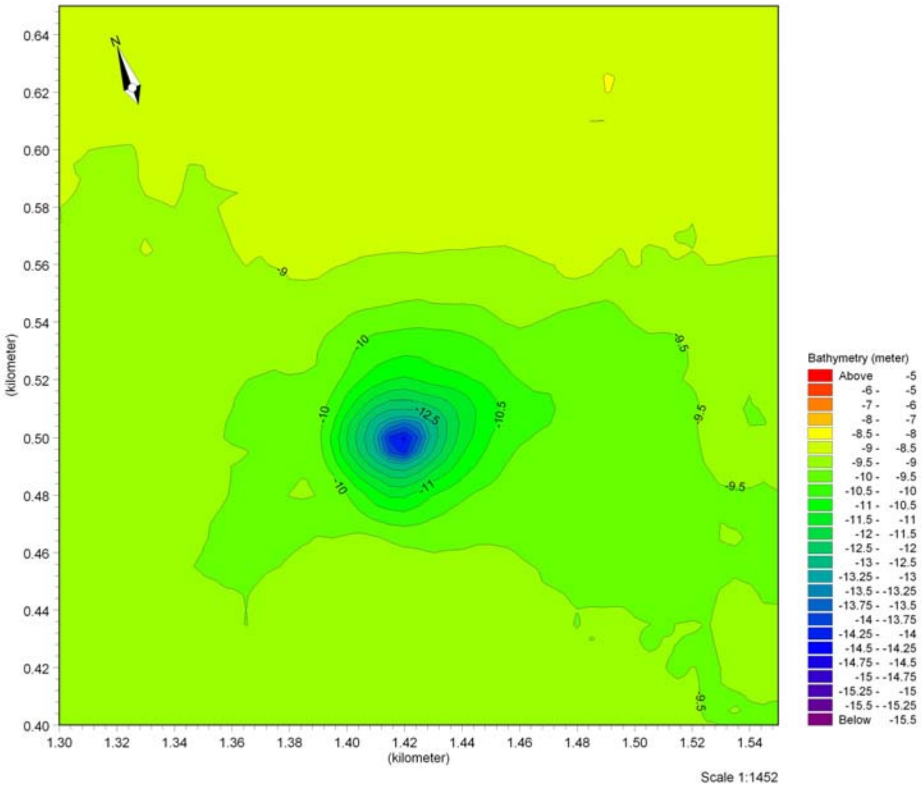


Figure 5-16 Scour hole formation around turbine foundation G4 (Robin Rigg), 2008-2009 survey (December 2008 – January 2009)

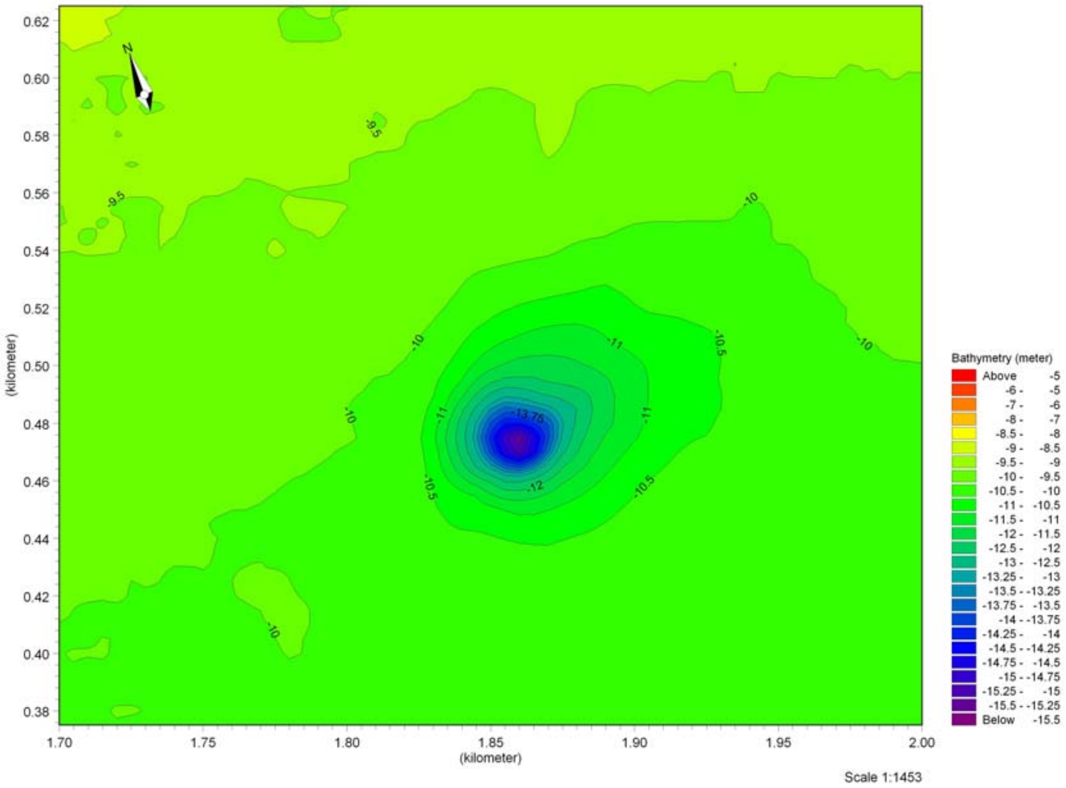


Figure 5-17 Scour hole formation around turbine foundation G5 (Robin Rigg), 2008-2009 survey (December 2008 – January 2009)

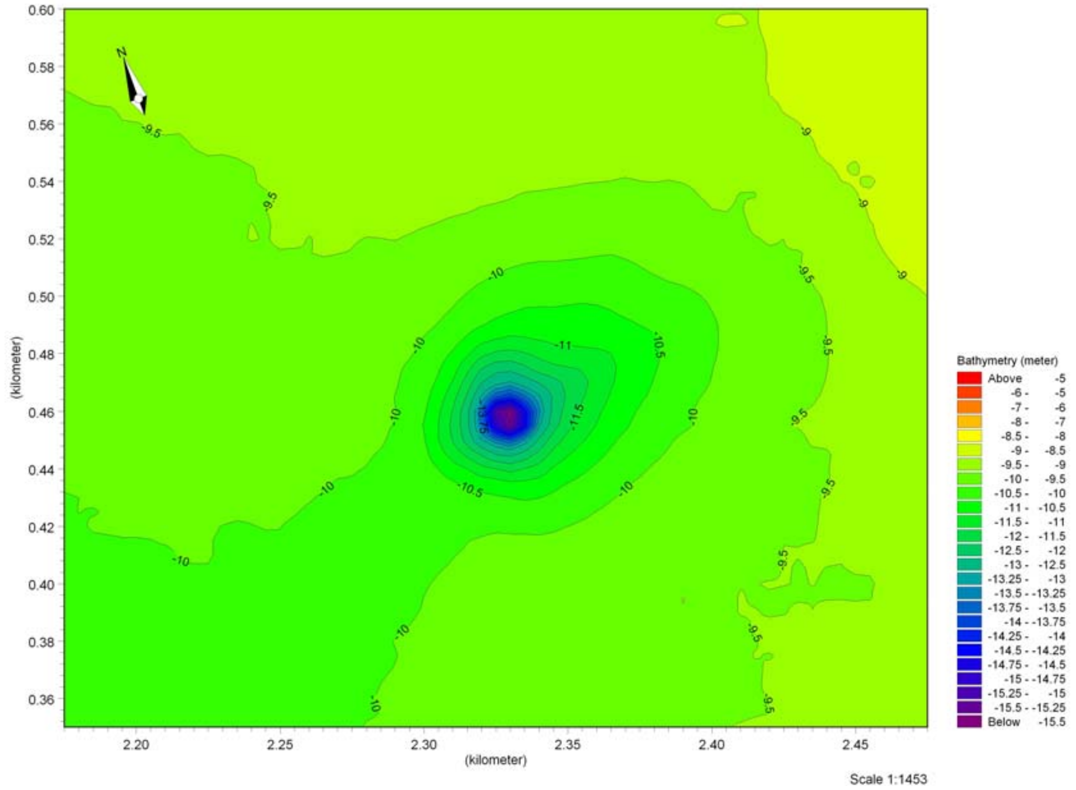


Figure 5-18 Scour hole formation around turbine foundation G6 (Robin Rigg), 2008-2009 survey (December 2008 – January 2009)

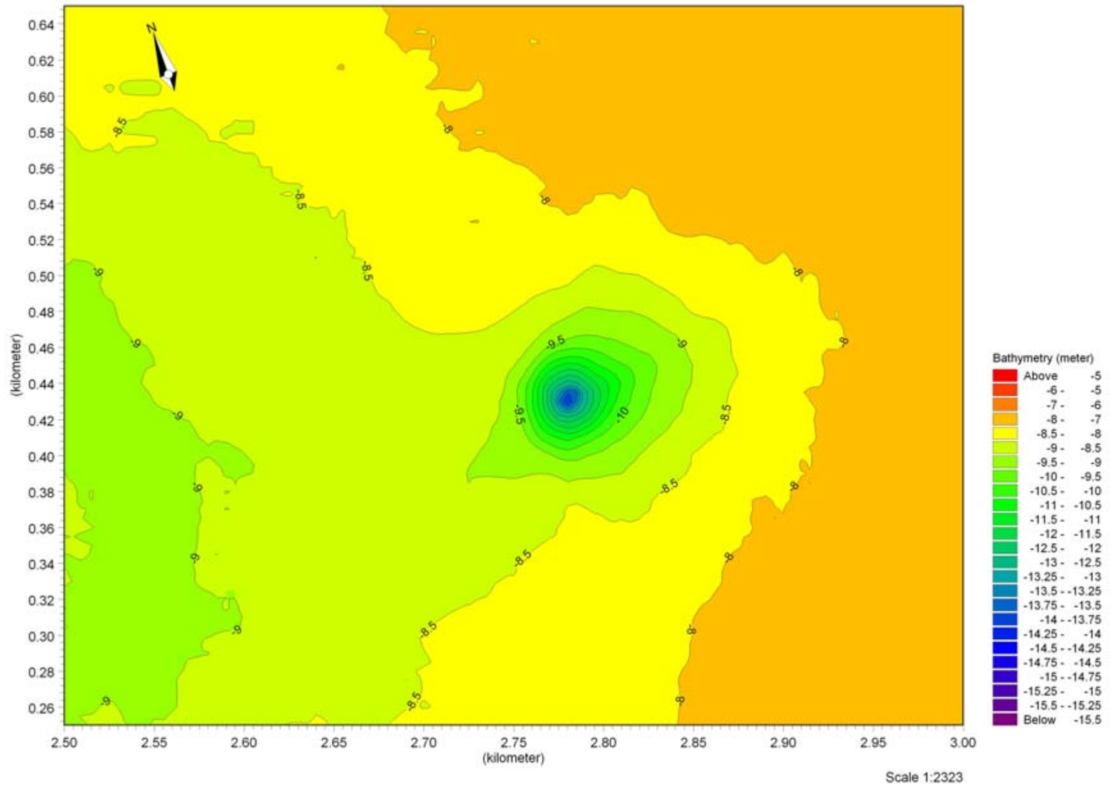


Figure 5-19 Scour hole formation around turbine foundation G7 (Robin Rigg), 2008-2009 survey (December 2008 – January 2009)

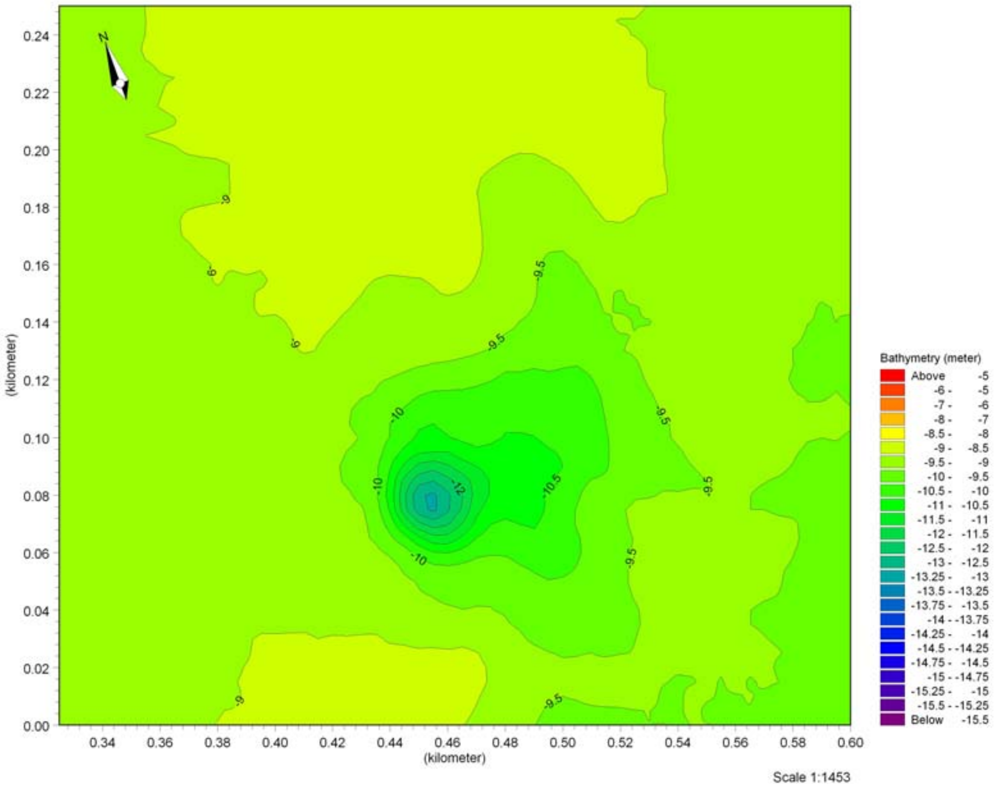


Figure 5-20 Scour hole formation around turbine foundation H1 (Robin Rigg), 2008-2009 survey (December 2008 – January 2009)

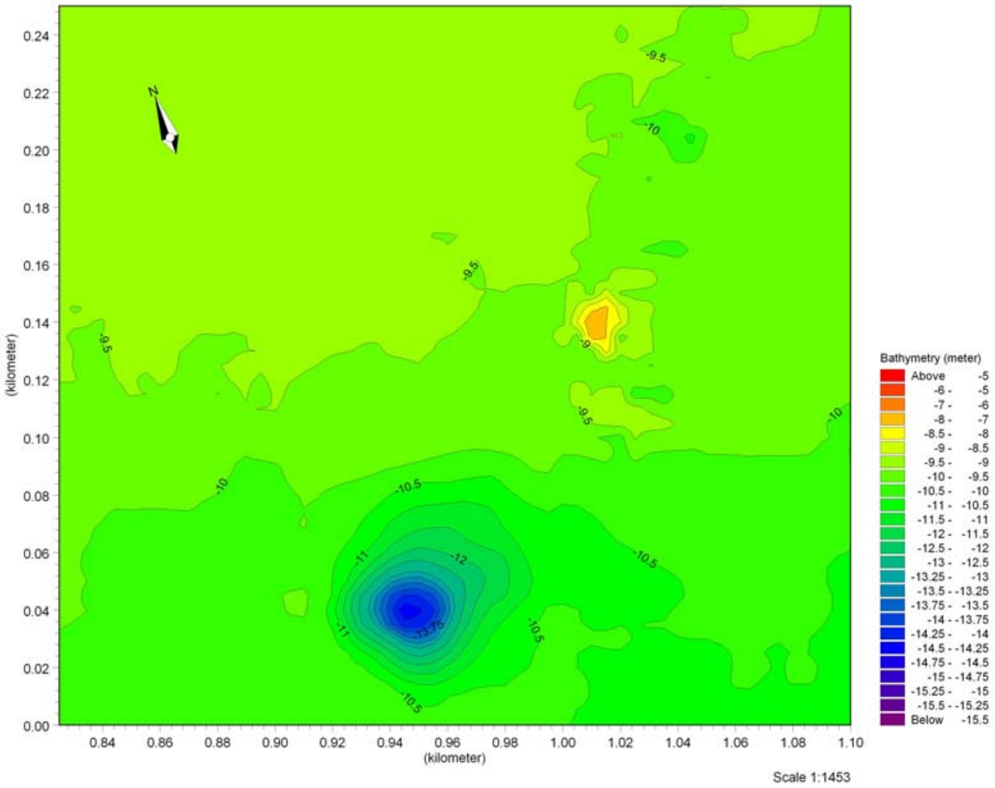


Figure 5-21 Scour hole formation around turbine foundation H2 (Robin Rigg), 2008-2009 survey (December 2008 – January 2009)

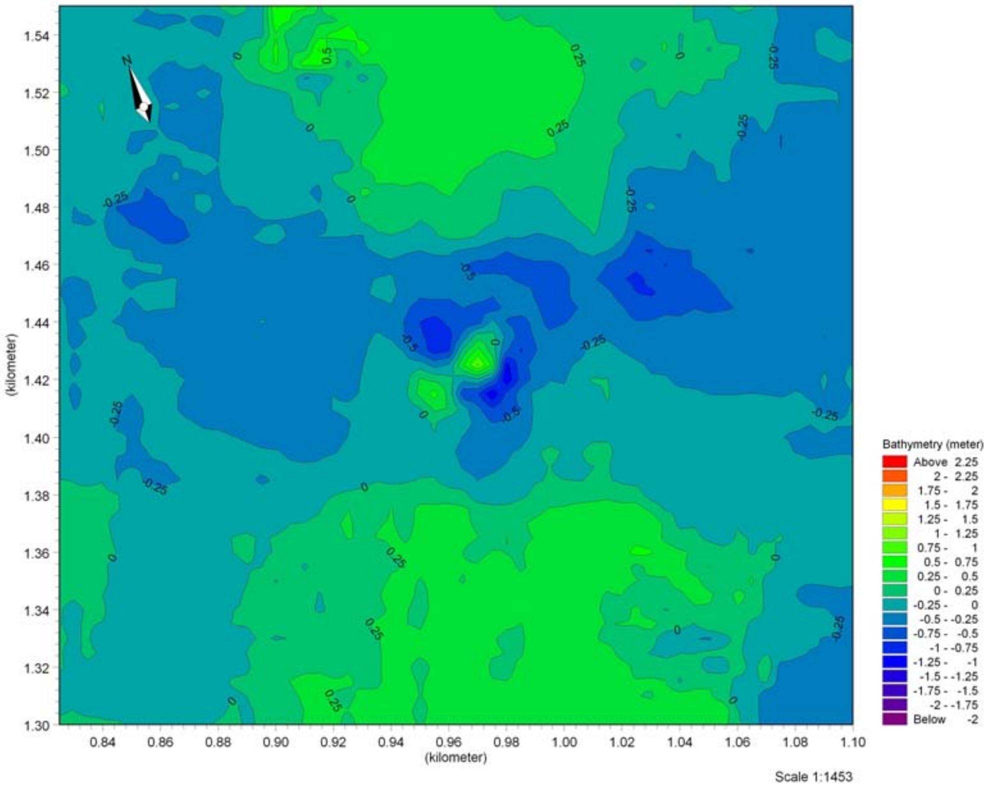


Figure 5-22 Difference in seabed levels at foundation position E3 (Robin Rigg) between December 2008 – January 2009 survey and March- April 2008 survey

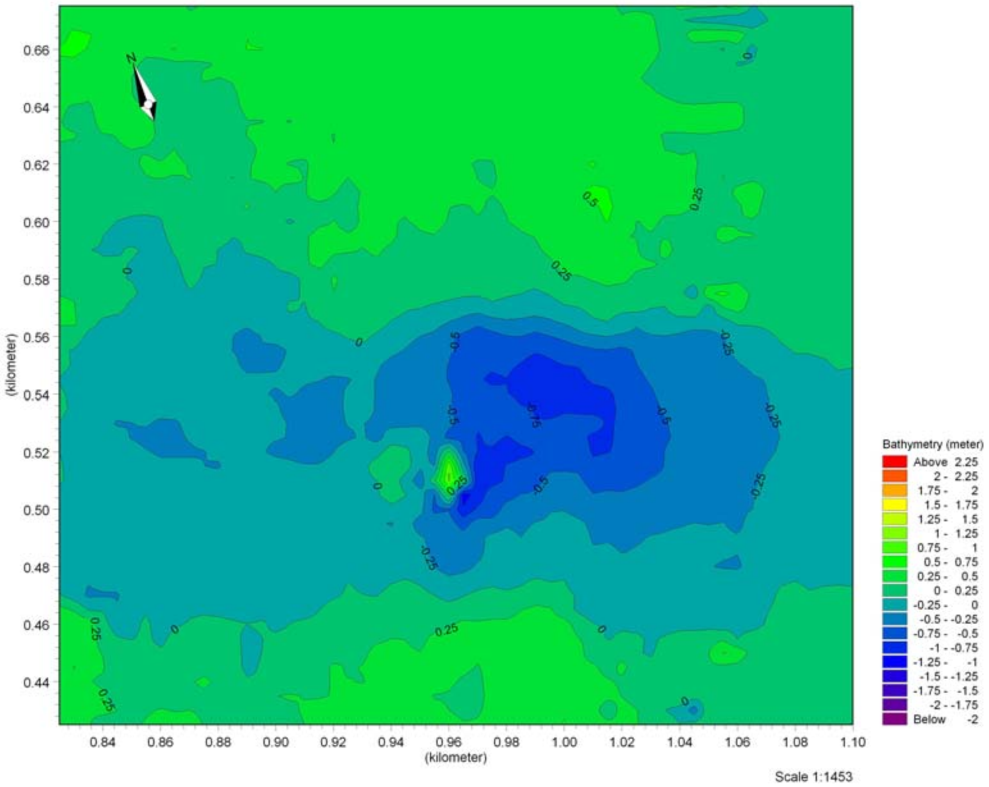


Figure 5-23 Difference in seabed levels at foundation position G3 (Robin Rigg) between December 2008 – January 2009 survey and March- April 2008 survey

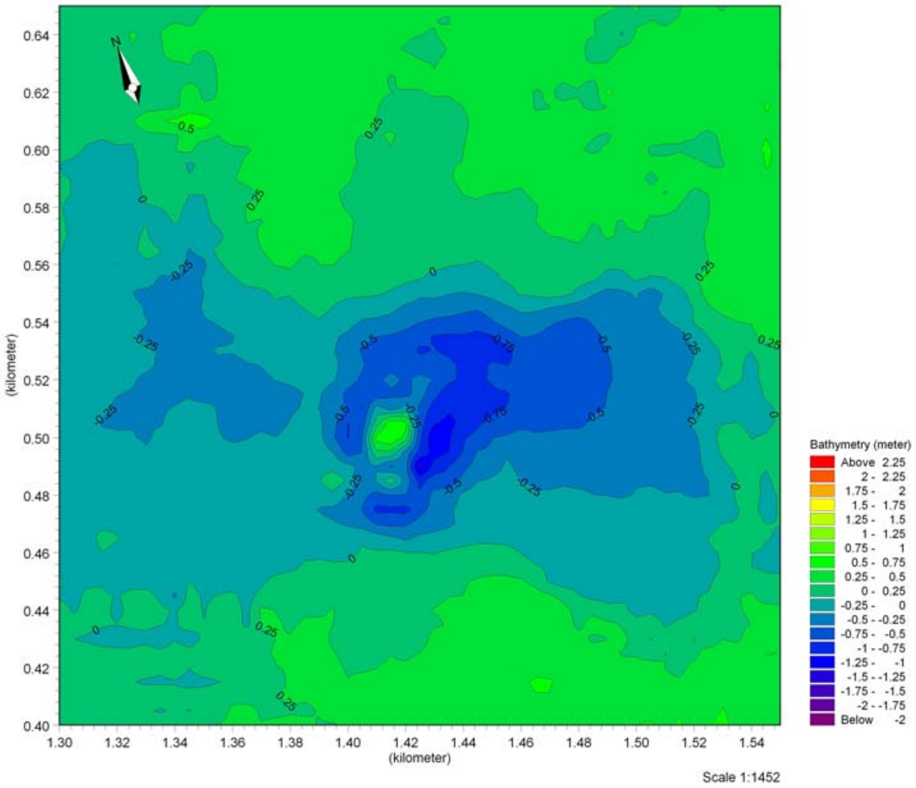


Figure 5-24 Difference in seabed levels at foundation position G4 (Robin Rigg) between December 2008 – January 2009 survey and March- April 2008 survey

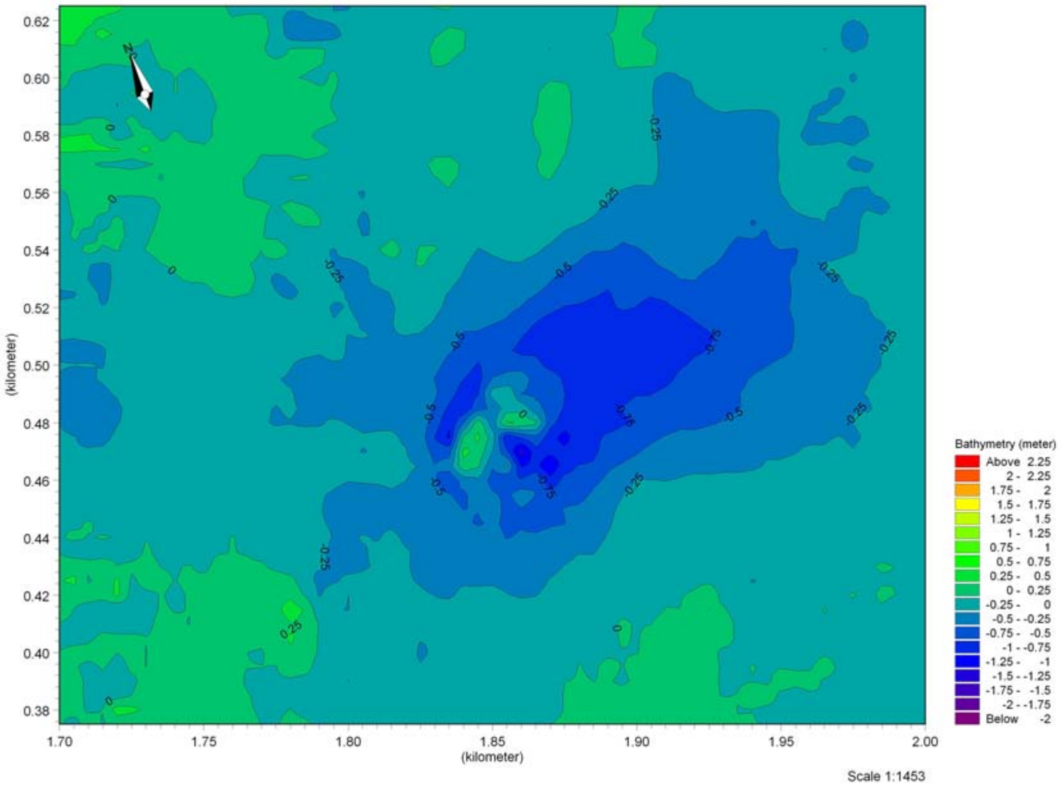


Figure 5-25 Difference in seabed levels at foundation position G5 (Robin Rigg) between December 2008 – January 2009 survey and March- April 2008 survey

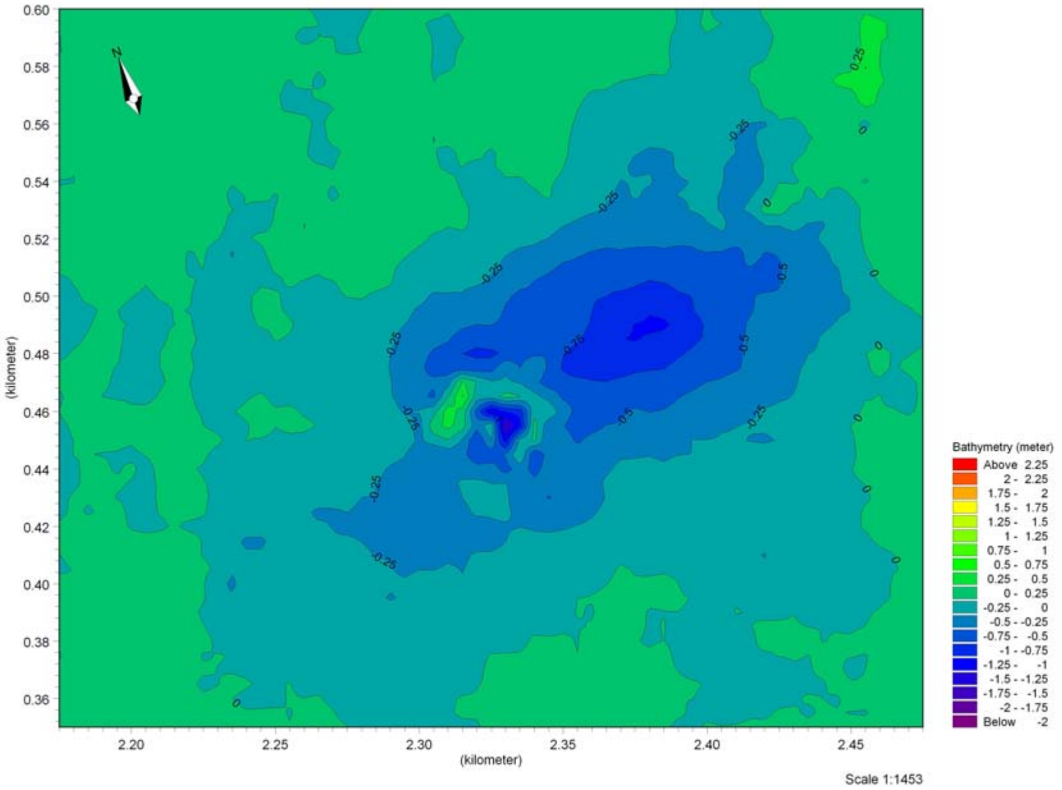


Figure 5-26 Difference in seabed levels at foundation position G6 (Robin Rigg) between December 2008 – January 2009 survey and March- April 2008 survey

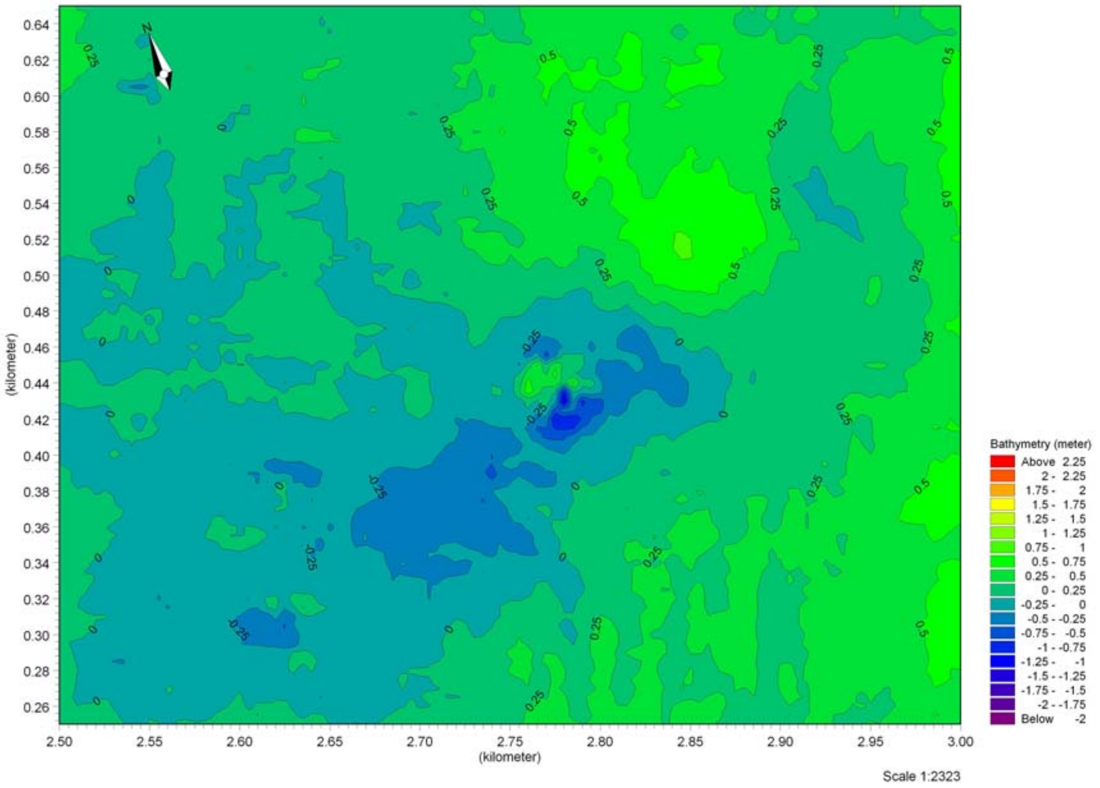


Figure 5-27 Difference in seabed levels at foundation position G7 (Robin Rigg) between December 2008 – January 2009 survey and March- April 2008 survey

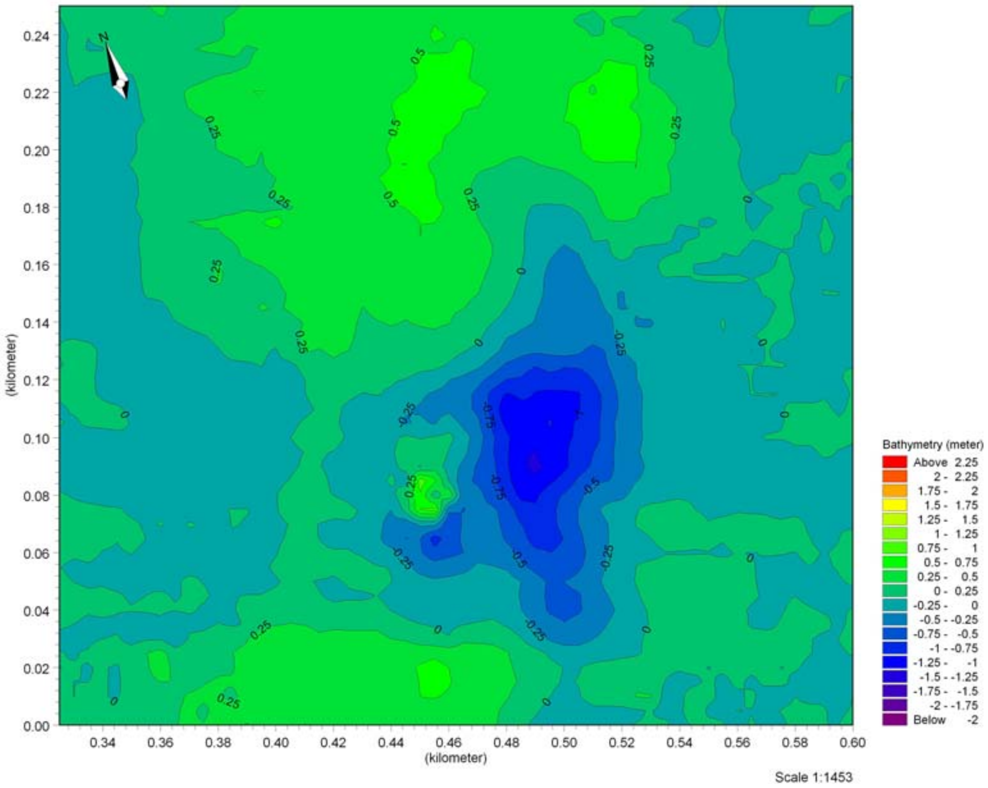


Figure 5-28 Difference in seabed levels at foundation position H1 (Robin Rigg) between December 2008 – January 2009 survey and March- April 2008 survey

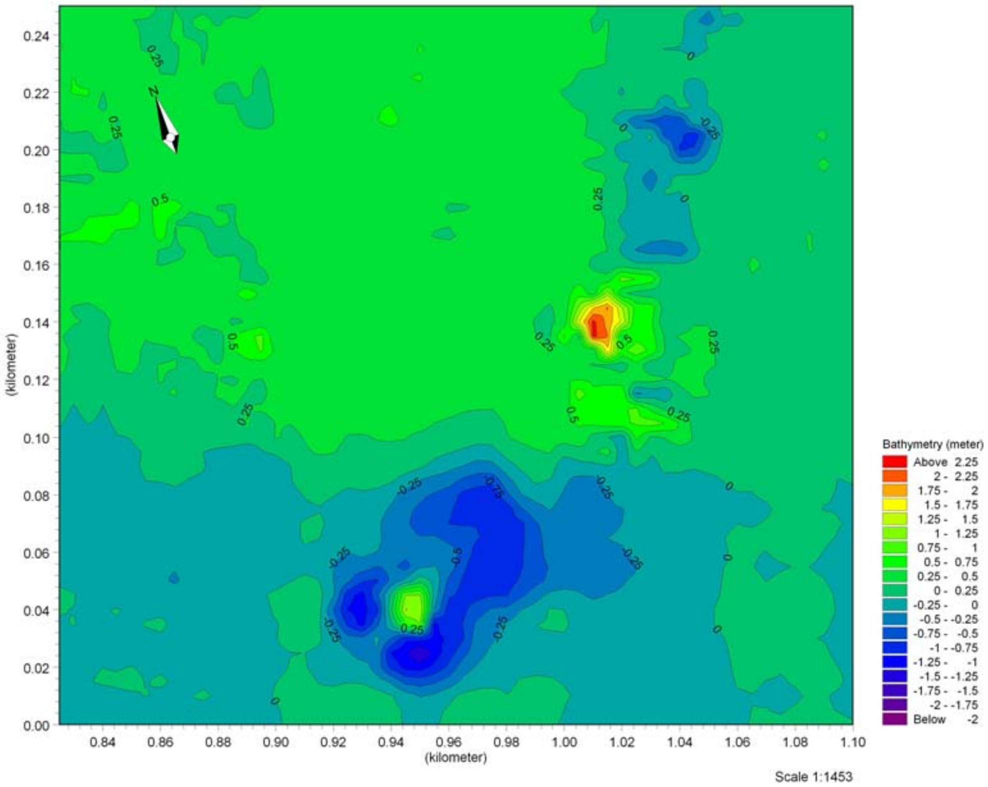


Figure 5-29 Difference in seabed levels at foundation position H2 (Robin Rigg) between December 2008 – January 2009 survey and March- April 2008 survey

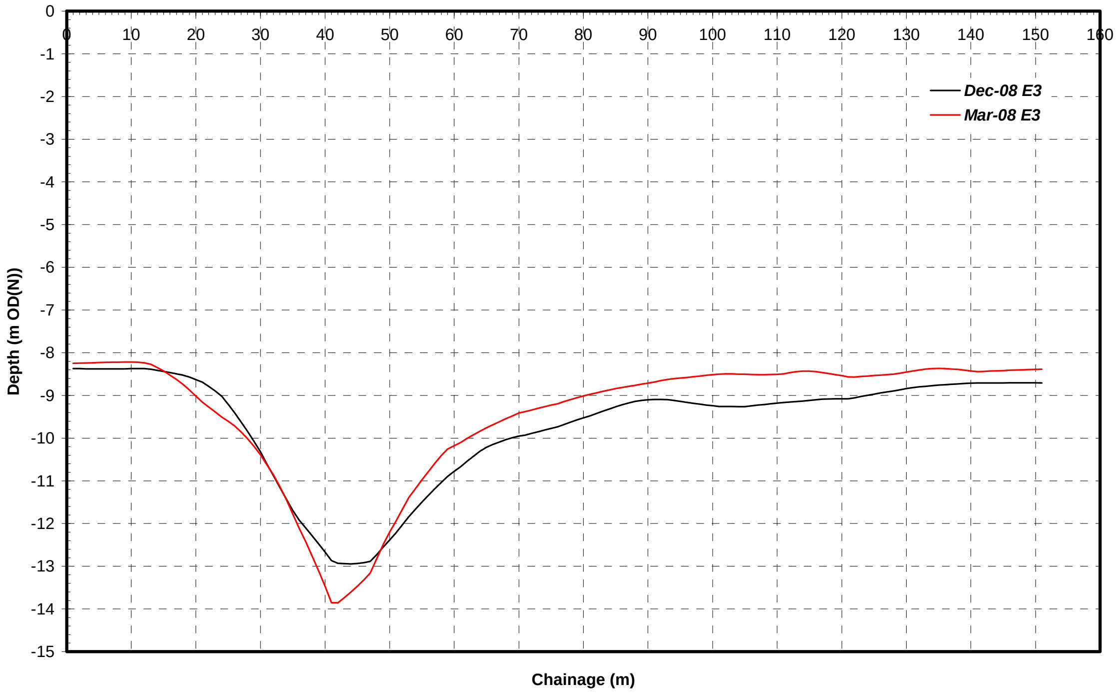


Figure 5-30 Comparison of cross-sections taken through principal axis of scour hole at foundation position E3 (Robin Rigg)

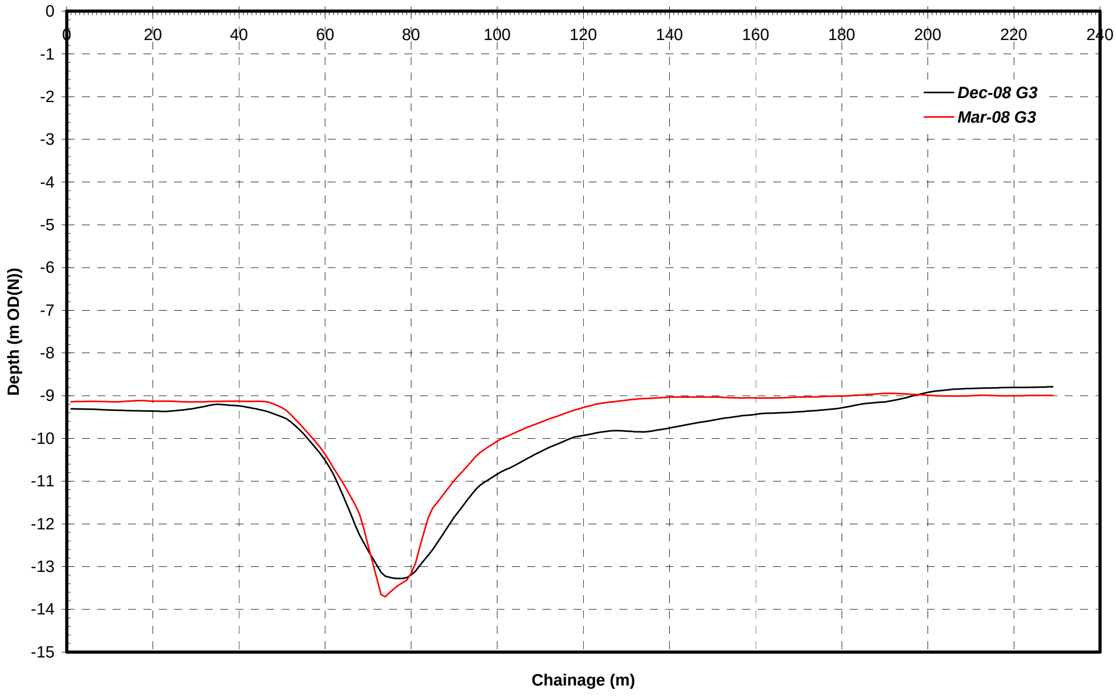


Figure 5-31 Comparison of cross-sections taken through principal axis of scour hole at foundation position G3 (Robin Rigg)

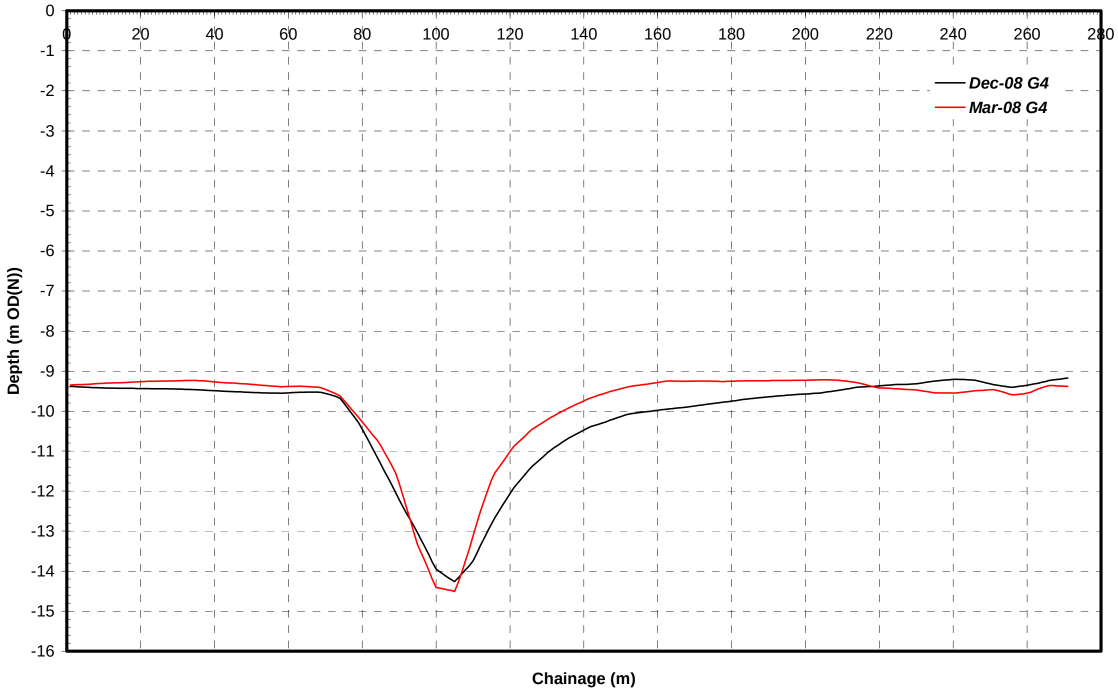


Figure 5-32 Comparison of cross-sections taken through principal axis of scour hole at foundation position G4 (Robin Rigg)

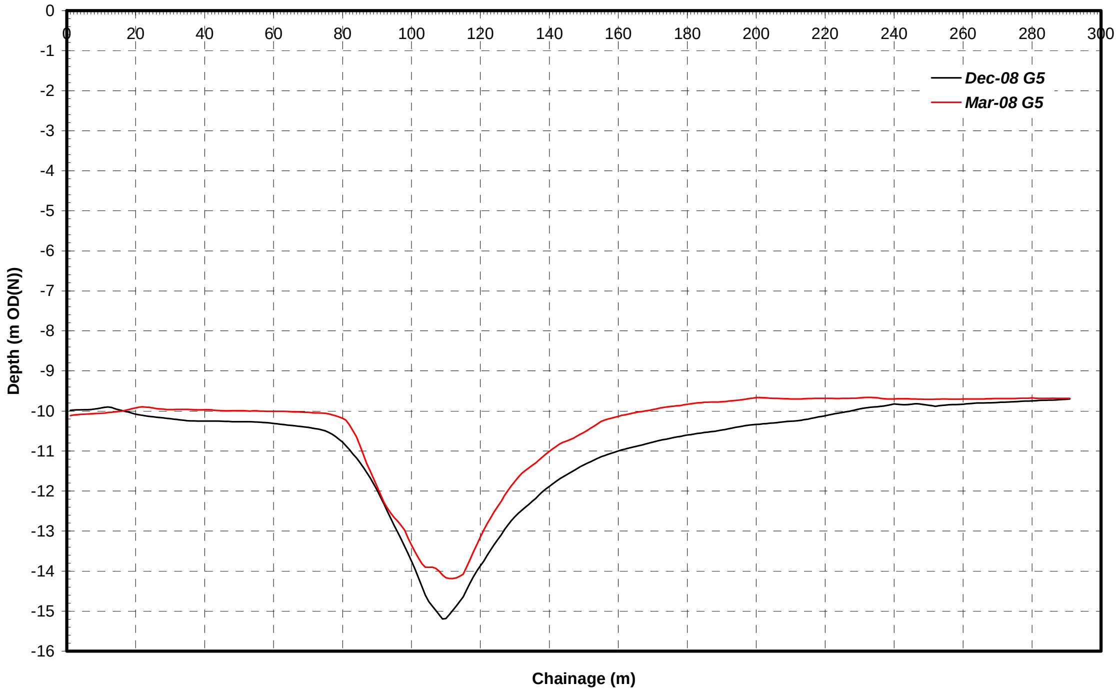


Figure 5-33 Comparison of cross-sections taken through principal axis of scour hole at foundation position G5 (Robin Rigg)

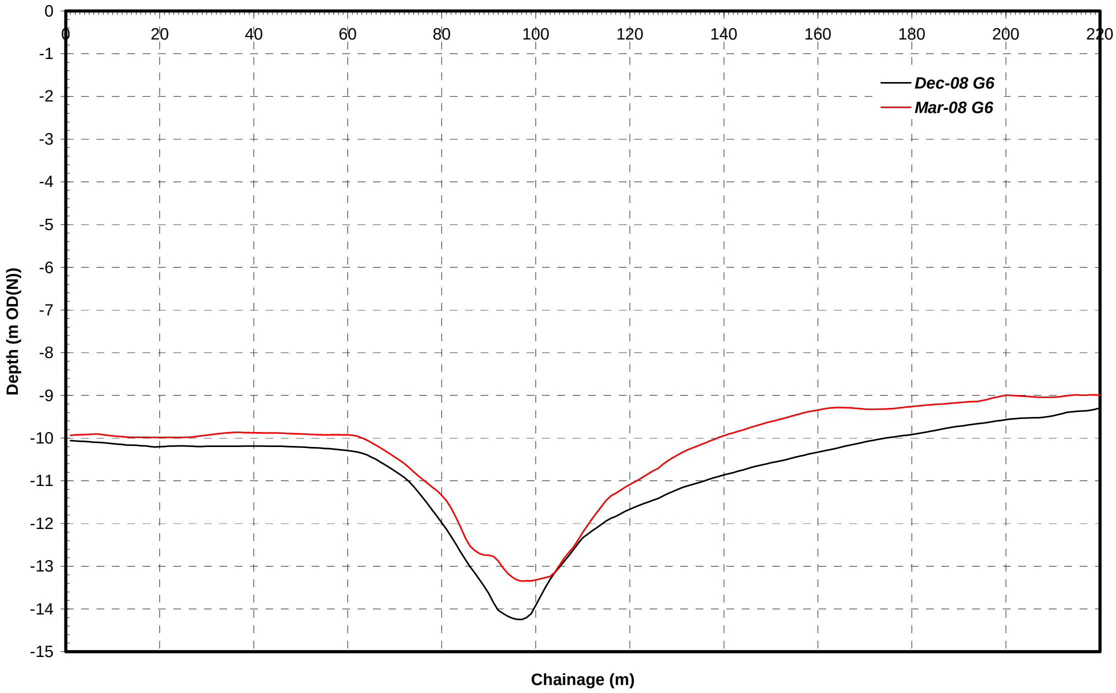


Figure 5-34 Comparison of cross-sections taken through principal axis of scour hole at foundation position G6 (Robin Rigg)

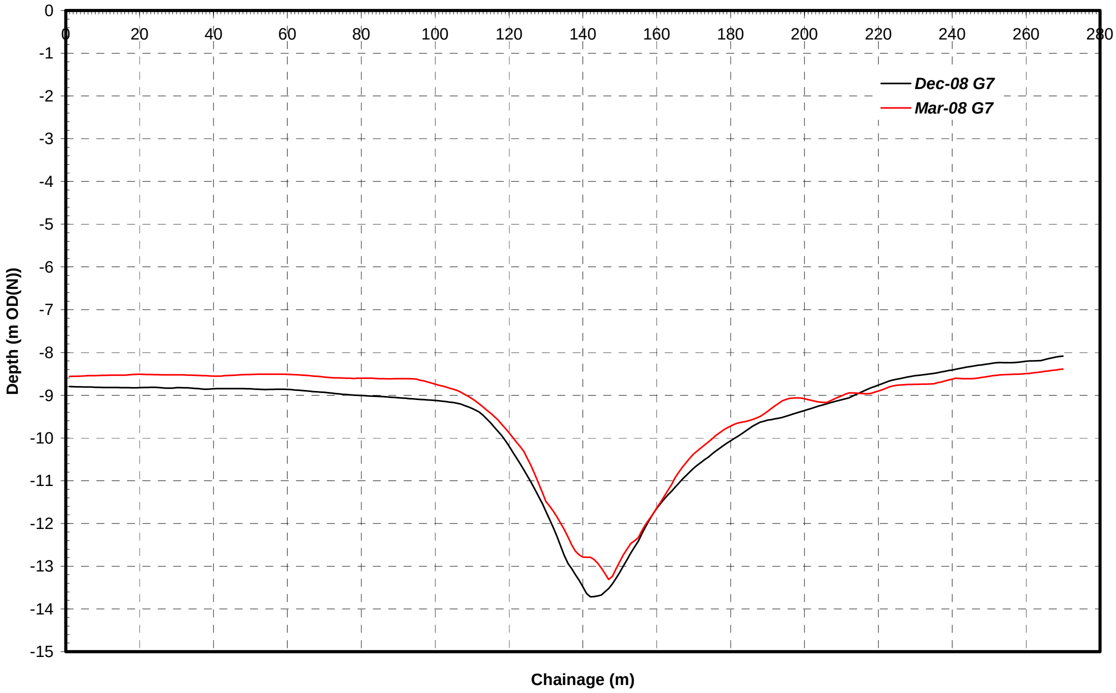


Figure 5-35 Comparison of cross-sections taken through principal axis of scour hole at foundation position G7 (Robin Rigg)

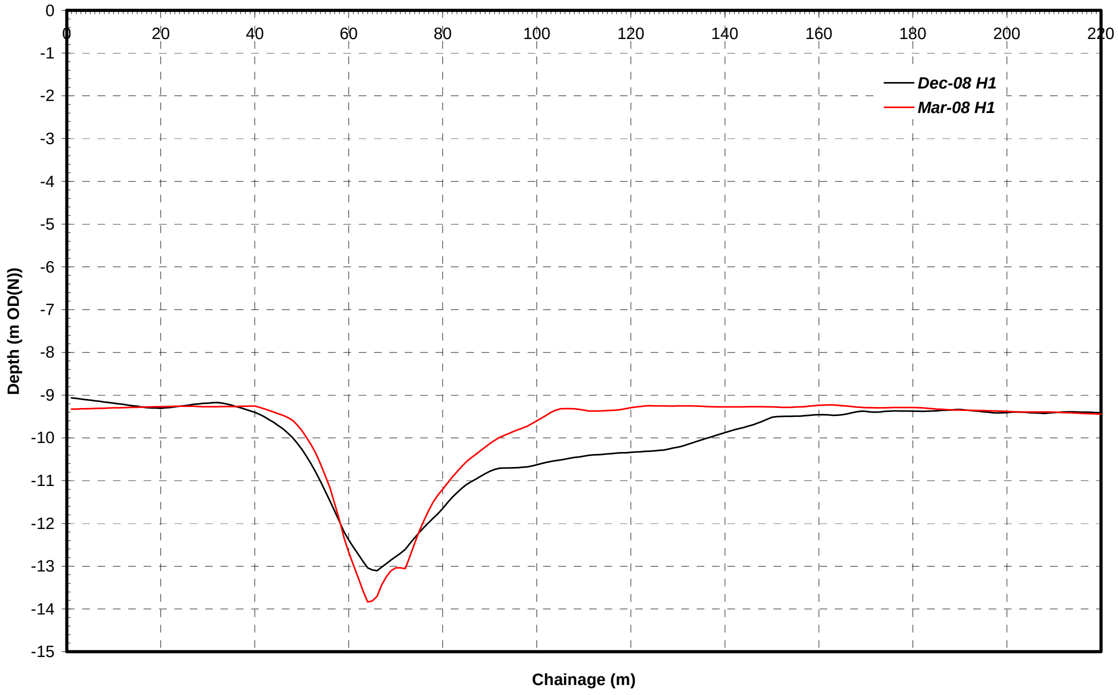


Figure 5-36 Comparison of cross-sections taken through principal axis of scour hole at foundation position H1 (Robin Rigg)

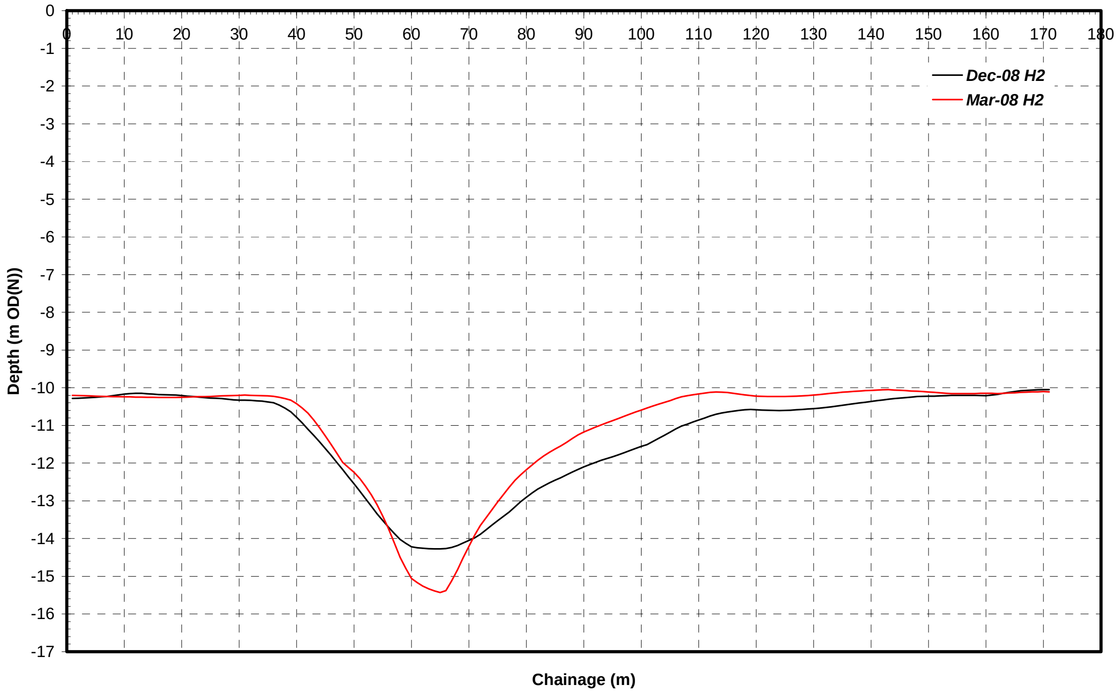


Figure 5-37 Comparison of cross-sections taken through principal axis of scour hole at foundation position H2 (Robin Rigg)

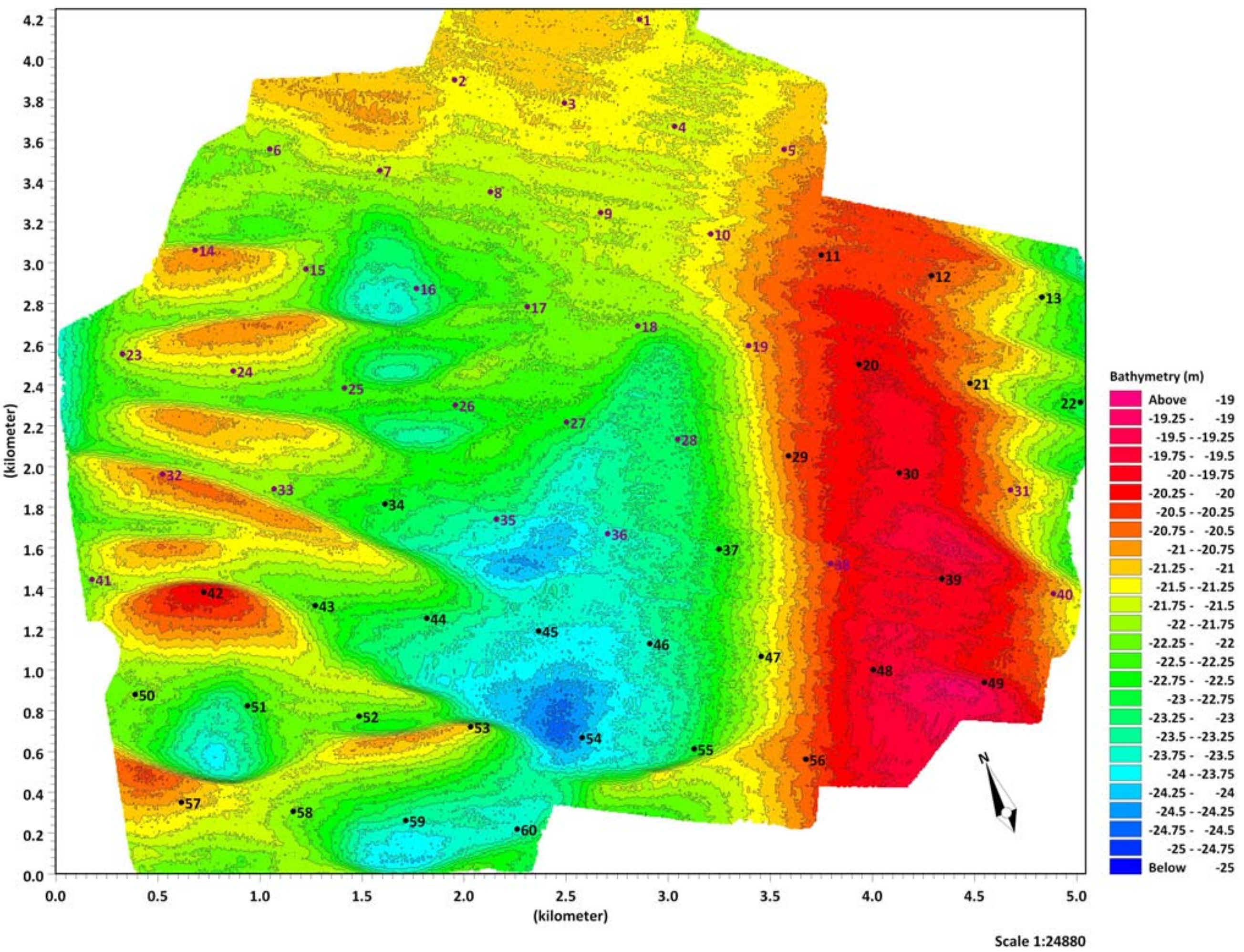


Figure 5-38 Princess Amalia (Q7) Wind Farm Site, showing the location of turbines (Note: numbers in red correspond to those foundations for which survey data has been obtained

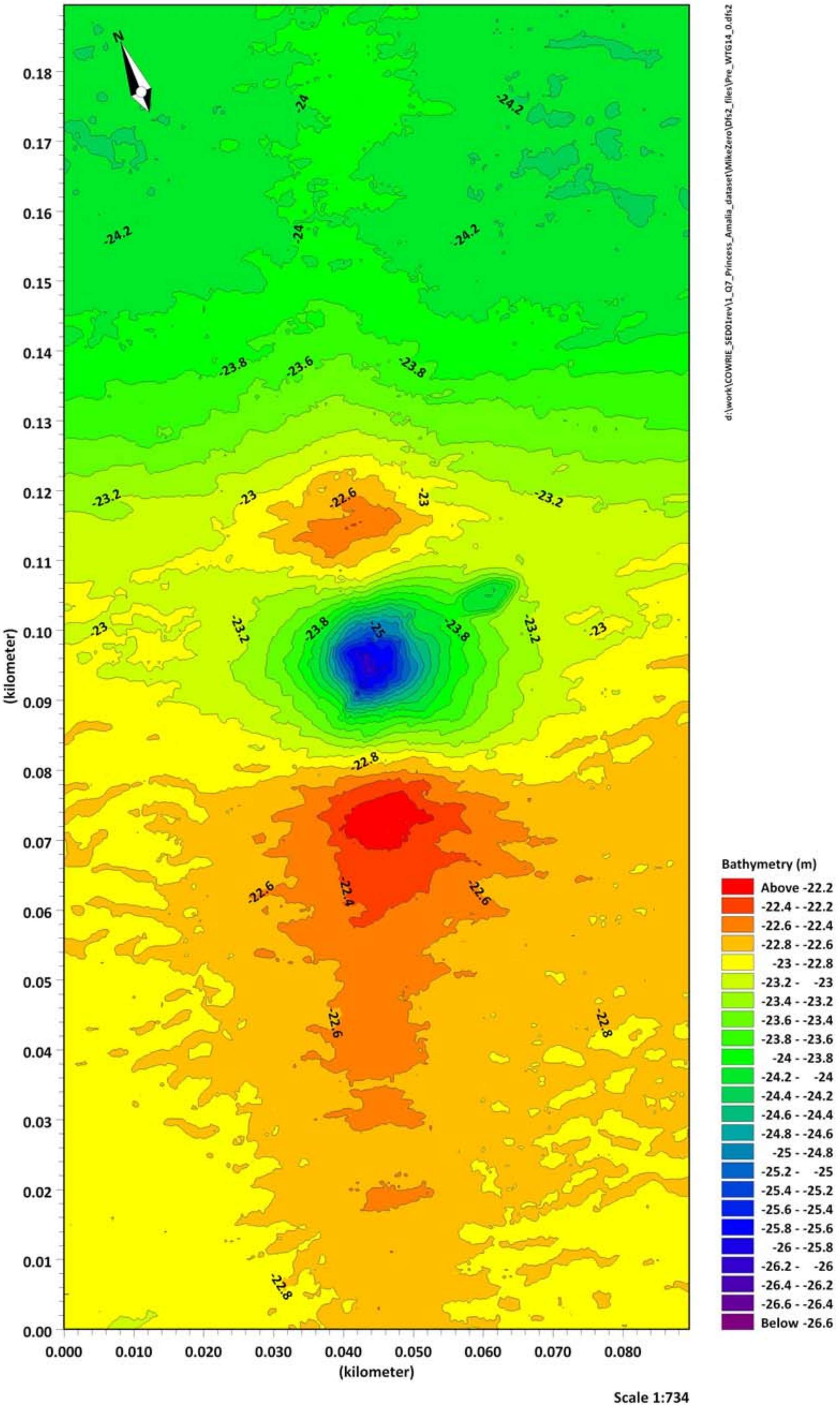


Figure 5-39 Wind turbine foundation WTG14, Princess Amalia Wind Farm

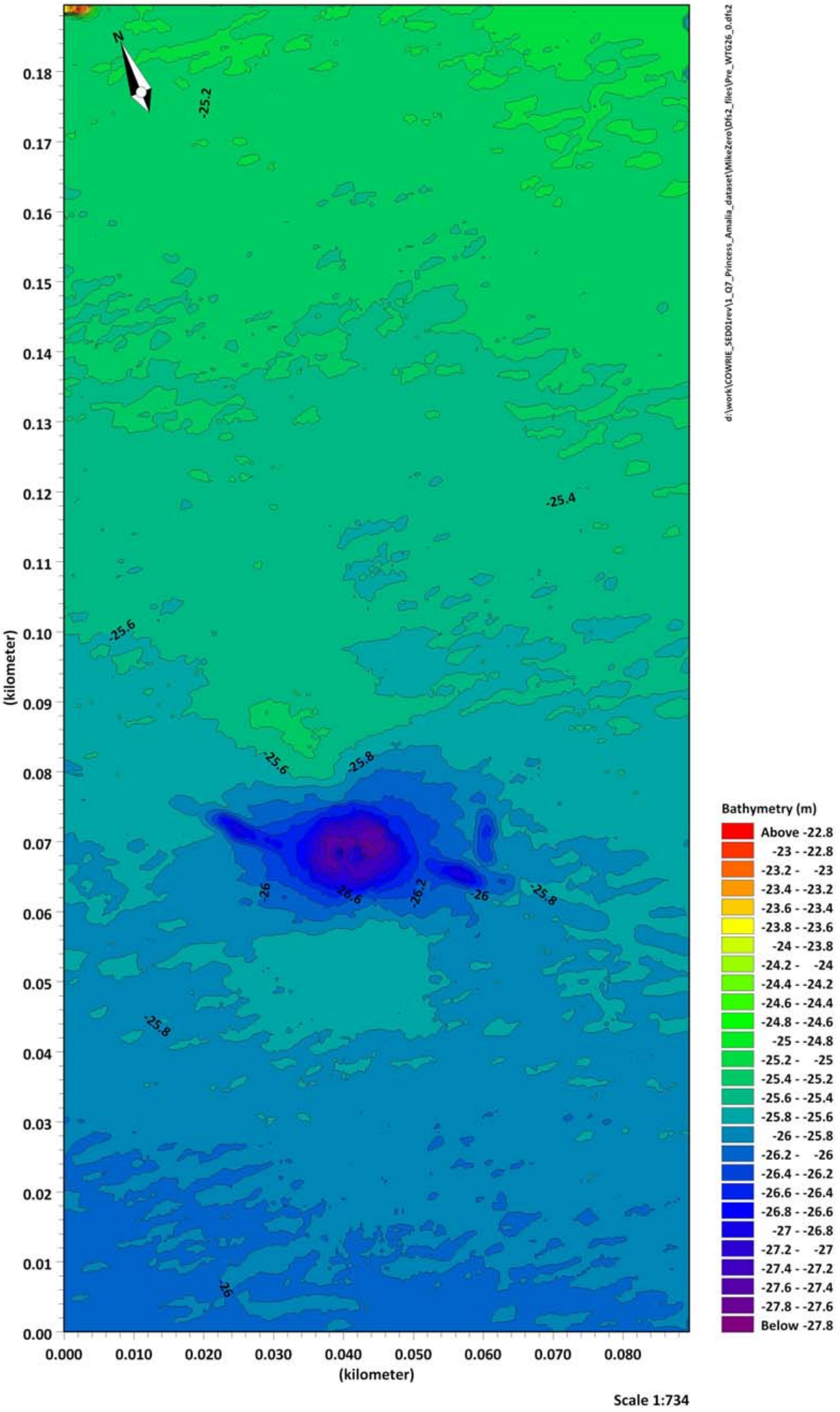


Figure 5-40 Wind turbine foundation WTG26, Princess Amalia Wind Farm

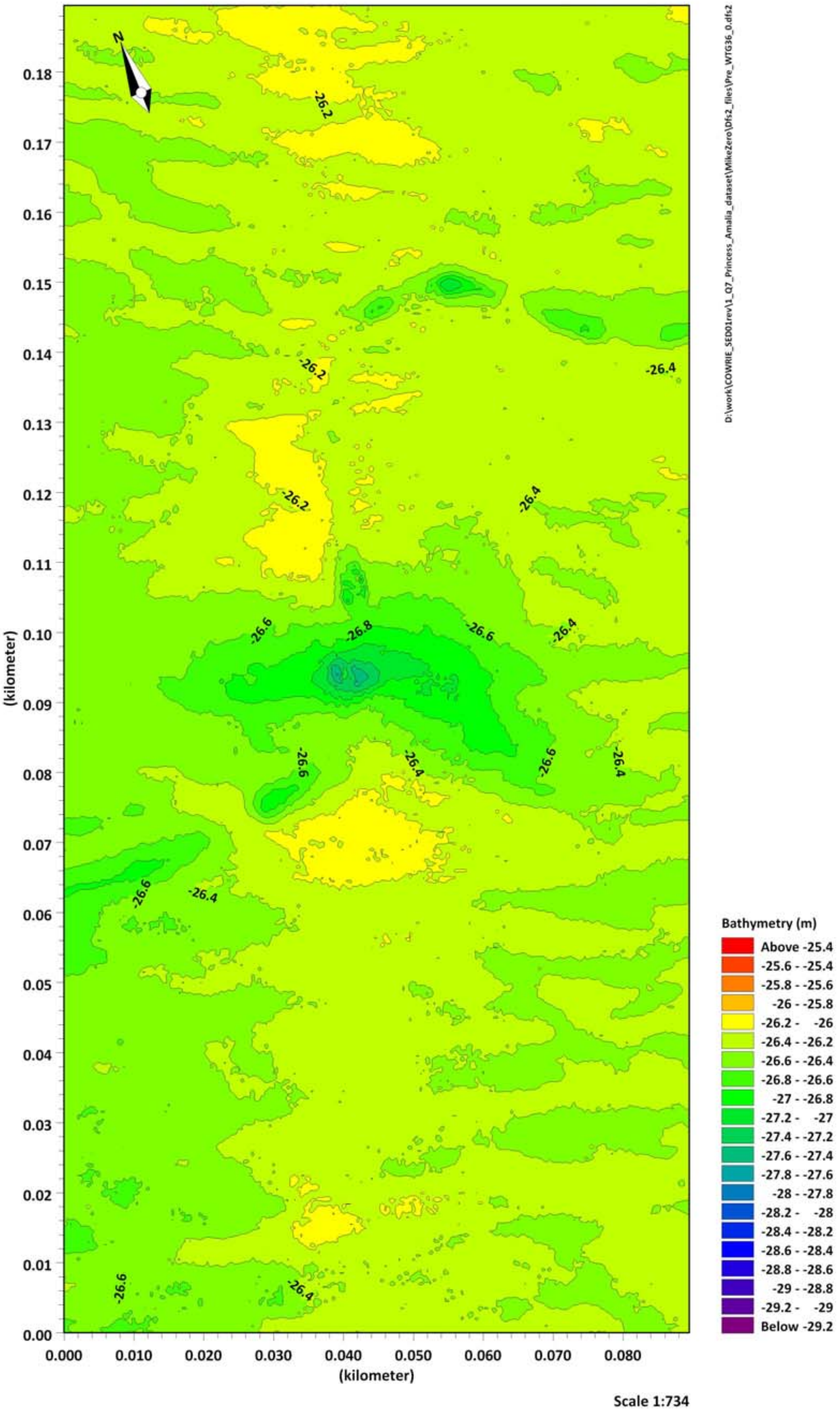


Figure 5-41 Wind turbine foundation WTG36, Princess Amalia Wind Farm

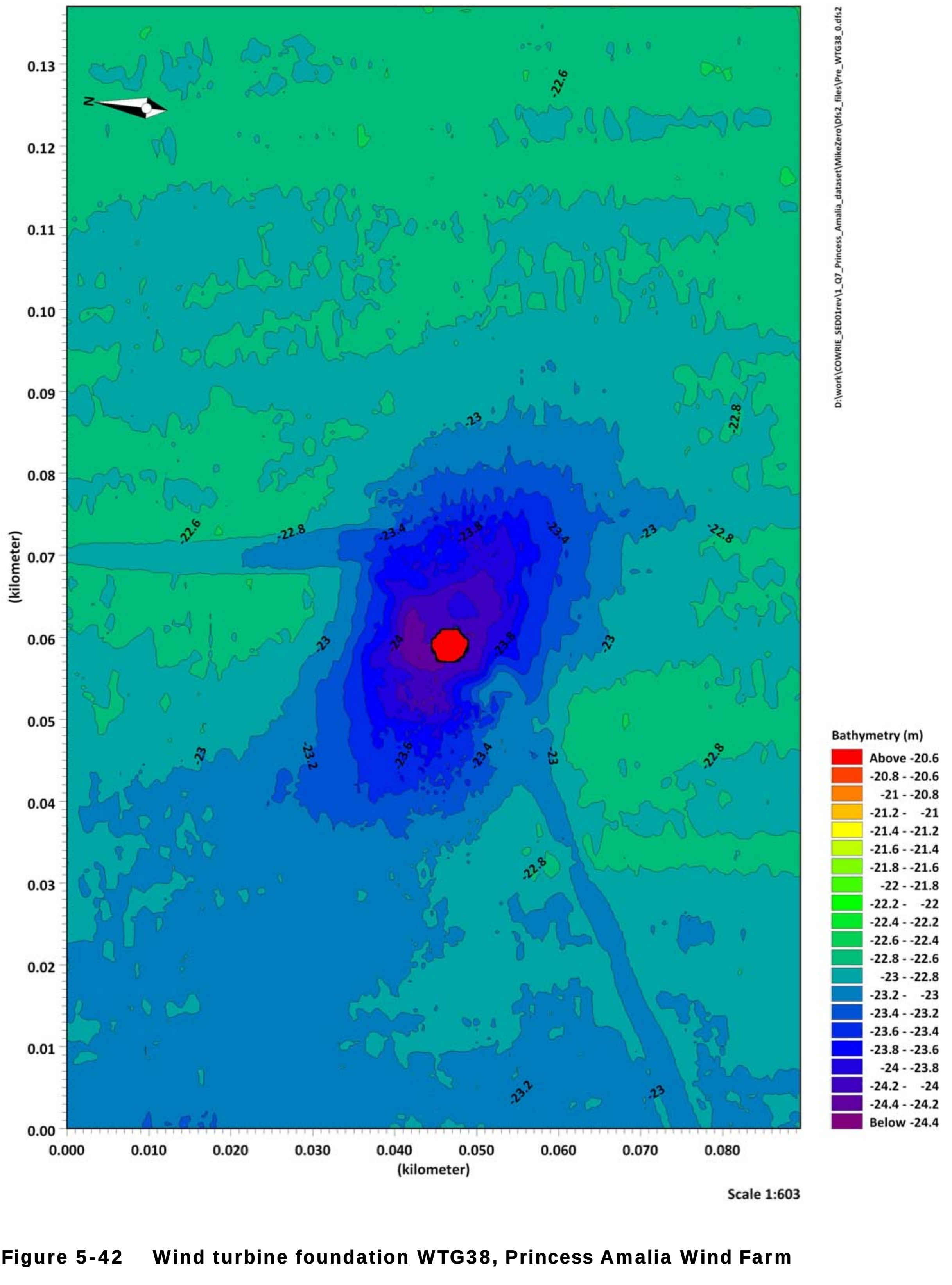


Figure 5-42 Wind turbine foundation WTG38, Princess Amalia Wind Farm

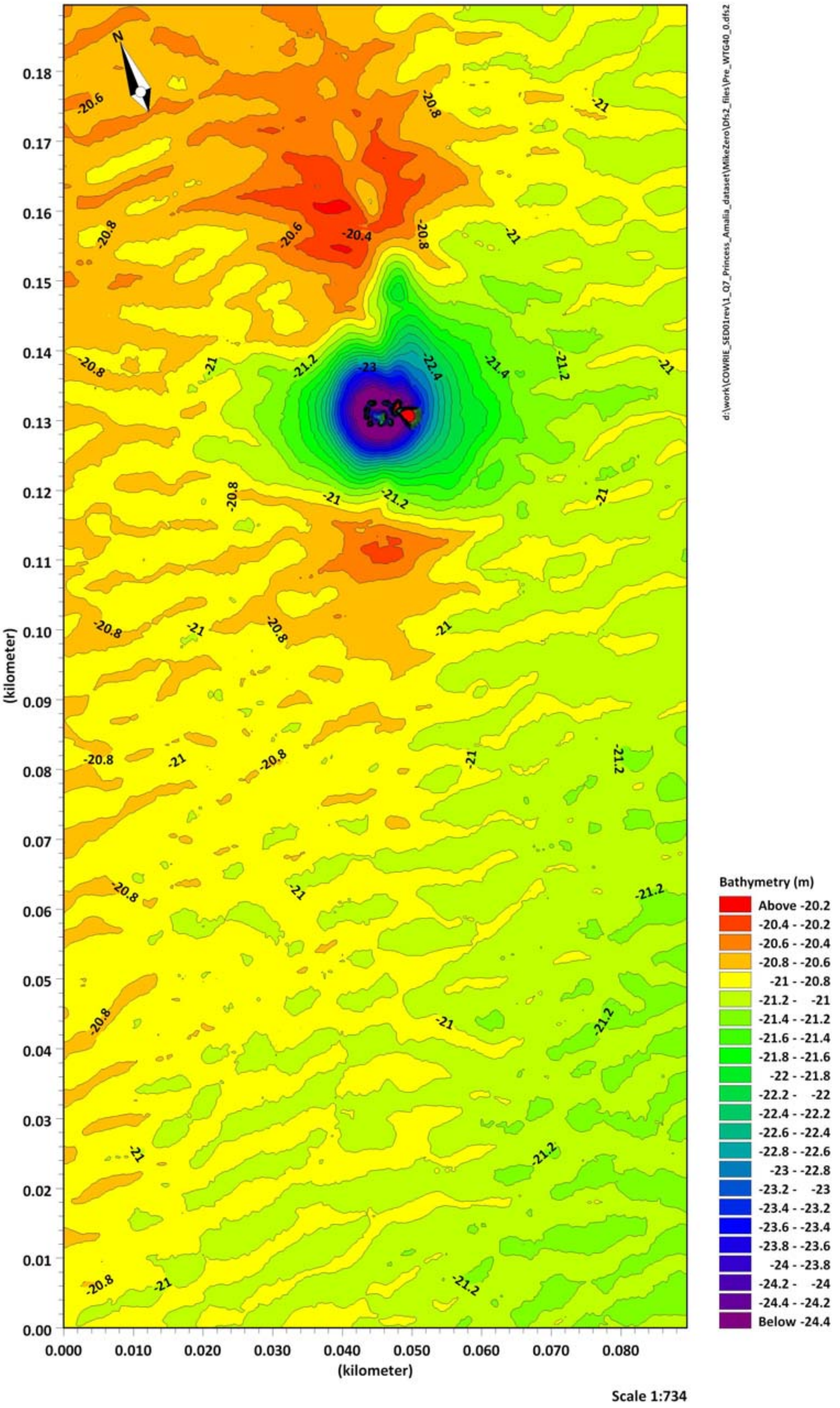


Figure 5-43 Wind turbine foundation WTG40, Princess Amalia Wind Farm

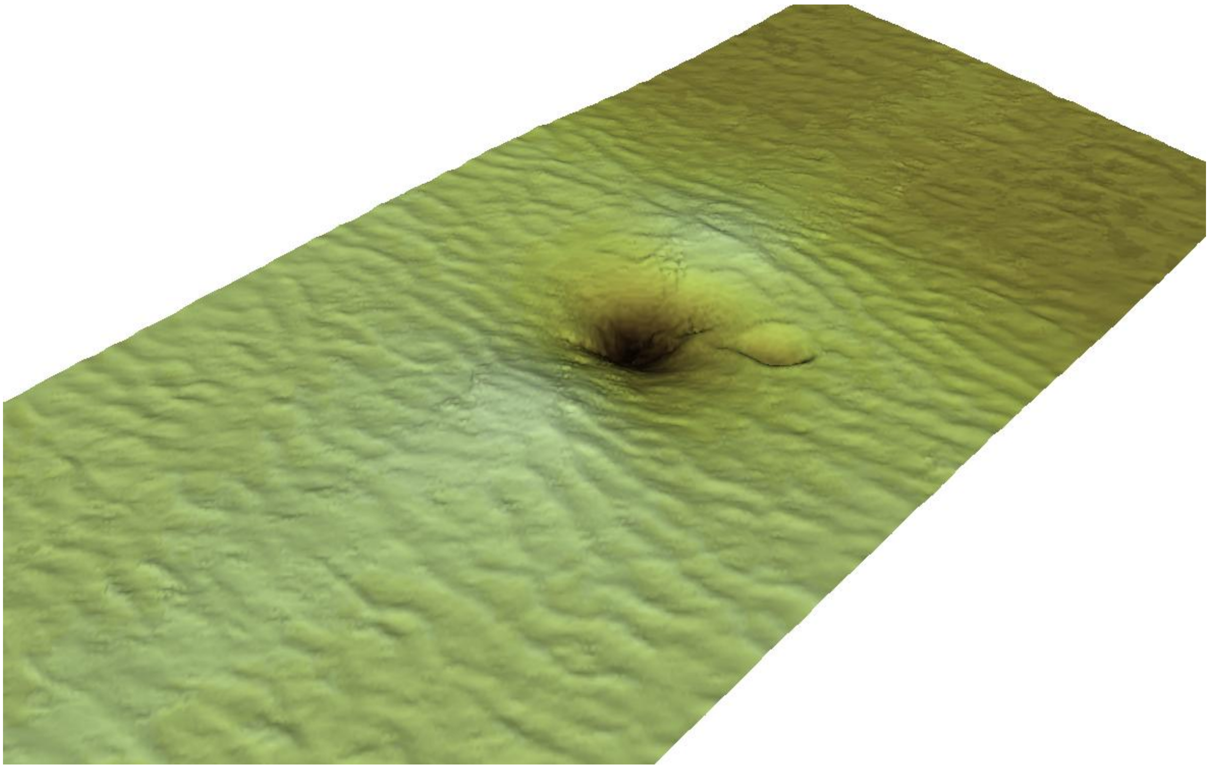


Figure 5-44 Wind turbine foundation WTG14 - 3D image of surface contours, Princess Amalia Wind Farm

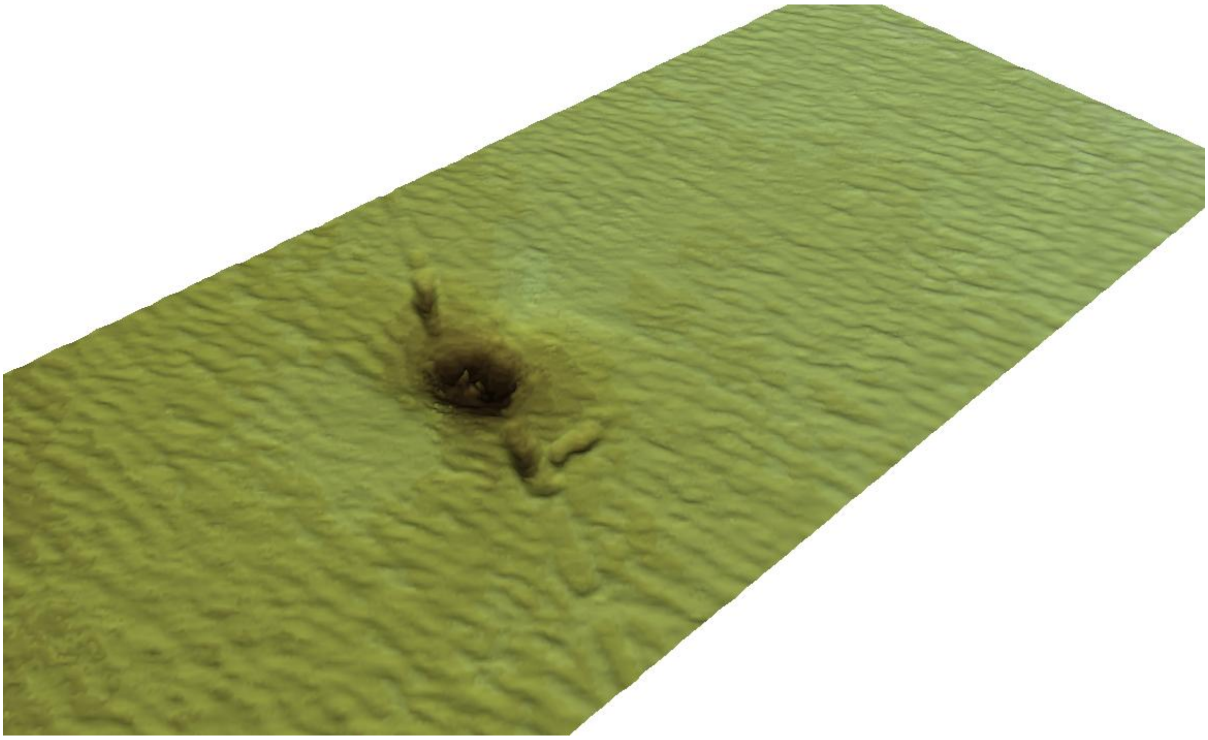


Figure 5-45 Wind turbine foundation WTG26 - 3D image of surface contours, Princess Amalia Wind Farm

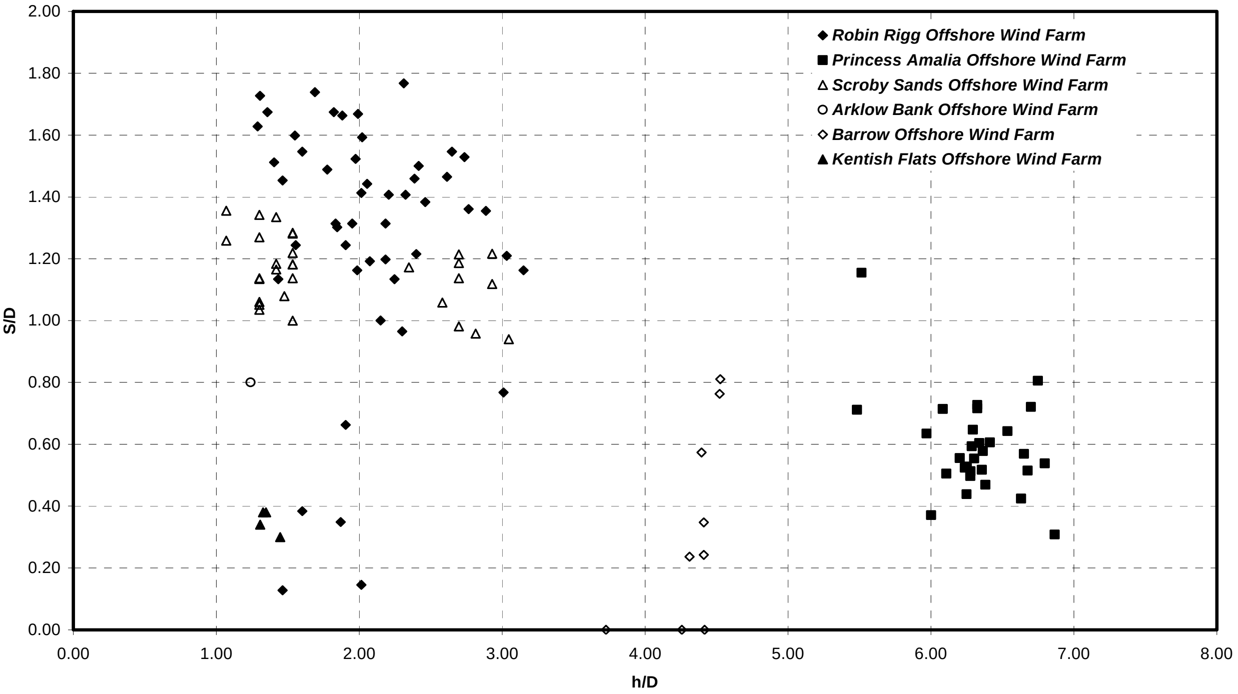


Figure 5-46 Non-dimensional plot of scour depth (S) data for offshore wind farms with no foundation scour protection in place (Note: D is monopile diameter and h is water depth to mean sea level)

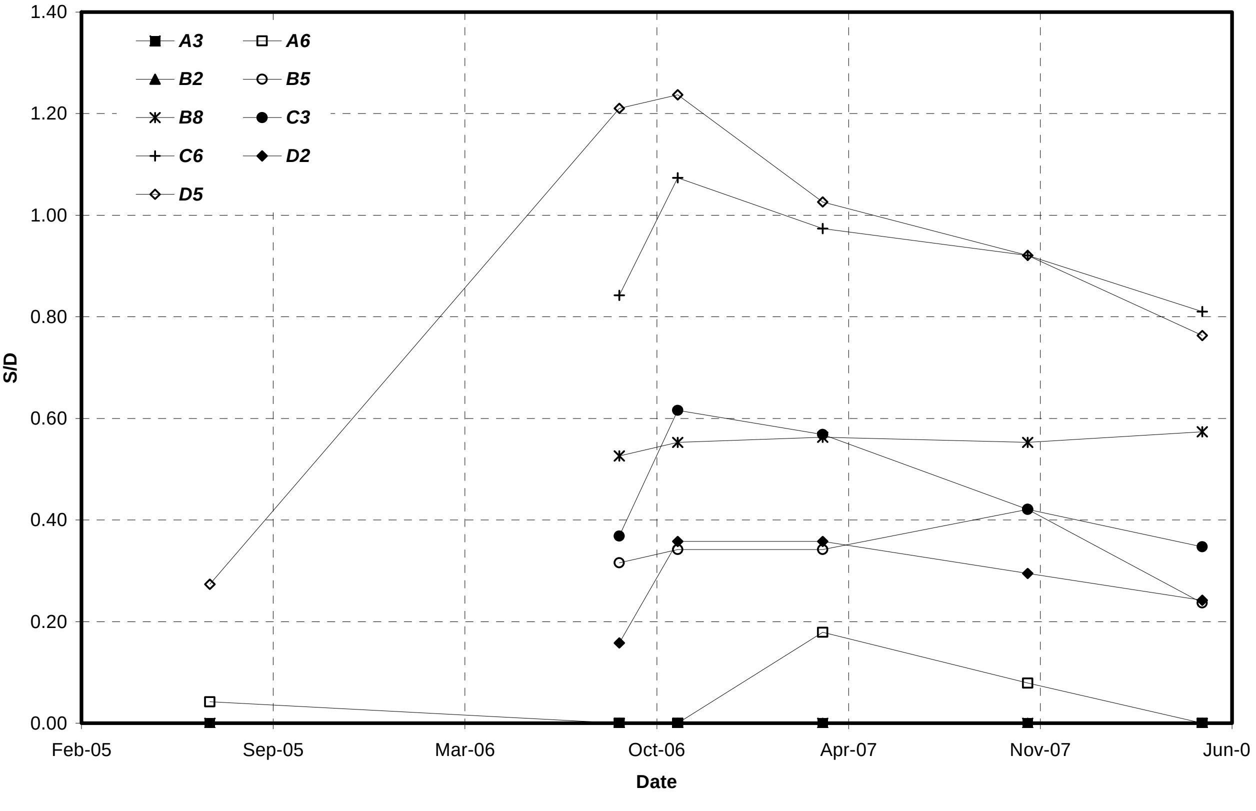


Figure 5-47 Variation of non-dimensional scour depth with time at Barrow Offshore Wind Farm

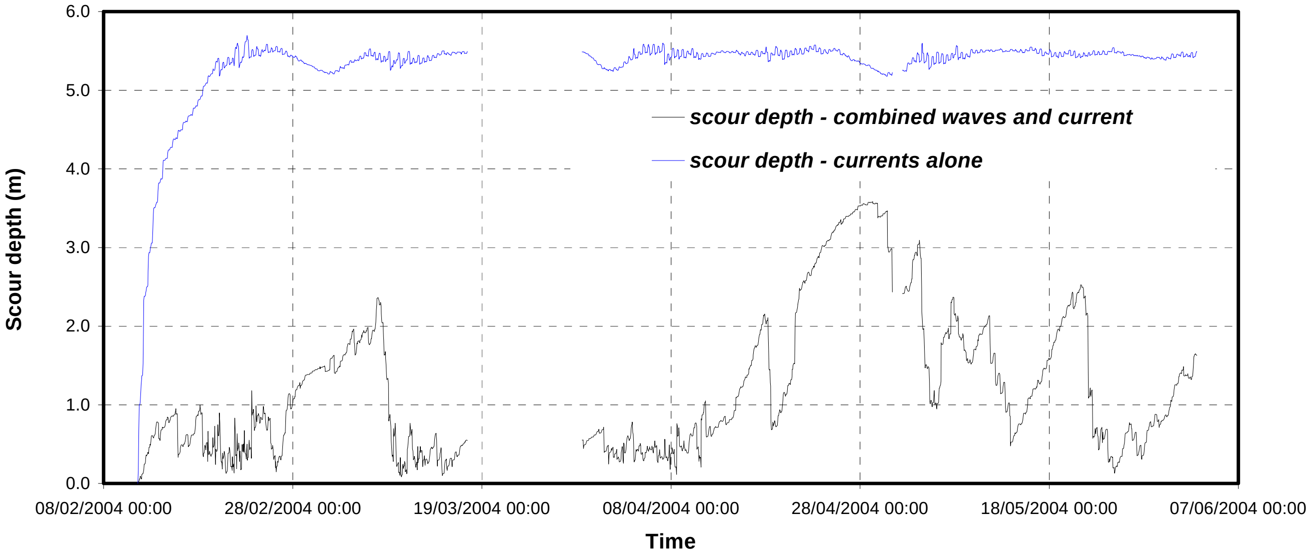


Figure 5-48 Modelled variation of foundation scour depth at a moderate water depth site (Harris *et al.*, 2010)

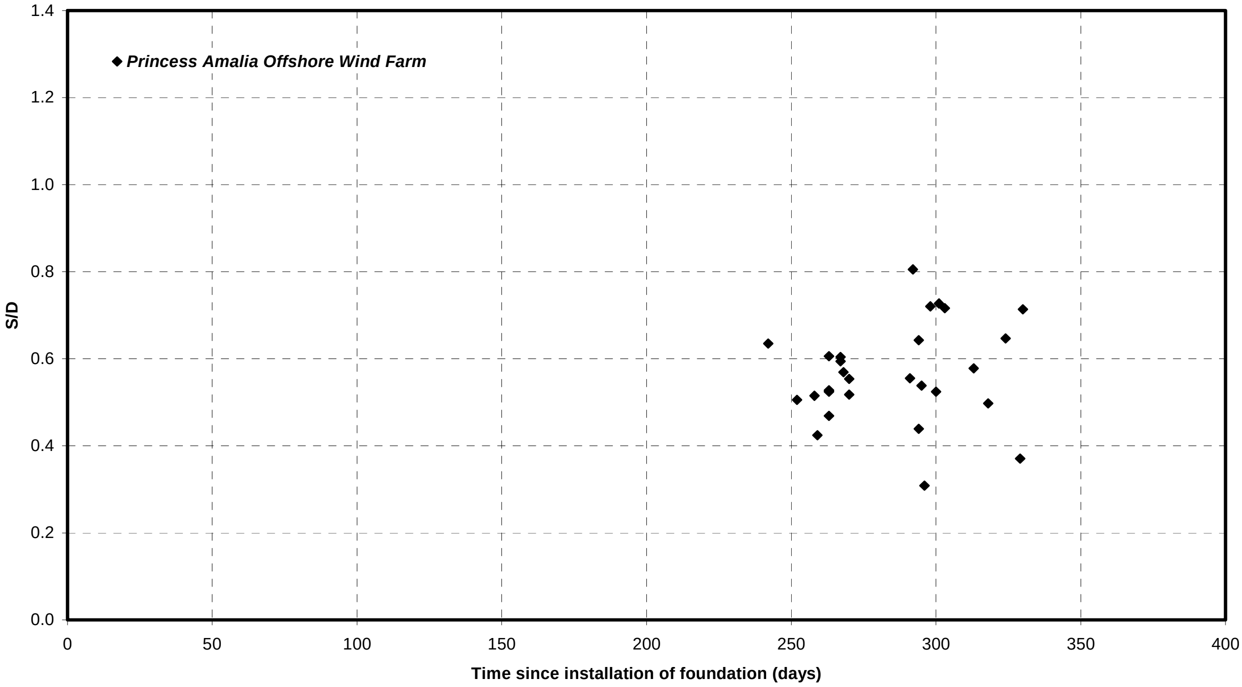


Figure 5-49 Variation of non-dimensional scour depth with non-dimensional time at Princess Amalia Offshore Wind Farm

Appendix A

Project Database

ARKLOW

Subfolder	Filename	File type	Short description	Date	Pages	Comments
No new data since SED01						

BARROW

Subfolder	Filename	File type	Short description	Date	Pages	Comments
Baseline\Reports	EX4554 - Barrow Offshore Wind Farm-ttc- sed processes study.pdf	pdf	Report of sedimentary mobility	May-02	122	
Monitoring\Post Construction\Morphology	Appendix A1-CS0195.A1.All.pdf	pdf	Wake Surveys - Near Bed Echo Intensity Summary - Flood Tide	May-07		
	Appendix A2-CS0195.A2.All.pdf	pdf	Wake Surveys - Near Bed Echo Intensity Summary - Ebb Tide	May-07		
	Appendix A Plot List.pdf	pdf	List of Plots		1	
	Appendix B1-CS0195.B1.All.pdf	pdf	Wake Surveys - Near Bed Echo Intensity Summary - Flood Tide	May-07	1	
	Appendix B2-CS0195.B2.All.pdf	pdf	Wake Surveys - Near Bed Echo Intensity Summary - Ebb Tide	May-07	1	
	Appendix C1-CS0195.C1.All.pdf	pdf	Wake Surveys - Near Bed Echo Intensity Summary - Flood Tide	May-07	1	
	Appendix C2-CS0195.C2.All.pdf	pdf	Wake Surveys - Near Bed Echo Intensity Summary - Ebb Tide	May-07	1	
	C6023Areport-rev01.pdf	pdf	Post Construction Geophysical Survey Final Report	Feb-07	125	
	C7007a-report-rev02.pdf	pdf	Post Construction Geophysical Survey Final Report	Aug-07	103	
	CS0195 Barrow Wakes Study Final Report.pdf	pdf	Turbine Wake Study Report	Jun-07	27	
	CS0195 Cover.pdf	pdf	Front cover of Turbine Wake Study Report CS0195	Jun-07	2	
Monitoring\Post Construction\Scour	C6023b-01.pdf	pdf	Scour Monitoring Survey Trackplot & Turbine Location	Feb-07	1	
	C6023Breport-rev01.pdf	pdf	Scour Monitoring Geophysical Survey Final Report	Feb-07	126	
	C7007b-report-rev01.pdf	pdf	Scour Monitoring Geophysical Survey Final Report	Aug-07	84	
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	Figure B*.pdf * = 1 to 8	pdf	Scour Monitoring - Turbine B1 to B8		1 each	
	Figure C*.pdf * = 1 to 7	pdf	Scour Monitoring - Turbine C1 to C7		1 each	
	Figure D*.pdf * = 1 to 8	pdf	Scour Monitoring - Turbine D1 to D8		1 each	
	Turbine A* Sections.pdf * = 1 to 7	pdf	C6023b Scour Monitoring - Turbine A1 to A7		1 each	
	Turbine B* Sections.pdf * = 1 to 8	pdf	C6023b Scour Monitoring - Turbine B1 to B8		1 each	
	Turbine C* Sections.pdf *	pdf	C6023b Scour Monitoring -		1 each	

	= 1 to 7		Turbine C1 to C7			
	Turbine D* Sections.pdf * = 1 to 8	pdf	C6023b Scour Monitoring - Turbine D1 to D8		1 each	
	Monitoring_Report_Full_2009.pdf	pdf	2009 Post Construction Monitoring Report	Jan-09	38	
	Scour_Monitoring_C7039.pdf	pdf	Cable Route Inspection & Scour Monitoring Survey - June 2008	Jun-08	92	
	Scour_Monitoring_C8016.pdf	pdf	Cable Route Inspection & Scour Monitoring Survey - September 2008	Sep-08	113	
Other	01_2007 benthic survey report_complete.pdf	pdf	Benthic & Sediment Survey: Comparitive Analysis of Pre- and Post- Construction Benthic and Sedimentological Data	Nov-07	96	
	AppD_9 x 13 cm.pdf	pdf	Photos of grab samples		15	
	barrow_factsheet.pdf	pdf	Factsheet		2	
	Barrow_Location.pdf	pdf	Location of development	May-05	2	
	barrow_newsletter.pdf	pdf	Newsletter		2	

BEATRICE

Subfolder	Filename	File type	Short description	Date	Pages	Comments
Baseline\Reports\Environmental Statement	Appendix_1.pdf	pdf	Safety, Health & Environmental Policy	Dec-05	1	p333
	Appendix_2.pdf	pdf	Environmental Legislation Pertaining to Oil and Gas Developments on the UKCS	Dec-05	6	p335-340
	Appendix_3.pdf	pdf	Organisations Contacted	Dec-05	3	p341-343
		pdf	Landscape and Visual Impact Assessment	Dec-05	75	p345-419
	Contents.pdf	pdf	Contents page	Dec-05	4	p3-6
	Environmental_statement_all.pdf	pdf	Whole ES Document (low resolution)	Dec-05	422	
	Introduction.pdf	pdf	ES Information sheet	Dec-05	2	p1-2
	References.pdf	pdf	References	Dec-05	14	p317-330
	Section_1.pdf	pdf	1 Non-Technical Summary	Dec-05	20	p9-28
	Section_2.pdf	pdf	2 Introduction	Dec-05	8	p31-38
	Section_3.pdf	pdf	3 Description of the Demonstrator Project	Dec-05	22	p41-62
	Section_4.pdf	pdf	4 Description of the Environmental Setting	Dec-05	68	p65-132
	Section_5.pdf	pdf	5 Project Consultation	Dec-05	16	p135-150
	Section_6.pdf	pdf	6 Scoping Potential Environmental Impacts	Dec-05	14	p153-166
	Section_7.pdf	pdf	7 Effects of Assembly at Onshore Location	Dec-05	4	p169-172
	Section_8.pdf	pdf	8 Effects on the Seabed and	Dec-	8	p175-182

			Marine Ecosystems	05		
	Section_9.pdf	pdf	9 Potential Impacts of Underwater Noise and Vibration	Dec-05	20	p185-204
	Section_10.pdf	pdf	10 Effects of the Demonstrator Project on Birds	Dec-05	24	p207-230
	Section_11.pdf	pdf	11 Landscape and Seascape Visual Impact Assessment	Dec-05	10	p233-242
	Section_12.pdf	pdf	12 Effects on Other Users of the Marine Environment	Dec-05	30	p245-274
	Section_13.pdf	pdf	13 Effects on Special Areas of Conservation and Special Protection Areas	Dec-05	20	p277-296
	Section_14.pdf	pdf	14 Environmental Management	Dec-05	4	p299-302
Baseline\Reports\Environmental Statement\Figures	fig*.jpg * = 1 to 18	jpg	Figures in ES		1 each	
Other	Beatrice Wind Farm Demonstrator Project - Welcome	htm	Internet shortcut			
	BEATRICE_WINDFARM.pdf	pdf	Non technical information about demonstrator project		6	
	Scoping_doc.pdf	pdf	Scoping Report		57	

BLYTH

Subfolder	**Filename**	**File type**	**Short description**	**Date**	**Pages**	**Comments**
Other	doc_01.pdf	pdf	Paper on Load Measurements on a 2MW Offshore Wind Turbine in the North Sea	5		
	file20295.pdf	pdf	Report on Blyth Harbour Wind Farm - Operational Aspects	2004	21	
	file20489.pdf	pdf	Report on Offshore Wind Turbines and Bird Activity at Blyth	2005	26	
	report_020.pdf	pdf	Design Methods for Offshore Wind Turbines at Exposed Sites	Nov-03	71	
	W3500563R1.pdf	pdf	Report 1 on Monitoring & Evaluation of Blyth Offshore Wind Farm - Installation and Commissioning	2001	57	
	W3500563R2.pdf	pdf	Report 2 on Monitoring & Evaluation of Blyth Offshore Wind Farm - Navaid Requirements for UK Offshore Wind Farms	2001	20	
	W3500563R3.pdf	pdf	Report 3 on Monitoring & Evaluation of Blyth Offshore Wind Farm - Projected Capital Costs of UK Offshore Wind Farms Based on the Experience at Blyth	2001	19	
	W3500563R4.pdf	pdf	Report 4 on Monitoring & Evaluation of Blyth Offshore Wind Farm - Health and Safety Guidelines	2001	34	
	W3500563R5.pdf	pdf	Report 3 on Monitoring & Evaluation of Blyth Offshore Wind Farm - Projected	2004	13	

			Operation and Maintenance Costs of UK Offshore Wind Farms Based on the Experience at Blyth			

BURBO BANK

Subfolder	**Filename**	**File type**	**Short description**	**Date**	**Pages**	**Comments**
Baseline\Data\Aquatech Survey Sediment Data	Burbo Grab lat longs.xls	xls	Grab survey data	Apr-02		
	PSA Analysis.xls	xls	PSA analysis data	May-02		
	Summary Burbo Flats PSA Data.xls	xls	Statistical summary of PSA data	May-02		
Baseline\Data\Gardline Liverpool Bay Monitoring Reports CS0038_Data\Final Report	BB1_Dep5_Tide_Current.csv	csv	Tide and current monitoring data - site BB1	Sep-02		
	BB1_Dep5_Waves.csv	csv	Wave monitoring data - site BB1	Sep-02		
	BB2_Dep5_Tide_Current.csv	csv	Tide and current monitoring data - site BB2	Sep-02		
	BB2_Dep5_Waves.csv	csv	Wave monitoring data - site BB2	Sep-02		
	Burbo Bank_psa-16_4_02.pdf	pdf	PSA analysis data	Apr-02	4	
	Burbo Bank_psa-7_2_02.pdf	pdf	PSA analysis data	Apr-02	12	
	Deployment.doc	doc	Deployment Report for Wave, Tide and Current Monitoring Sites	Jan-02	2	
	Samples results.xls	xls	PSA sampling results	May-02		
Baseline\Data\Gardline Liverpool Bay Monitoring Reports CS0038_Data\Interim Report1	BB1_Dep2_Orbital_Current_Stats.csv	csv	Tide and current monitoring data - site BB1	Mar-02		
	BB1_Dep2_Tides&Currents.csv	csv	Tide and current monitoring data - site BB1	Mar-02		
	BB1_Dep2_Waves_Stats.csv	csv	Wave monitoring data - site BB1	Mar-02		
	BB2_Dep2_Oribital_Current_Stats.csv	csv	Tide and current monitoring data - site BB2	Mar-02		
	BB2_Dep2_Tides&Currents_Turbidity.csv	csv	Tide and current monitoring data - site BB2	Mar-02		
	BB2_Dep2_Waves_Stats_&_FTU_Stats.csv	csv	Wave monitoring data - site BB2	Mar-02		
	Notes for Data Files.doc	doc	Notes for tide, current & wave monitoring data	Mar-02	1	
Baseline\Data\Gardline Liverpool Bay Monitoring Reports CS0038_Data\Interim Report2	BB1_Dep1_Tides_Currents.csv	csv	Tide and current monitoring data - site BB1	Jun-02		
	BB1_Dep1_Waves.csv	csv	Wave monitoring data - site BB1	Jun-02		
	BB1_Dep3_Tides_Currents.csv	csv	Tide and current monitoring data - site BB1	Jun-02		
	BB1_Dep3_Waves.csv	csv	Wave monitoring data - site BB1	Jun-02		

	BB2_Dep1_Tides_Currents.csv	csv	Tide and current monitoring data - site BB2	Jun-02		
	BB2_Dep1_Waves.csv	csv	Wave monitoring data - site BB2	Jun-02		
	BB2_Dep3_Tides_Currents.csv	csv	Tide and current monitoring data - site BB2	Jun-02		
	BB2_Dep3_Waves.csv	csv	Wave monitoring data - site BB2	Jun-02		
Baseline\Data\Gardline Liverpool Bay Monitoring Reports CS0038_Data\Interim Report3	BB1_Dep4_Tides_Currents.csv	csv	Tide and current monitoring data - site BB1	Jul-02		
	BB1_Dep4_Waves.csv	csv	Wave monitoring data - site BB1	Jul-02		
	BB2_Dep4_Tides_Currents.csv	csv	Tide and current monitoring data - site BB2	Jul-02		
	BB2_Dep4_Waves.csv	csv	Wave monitoring data - site BB2	Jul-02		
Baseline\Reports\	Coastal Process Study R962.pdf	pdf	Report on Coastal Process Study	Sep-02	152	
	Titan Geophys Study CS0038 Report.doc	doc	Draft Report on Burbo Bank Offshore Wind Farm Geophysical Survey	May-02	33	
Baseline\Reports\Coastal Process Study_Figs	figure-*rot.jpg * = 01 to 06, 26 to 29, 34 to 36, 38, 40 to 42	jpg	Figures in Coastal Processes Study R962	Aug-02		
Baseline\Reports\Environmental Statement	BurboVol_2_0Contents.pdf	pdf	Contents & Glossary	Sep-02	12	
	BurboVol_2_1Introduction.pdf	pdf	Introduction	Sep-02	8	p1-8
	BurboVol_2_2Description.pdf	pdf	Project Description	Sep-02	22	p9-30
	BurboVol_2_3Policy.pdf	pdf	Regulatory and Policy Context	Sep-02	12	p31-42
	BurboVol_2_4Physical.pdf	pdf	Physical Environment	Sep-02	52	p43-94
	BurboVol_2_5Biological.pdf	pdf	Biological Environment	Sep-02	94	p95-188
	BurboVol_2_6Human.pdf	pdf	Human Environment	Sep-02	52	p189-240
	BurboVol_2_7Visual.pdf	pdf	Visual Environment	Sep-02	22	p241-262
	BurboVol_2_8Onshore.pdf	pdf	Onshore Environment	Sep-02	26	p263-288
	BurboVol_2_9References.pdf	pdf	References	Sep-02	24	p289-312
	Non Technical Summary.pdf	pdf		Sep-02	18	
Baseline\Reports\Environmental Statement\Appendices	BurboAppVol4APhysical.pdf	pdf	Coastal Process Study	Sep-02	152	
	BurboAppVol4BBirds.pdf	pdf	Ornithology Final Report	Sep-02	90	
	BurboAppVol4CMarine.pdf	pdf	Marine Ecology	Aug-02	134	
	BurboAppVol4Contents.pdf	pdf	Contents page	Sep-02	4	
	BurboAppVol4DFisheries.pdf	pdf	Report on Commercial Fisheries	Sep-02	22	
	BurboAppVol4ENavigation.p	pdf	Navigation Risk Assessment	Aug-	94	

	df			02		
	BurboAppVol4FArchaelogy.pdf	pdf	Archaeological Report	Aug-02	62	
	BurboAppVol4GLandscape.pdf	pdf	Seascape and Visual Assessment	Jul-02	138	
Baseline\Reports\Gardline Liverpool Bay Monitoring Reports CS0038	Gardline Final Report CS0038.doc	doc	Wave, Tide and Current Monitoring - Final Report with processed data	Dec 01 - Aug 2002	29	
	Gardline Interim Report1 CS0038.doc	doc	Wave, Tide and Current Monitoring - Interim Report No.1 with processed data	Jan - Mar 2002	19	
	Gardline Interim Report2 CS0038.doc	doc	Wave, Tide and Current Monitoring - Interim Report No.2 with processed data	Dec 01 - Jan 2002 & Mar - April 2002	21	
	Gardline Interim Report3 CS0038.doc	doc	Wave, Tide and Current Monitoring - Interim Report No.3 with processed data	Apr - June 2002	17	
Baseline\Reports\Gardline Liverpool Bay Monitoring Reports CS0038\Final Report CS0038_Figs	Coverage.xls	xls	Deployment summary	Sep-02		
	Figure *.wmf ** = 19 to 76*	wmf	Time series graphs for each deployment	Sep-02		
	Figures.ppt	ppt	Figures in report	Sep-02		
	Table*.xls ** = 06, 07, 10 to 13*	xls	Frequency distribution tables for each deployment	Sep-02		
Baseline\Reports\Gardline Liverpool Bay Monitoring Reports CS0038\Interim Report1 CS0038_Figs	AllPlots.ppt	ppt	Figures in report	Mar-02		
	Fig**.wmf ** = 03 to 53*	wmf	Time series graphs for each deployment	Mar-02		
	Table*.xls ** = 08 to 13*	xls	Frequency distribution tables for each deployment	Mar-02		
	Tables4-7.doc	doc	Harmonic Analysis Report	Mar-02		
Baseline\Reports\Gardline Liverpool Bay Monitoring Reports CS0038\Interim Report2 CS0038_Figs	Figure *.wmf **= 3 to 110*	wmf	Time series graphs for each deployment	Jun-02		
	Table_*.doc **=4 to 7 and 14 to 17*	doc	Harmonic Analysis Report	Jun-02		
	Table_*.xls ** = 8 to 13 and 18 to 22*	xls	Frequency distribution tables for each deployment	Jun-02		
Baseline\Reports\Gardline Liverpool Bay Monitoring Reports CS0038\Interim Report3 CS0038_Figs	Figure *.wmf **= 3 to 48*	wmf	Time series graphs for each deployment	Jul-02		
	Figures.ppt	ppt	Figures in report	Jul-02		
	Table *.doc **=4 to 7*	doc	Harmonic Analysis Report	Jul-02		
	Table *.xls ** = 8 to 11*	xls	Frequency distribution tables for each deployment	Jul-02		
Baseline\Reports\Titan Geophys Study CS0038 Report_Figs	boomer Data Ex *.jpg **=6 and 7*	jpg	Boomer data extract	Jun-02		
	ES Data Ex *.jpg	jpg	Echosounder data extract	Jun-02		
	SSS Data Ex *.jpg	jpg	Siodescan Sonar data extract	Jun-02		

Monitoring\Post Construction\Combination	Burbo Yr1 Post-construction Monitoring Reportv2.pdf	pdf	Post construciton Year 1 Monitoring Report - final version	Dec-08	44	Year 2 report to be issued soon
Monitoring\Post Construction\Scour\C6032 DraftReport	C6032-Report.pdf	pdf	Rock Armour Post_lay Inspection Survey Report	Dec-06	72	
Monitoring\Post Construction\Scour\C6032 _XYZ_Data	BB* 0_5m Rev1.xyz **= 12 to 42*	XYZ	XYZ text files	Dec-06		

GENERAL

Subfolder	Filename	File type	Short description	Date	Pages	Comments
Non COWRIE	Cabling Techniques.pdf	pdf	Review of Cabling Techniques and Environmental Effects Applicable to the Offshore Wind Farm Industry - Technical Report	Jan-08	164	BERR
	Dynamics of Scour Pits.pdf	pdf	Dynamics of scour pits and scour protection - Synthesis report and recommendations	Dec-08	98	DECC
	w3500596.pdf	pdf	Potential Effects of Offshore Wind Developments on Coastal Processes	2002	127	
	Ind 31522.pdf	pdf	Best Practice Guidelines: Consultation for Offshore Wind Energy Developments	2002	32	BWEA
	Ind 31639.pdf	pdf	Methodology for Assessing the Marine Navigational Safety Risks of Offshore Wind Farms	Nov-05	160	Guidance on Assessment of the Impact of OWF (DTI)
	Ind 31641.pdf	pdf	Seascape and Visual Impact Report	Nov-05		
	Ind 31798.pdf	pdf	Sand banks, sand transport and offshore wind farms	Jul-04	69	

GREATER GABBARD

Subfolder	Filename	File type	Short description	Date	Pages	Comments
Baseline\Data	Emu_Data_received_on_Gabbard.doc	doc	The type, date and location of data collected by Emu		1	
	GGOWL Data Return Matrix.xls	xls	GGOWL Data Return Matrix, including the type, date and location of the collected data			
Baseline\Data\Bathy	conversion for DAP 160205.doc	doc	Geodetic Calculator - Coordinate Transformation Summary Report		1	
	GGOWL_Titan_survey_wgs84dd_xyz.txt	txt	text file XYZ data			
	GGOWL_Titan_survey_wgs84dd_xyz_OSGB.txt	txt	text file XYZ data			
	Titan_survey_datum_corrected.txt	txt	text file XYZ data			
	data_note.txt	txt	Data conversion note			
	J1020805_MainSiteEast_2m.xyz	XYZ	XYZ text file			

	J1020805_MainSiteWest_2m.xyz	XYZ	XYZ text file			
	J1020805_Transects_2m.xyz	XYZ	XYZ text file			
	J1020805_WestSite_2m.xyz	XYZ	XYZ text file			
Baseline\Data\GGOWL Turbidity Data	Final postitions.txt	txt	Final Sampling Positions			
Baseline\Data\GGOWL Turbidity Data\GG1	GG1_turbidity_data.xls	xls	Metocean Deployment 1: GG1 Winter 2004-2005 Data			
	GG_G1_D1_SSC.csv	csv	Deployment 1: GG1 SSC Data			
	GG_G1_D1_Turb_Raw.csv	csv	Deployment 1: GG1 Raw Turbidity Data			
	GG_G1_D1_Turb_Raw_Db.csv	csv	Deployment 1: GG1 Raw Turbidity Data			
	GG_G1_YSI_D1.csv	csv	Deployment 1: GG1 Data			
Baseline\Data\GGOWL Turbidity Data\GG2	GG2_turbidity_data.xls	xls	Metocean Deployment 1: GG2 Winter 2004-2005 Data			
	GG_G2_D1_SSC.csv	csv	Deployment 1: GG2 SSC Data			
	GG_G2_D1_Turb_Raw.csv	csv	Deployment 1: GG2 Raw Turbidity Data			
	GG_G2_D1_Turb_Raw_Db.csv	csv	Deployment 1: GG2 Raw Turbidity Data			
	GG_G2_YSI_D1.csv	csv	Deployment 1: GG2 Data			
Baseline\Data\GGOWL Turbidity Data\GG3	GG3_turbidity_data.xls	xls	Metocean Deployment 1: GG3 Winter 2004-2005 Data			
	GG_G3_D1_Turb_Raw.csv	csv	Deployment 1: GG3 Raw Turbidity Data			
	GG_G3_D1_Turb_Raw_Db.csv	csv	Deployment 1: GG3 Raw Turbidity Data			
Baseline\Data\GGOWL Turbidity Data\GG4	GG4_turbidity_data.xls	xls	Metocean Deployment 1: GG4 Winter 2004-2005 Data			
	GG_G4_D1_Turb_Raw.csv	csv	Deployment 1: GG4 Raw Turbidity Data			
	GG_G4_D1_Turb_Raw_Db.csv	csv	Deployment 1: GG4 Raw Turbidity Data			
Baseline\Data\GGOWL Turbidity Data\GG6	GG6_turbidity_data.xls	xls	Metocean Deployment 1: GG6 Winter 2004-2005 Data			
	GG_G6_D1_SSC.csv	csv	Deployment 1: GG6 SSC Data			
	GG_G6_D1_Turb_Raw.csv	csv	Deployment 1: GG6 Raw Turbidity Data			
	GG_G6_D1_Turb_Raw_Db.csv	csv	Deployment 1: GG6 Raw Turbidity Data			
	GG_G6_YSI_D1.csv	csv	Deployment 1: GG6 Data			
Baseline\Data\Reports	BGS Rep CR-04-168b_final.pdf	pdf	OWF Study: A Geological Review	2005	26	
	GG_Ocean_Survey_Spec.pdf	pdf	Oceanographic Survey Specification	Jun-04	12	
Baseline\Reports\Marine Survey Project - EMU Ltd Drawings	J1020805_01a.pdf	pdf	Seismic Trackplot 1 of 6	Jul-05	1	
	J1020805_01b.pdf	pdf	Seismic Trackplot 2 of 6	Jul-05	1	
	J1020805_01c.pdf	pdf	Seismic Trackplot 3 of 6	Jul-05	1	
	J1020805_01d.pdf	pdf	Seismic Trackplot 4 of 6	Jul-05	1	
	J1020805_01e.pdf	pdf	Seismic Trackplot 5 of 6	Jul-05	1	
	J1020805_01f.pdf	pdf	Seismic Trackplot 6 of 6	Jul-05	1	

	J1020805_02a.pdf	pdf	Bathymetry 1 of 6	Jul-05	1	
	J1020805_02b.pdf	pdf	Bathymetry 2 of 6	Jul-05	1	
	J1020805_02c.pdf	pdf	Bathymetry 3 of 6	Jul-05	1	
	J1020805_02d.pdf	pdf	Bathymetry 4 of 6	Jul-05	1	
	J1020805_02e.pdf	pdf	Bathymetry 5 of 6	Jul-05	1	
	J1020805_02f.pdf	pdf	Bathymetry 6 of 6	Jul-05	1	
	J1020805_03.pdf	pdf	Seabed Features	Jul-05	1	
	J1020805_04a.pdf	pdf	Sediment Isopachs 1 of 6	Jul-05	1	
	J1020805_04b.pdf	pdf	Sediment Isopachs 2 of 6	Jul-05	1	
	J1020805_04c.pdf	pdf	Sediment Isopachs 3 of 6	Jul-05	1	
	J1020805_04d.pdf	pdf	Sediment Isopachs 4 of 6	Jul-05	1	
	J1020805_04e.pdf	pdf	Sediment Isopachs 5 of 6	Jul-05	1	
	J1020805_04f.pdf	pdf	Sediment Isopachs 6 of 6	Jul-05	1	
	J1020805_05a.pdf	pdf	Depth to top of London Clay 1 of 6	Jul-05	1	
	J1020805_05b.pdf	pdf	Depth to top of London Clay 2 of 6	Jul-05	1	
	J1020805_05c.pdf	pdf	Depth to top of London Clay 3 of 6	Jul-05	1	
	J1020805_05d.pdf	pdf	Depth to top of London Clay 4 of 6	Jul-05	1	
	J1020805_05e.pdf	pdf	Depth to top of London Clay 5 of 6	Jul-05	1	
	J1020805_05f.pdf	pdf	Depth to top of London Clay 6 of 6	Jul-05	1	
	J1020805_06a.pdf	pdf	Profiles Main Site 1 of 3	Jul-05	1	
	J1020805_06b.pdf	pdf	Profiles Main Site 2 of 3	Jul-05	1	
	J1020805_06c.pdf	pdf	Profiles Main Site 3 of 3	Jul-05	1	
Other	geotech report.pdf	pdf	Geotechnical Soil Investigation	May-04	39	
	cpt graph IGN rev1.xls	xls	GGOWF Inner Gabbard North Cone Data	Sep-04		

GUNFLEET SANDS

Subfolder	**Filename**	**File type**	**Short description**	**Date**	**Pages**	**Comments**
Other	Gunfleet Sands Leaflet.pdf	pdf	Onshore Construction Leaflet		2	
	BH_DP 010510 GH report.pdf	pdf	Assessment of the Proposed Gunfleet Sand Offshore Project	May-00	41	

HORNS REV

Subfolder	**Filename**	**File type**	**Short description**	**Date**	**Pages**	**Comments**
Baseline\Reports	EIA of Hydrography.pdf	pdf	Environmental Impact Assessment of Hydrography	Dec-99	50	
	Review_2002_EIA.pdf	pdf	Environmental Impact Assessment and Monitoring 2002	Feb-02	42	

	Env Monitoring 2001.pdf	pdf	Annual Status Report for the Environmental Monitoring Programme (1st Jan 01 - 31st Dec 01)	Oct-02	49	
	Memorandum_Baseline_surveys_2001.pdf	pdf	Introducing hard substrate habitats Baseline Survey 2001	Aug-02	9	
Monitoring\Post Construction\Combination	Env Monitoring 2003.pdf	pdf	Annual Status Report for the Environmental Monitoring Programme (1st Jan 03 - 31st Dec 03)	Jun-04	73	
	Env Monitoring 2004.pdf	pdf	Annual Status Report for the Environmental Monitoring Programme (1st Jan 04 - 31st Dec 04)	Jul-05	96	
	Review_2003_EIA.pdf	pdf	Environmental Impact Assessment and Monitoring 2003	Sep-03	72	
	Review_2005_EIA.pdf	pdf	Environmental Impact Assessment and Monitoring 2005	Nov-06	150	
	Infauna Monitoring 2003.pdf	pdf	Infauna Monitoring Annual Status Report 2003	May-04	61	
	Infauna Monitoring 2004.pdf	pdf	Infauna Monitoring Annual Status Report 2004	Apr-05	64	
Other	Status_Investigations_on_the_artificial_reef.pdf	pdf	Investigations on the artificial reef effect on fish from marine wind turbine park at Horns Reef	Jan-02	12	
	EIA on Birds.pdf	pdf	Effects on birds of an offshore wind park at Horns Rev: Environmental Impact Assessment	2000	112	
	Progress Report.pdf	pdf	Progress Report (1st Jan - 30th June 02)	Jun-02	2	
	Progress_memornadum_2.pdf	pdf	Control and monitoring programme - Artificial Reef: Progress memorandum 2	Jan-02	9	
	Progress_memorandum_3.pdf	pdf	Control and monitoring programme - Hard Bottom Substrate: Progress memorandum 3	Jul-02	4	
	Seabird Surveys.pdf	pdf	Status report of seabird surveys at Horns Rev, 2000-2001	2002	26	

KENTISH FLATS

Subfolder	**Filename**	**File type**	**Short description**	**Date**	**Pages**	**Comments**
Baseline\Report	Kentish Flats Environmental Statement	pdf	Environmental Statement & Technical Addendum	Aug/Nov-02	430	
Monitoring\Post Construction\Combination\FEPA	KF_FEPA_2009_Monitoring Summary.pdf	pdf	FEPA Monitoring Summary Report	Mar-09	74	
Other	Factsheet	pdf	Kentish Flats Factsheet		8	
Other	BWEA_Radar	pdf	Investigation of Technical and Operational Effects on Marine Radar Close to Kentish Flats Offshore Wind Farm	Apr-07	57	

LYNN & INNER DOWSING						
Subfolder	**Filename**	**File type**	**Short description**	**Date**	**Pages**	**Comments**
Baseline\Data\Pre-Construction Marine Geophysical EMU	J.1.02.0368.015.pdf	pdf	Seabed Features Box 3	Feb-02	1	
	J.1.02.0368.023.pdf	pdf	Seabed Features Box 4	Feb-02	1	
	Maag anomalies 01180D2272-01.pdf	pdf	Magnetic Anomalies	Apr-07	1	
	Maag anomalies 01180D2274-02.pdf	pdf	Magnetic Anomalies	Apr-07	1	
	Maag anomalies 01180D2275-01.pdf	pdf	Magnetic Anomalies	Apr-07	1	
	J.1.02.0368.008.dwg	dwg	DWG File			
	J.1.02.0368.015.dwg	dwg	DWG File			
	J.1.02.0368.017.dwg	dwg	DWG File			
	J.1.02.0368.023.dwg	dwg	DWG File			
	target_points.dwg	dwg	DWG File			
Baseline\Reports	Coastal Processes Report.pdf	pdf	Lincolnshire Wind Farms: Coastal Processes Final Report	Feb-03	27	
	Non Technical Summary.pdf	pdf	Non Technical Summary		18	
Monitoring\During Construction\ADCP Data	CS0108 Lynn & Inner Dowsing Site 1 Current Data ReportV1.pdf	pdf	Current Data Report: During Construction - Site 1 (12/06/2007 - 14/07/2007)	Nov-07	28	Titan Environmental Surveys
	Site1_Data.txt	txt	Site 1 Data	2007		
	Site1_Data Averaged.txt	txt	Site 1 Data	2007		
	Site1_Header.txt	txt	Site 1 Data	2007		
	Site1_Near_Bed_Data.txt	txt	Site 1 Data	2007		
	Site1_Near_Surface_Data.txt	txt	Site 1 Data	2007		
	System_1_Data Time Series Averaged.wmf	wmf	Site 1 Data Output	2007	1	
	System_1_File Summary.txt	txt	Site 1 Data Output	2007		
	System_1_Summary.doc	doc	Site 1 Data Output	2007	1	
	System_1_Summary.wmf	wmf	Site 1 Data Output	2007	1	
	System_1_Time Series Averaged.doc	doc	Site 1 Data Output	2007	1	
	CS0108 Lynn & Inner Dowsing Site 2 Current Data ReportV1.pdf	pdf	Current Data Report: During Construction - Site 1 (12/06/2007 - 12/07/2007)	Nov-07	28	Titan Environmental Surveys
	Site2_Data.txt	txt	Site 2 Data	2007		
	Site2_Data Averaged.txt	txt	Site 2 Data	2007		
	Site2_Header.txt	txt	Site 2 Data	2007		
	Site2_Near_Bed_Data.txt	txt	Site 2 Data	2007		
	Site2_Near_Surface_Data.txt	txt	Site 2 Data	2007		
	System_2_Data Time Series Averaged.wmf	wmf	Site 2 Data Output	2007	1	
	System_2_File Summary.txt	txt	Site 2 Data Output	2007		
	System_2_Summary.doc	doc	Site 2 Data Output	2007	1	
	System_2_Summary.wmf	wmf	Site 2 Data Output	2007	1	
	System_2_Time Series Averaged.doc	doc	Site 2 Data Output	2007	1	

	CS0108 Lynn & Inner Dowsing Site 3 Current Data ReportV1.pdf	pdf	Current Data Report: During Construction - Site 1 (12/06/2007 - 15/07/2007)	Nov-07	31	Titan Environmental Surveys
	Site3_Data.txt	txt	Site 3 Data	2007		
	Site3_Data Averaged.txt	txt	Site 3 Data	2007		
	Site3_Header.txt	txt	Site 3 Data	2007		
	Site3_Near_Bed_Data.txt	txt	Site 3 Data	2007		
	Site3_Near_Surface_Data.txt	txt	Site 3 Data	2007		
	System_3_Data Time Series Averaged.wmf	wmf	Site 3 Data Output	2007	1	
	System_3_File Summary.txt	txt	Site 3 Data Output	2007		
	System_3_Summary.doc	doc	Site 3 Data Output	2007	1	
	System_3_Summary.wmf	wmf	Site 3 Data Output	2007	1	
	System_3_Time Series Averaged.doc	doc	Site 3 Data Output	2007	1	
	CS0108 Lynn & Inner Dowsing Site 4 Current Data ReportV1.pdf	pdf	Current Data Report: During Construction - Site 1 (12/06/2007 - 12/07/2007)	Nov-07	28	Titan Environmental Surveys
	Site4_Data.txt	txt	Site 4 Data	2007		
	Site4_Data Averaged.txt	txt	Site 4 Data	2007		
	Site4_Header.txt	txt	Site 4 Data	2007		
	Site4_Near_Bed_Data.txt	txt	Site 4 Data	2007		
	Site4_Near_Surface_Data.txt	txt	Site 4 Data	2007		
	System_4_Data Time Series Averaged.wmf	wmf	Site 4 Data Output	2007	1	
	System_4_File Summary.txt	txt	Site 4 Data Output	2007		
	System_4_Summary.doc	doc	Site 4 Data Output	2007	1	
	System_4_Summary.wmf	wmf	Site 4 Data Output	2007	1	
	System_4_Time Series Averaged.doc	doc	Site 4 Data Output	2007	1	
Other	Ind 32174.pdf	pdf	IDOWF Wave Measurements (March to June 2004)	Jul-04	44	
	lynn_factsheet.pdf	pdf	Lynn & Inner Dowsing Fact Sheet		1	
	lynn_innerd_newsletter1009.pdf	pdf	Newsletter	2009	4	

NORTH HOYLE

Subfolder	Filename	File type	Short description	Date	Pages	Comments
Baseline\Reports	Marine Sediments.pdf	pdf	NHOWF Technical Assessment Report: Marine Sediments	Jan-02	53	
Monitoring\Post Construction\Combination\FEPA	NH_FEPA_2006-7_Chapter0.pdf	pdf	Final Annual FEPA Monitoring Report (2006-7) & Five Year Monitoring Programme Summary	Aug-08	3	
	NH_FEPA_2006-7_Chapter1.pdf	pdf	Final Annual FEPA Monitoring Report (2006-7) - Chapter 1: Executive Summary	Aug-08	11	
	NH_FEPA_2006-7_Chapter2.pdf	pdf	Final Annual FEPA Monitoring Report (2006-7) - Chapter 2: Introduction	Aug-08	1	

	NH_FEPA_2006-7_Chapter3.pdf	pdf	Final Annual FEPA Monitoring Report (2006-7) - Chapter 3: Background	Aug-08	2	
	NH_FEPA_2006-7_Chapter4.pdf	pdf	Final Annual FEPA Monitoring Report (2006-7) - Chapter 4: Marine Sediments	Aug-08	24	
	NH_FEPA_2006-7_Chapter5.pdf	pdf	Final Annual FEPA Monitoring Report (2006-7) - Chapter 5: Benthic Organisms	Aug-08	35	
	NH_FEPA_2006-7_Chapter6.pdf	pdf	Final Annual FEPA Monitoring Report (2006-7) - Chapter 6: Epifaunal and demersal fish	Aug-08	32	
	NH_FEPA_2006-7_Chapter7.pdf	pdf	Final Annual FEPA Monitoring Report (2006-7) - Chapter 7: Marine Fish	Aug-08	8	
	NH_FEPA_2006-7_Chapter8.pdf	pdf	Final Annual FEPA Monitoring Report (2006-7) - Chapter 8: Electromagnetic Fields	Aug-08	5	
	NH_FEPA_2006-7_Chapter9.pdf	pdf	Final Annual FEPA Monitoring Report (2006-7) - Chapter 9: Underwater Noise Vibration	Aug-08	14	
	NH_FEPA_2006-7_Chapter10.pdf	pdf	Final Annual FEPA Monitoring Report (2006-7) - Chapter 10: Ornithology	Aug-08	70	
	NH_FEPA_2006-7_Chapter11.pdf	pdf	Final Annual FEPA Monitoring Report (2006-7) - Chapter 11: Marine Mammals	Aug-08	19	
	NH_FEPA_2006-7_Chapter12.pdf	pdf	Final Annual FEPA Monitoring Report (2006-7) - Chapter 12: Concluding Statement	Aug-08	9	
Other	31windpower.pdf	pdf	Offshore wind farm prospecting	Aug-04	2	
	file41542.pdf	pdf	Capital Grant Scheme for the NHOWF: 2nd Annual Report (June 05 - June 06)	2006	10	
	file47340.pdf	pdf	Capital Grant Scheme for the NHOWF: 3rd Annual Report (June 06 - June 07)	2007	17	
	Offshore design parameters.pdf	pdf	Offshore Design Parameters	Jul-02	9	

NYSTED

Subfolder	Filename	File type	Short description	Date	Pages	Comments
Baseline/Reports	Review_2002_EIA.pdf	pdf	The Danish offshore wind farm demonstration project: EIA & Monitoring	Feb-02	42	
Monitoring\During Construction\Combination	Review_2003_EIA.pdf	pdf	The Danish offshore wind farm demonstration project: EIA & Monitoring	Sep-03	72	
Monitoring\Post Construction\Combination	Review_2004_EIA.pdf	pdf	The Danish offshore wind farm demonstration project: EIA & Monitoring	Oct-05	135	
	Review_2005_EIA.pdf	pdf	The Danish offshore wind farm demonstration project: EIA & Monitoring	Nov-06	150	
Other	24_0900_pervolund_01.pdf	pdf	165MW NOWF: First year of operation - performance as planned		8	
	havvindm_korr_16nov_UK.pdf	pdf	OWF and the Environment: Danish Experiences from Horns Rev and Nysted		41	

	ISC_Nysted_Transformer_Platform.pdf	pdf	NOWF Transformer Platform		7	
	nysted_technical_sheet.pdf	pdf	The construction of NOWF - Technical Sheet		16	

RHYL FLATS

Subfolder	Filename	File type	Short description	Date	Pages	Comments
Baseline\Data	AdmShift_CableRouteXYZ_2m.XYZ	XYZ	XYZ Text File			
	AdmShift_MainAreaIncCableXYZ_2m.XYZ	XYZ	XYZ Text File			
	FINAL 4009a Cable Route Filt NEG 10mBIN.XYZ	XYZ	XYZ Text File			
	f-6220-07-seaf-0.dgn	dgn	CAD Design File			
	f-6220-19-rte2-b.dgn	dgn	CAD Design File			
Baseline\Data\COWL ADCP	COWL RCM 2002 Rhyl Flats.xls	xls	COWL June/July-02 Survey Data			Titan Survey
	Susp Solids Results.xls	xls	COWL ADCP Suspended Sediment Results - Transects A&B			
	Transect A FS1.xls	xls	COWL ADCP Transect A Resullts: Site 1	Jun-02		
	Transect A FS2.xls	xls	COWL ADCP Transect A Resullts: Site 2	Jun-02		
	Transect A FS3.xls	xls	COWL ADCP Transect A Resullts: Site 3	Jun-02		
	Transect A FS4.xls	xls	COWL ADCP Transect A Resullts: Site 4	Jun-02		
	Transect A FS5.xls	xls	COWL ADCP Transect A Resullts: Site 5	Jun-02		
	Transect A FS6.xls	xls	COWL ADCP Transect A Resullts: Site 6	Jun-02		
	Transect A FS7.xls	xls	COWL ADCP Transect A Resullts: Site 7	Jun-02		
	Transect A FS8.xls	xls	COWL ADCP Transect A Resullts: Site 8	Jun-02		
	Transect B FS1.xls	xls	COWL ADCP Transect B Resullts: Site 1	Jun-02		
	Transect B FS2.xls	xls	COWL ADCP Transect B Resullts: Site 2	Jun-02		
	Transect B FS3.xls	xls	COWL ADCP Transect B Resullts: Site 3	Jun-02		
	Transect B FS4.xls	xls	COWL ADCP Transect B Resullts: Site 4	Jun-02		
	Transect B FS5.xls	xls	COWL ADCP Transect B Resullts: Site 5	Jun-02		
	Transect B FS6.xls	xls	COWL ADCP Transect B Resullts: Site 6	Jun-02		
	Transect B FS7.xls	xls	COWL ADCP Transect B Resullts: Site 7	Jun-02		
	Transect B FS8.xls	xls	COWL ADCP Transect B Resullts: Site 8	Jun-02		
Baseline\Data\COWL ADCP\Water Samples	*.000 Files (96 in total)	000	Water Samples (Compressed Files)			
Baseline\Reports	Constable Bank Windfarm	pdf	Geophysical Survey (Aug-Nov	Dec-	29	

	Geophysical Survey.pdf		01) - Text	01		
	Pre-Construction Survey Report Vol1 C5025B.pdf	pdf	Pre-Construction Survey (Aug 05): Vol 1	Dec-05	21	
	Pre-Construction Survey Report Vol2 C5025B.pdf	pdf	Pre-Construction Survey (Aug 05): Vol 2	Dec-05	70	
Baseline\Reports\EIA Report	EIA Inside Front Cover.pdf	pdf	Environmental Statement 2002: Front Cover	2002	1	
	EIA Volume 1 contents and team.pdf	pdf	Environmental Statement 2002: Contents	2002	5	
	EIA Volume I Non Technical Summary.pdf	pdf	Environmental Statement 2002: Non Technical Summary	2002	12	
	EIA Volume I Section 01.pdf	pdf	Environmental Statement 2002: Section 1	2002	15	
	EIA Volume I Section 02.pdf	pdf	Environmental Statement 2002: Section 2	2002	16	
	EIA Volume I Section 03.pdf	pdf	Environmental Statement 2002: Section 3	2002	25	
	EIA Volume I Section 04.pdf	pdf	Environmental Statement 2002: Section 4	2002	9	
	EIA Volume I Section 05.pdf	pdf	Environmental Statement 2002: Section 5	2002	9	
	EIA Volume II Section 06.pdf	pdf	Environmental Statement 2002: Section 6	2002	37	
	EIA Volume II Section 07.pdf	pdf	Environmental Statement 2002: Section 7	2002	107	
	EIA Volume II Section 08.pdf	pdf	Environmental Statement 2002: Section 8	2002	133	
	EIA Volume II Section 09.pdf	pdf	Environmental Statement 2002: Section 9	2002	9	
	EIA Volume III Section 10.pdf	pdf	Environmental Statement 2002: Section 10	2002	15	
	EIA Volume III Section 11.pdf	pdf	Environmental Statement 2002: Section 11	2002	27	
	EIA Volume III Section 12.pdf	pdf	Environmental Statement 2002: Section 12	2002	27	
	EIA Volume III Section 13.pdf	pdf	Environmental Statement 2002: Section 13	2002	4	
Baseline\Reports\EIA Report\Annexes	EIA Volume V - A Archaeology Annex FINAL.pdf	pdf	EIA Volume V - A Archaeology	2002	17	
	EIA Volume V - B Bethic Survey Results Annex FINAL.pdf	pdf	EIA Volume V - B Bethic Survey Results Annex	2002	11	
	EIA Volume V - C References FINAL.pdf	pdf	EIA Volume V - C References	2002	15	
	EIA Volume V - D Sound Propagation FINAL.pdf	pdf	EIA Volume V - D Sound Propagation	2002	59	
	EIA Volume V - E Terrestrial Ecology Annex FINAL.pdf	pdf	EIA Volume V - E Terrestrial Ecology	2002	26	
	EIA Volume V - F EME EH&S Annex FINAL.pdf	pdf	EIA Volume V - F EME EH&S	2002	4	
	EIA Volume V - G ornithology Annex FINAL.pdf	pdf	EIA Volume V - G Ornithology	2002	52	
	EIA Volume V - H Landscape and Visual Amenity FINAL.pdf	pdf	EIA Volume V - H Landscape and Visual Amenity	2002	23	
	EIA Volume V - I Airborne Noise Annex FINAL.pdf	pdf	EIA Volume V - I Airborne Noise	2002	41	
	EIA Volume V - J Planning Policies.pdf	pdf	EIA Volume V - J Planning Policies	2002	5	

	EIA Volume V - K SLVA Annex FINAL.pdf	pdf	EIA Volume V - K SLVA	2002	79	
	EIA Volume V - Index of Annexes FINAL.pdf	pdf	EIA Volume V - Index of Annexes	2002	1	
Baseline\Reports\EIA Report\Non Technical Summary	EIA Volume1 NTS - Stand Alond Version (COWL).pdf	pdf	RFOWF: Environmental Statement - Non Technical Summary	Mar-02	16	

ROBIN RIGG

Subfolder	Filename	File type	Short description	Date	Pages	Comments
Baseline\Reports	Environmental Statement.pdf	pdf	Environmental Statement: Supporting Applications for an OWF at Robin Rigg		331	Produced by Natural Power
	ES Non Technical Summary.pdf	pdf	Environmental Statement: Non Technical Summary		51	
Other	0006209.pdf	pdf	Electricity Act 1989 (Consent)		6	
	press_release.pdf	pdf	Press Release	Sep-09	2	
	rrp02-02.pdf	pdf	RROWF (Navigation & Fishing): (Scotland) Bill Committeee - Agenda	Nov-02	53	
	sb02-88.pdf	pdf	RROWF (Navigation & Fishing) (Scotland) Bill	Aug-02	24	

SCROBY SANDS

Subfolder	Filename	File type	Short description	Date	Pages	Comments
No new data since SED01						

THANET

Subfolder	Filename	File type	Short description	Date	Pages	Comments
Other	Decommissioning EIA.pdf	pdf	TOWF Decommissioning: Summary of Environmental Impact	May-07	13	
	Decommissioning Plan.pdf	pdf	Offshore Decommissioning Plan	May-08	33	

THORNTON BANK

Subfolder	Filename	File type	Short description	Date	Pages	Comments
Baseline\Reports	Environmental Impact Study (Dutch).pdf	pdf	Environmental Impact Study (in Dutch)	Sep-03	266	
	Non Techincal Summary (Dutch).pdf	pdf	Non Techincal Summary (in Dutch)	Sep-03	52	
Monitoring\During Construction\Scour	A_Bolle_biography.pdf	pdf	Presenting Author Biography for Annelies Bolle, Project	Sep-09	1	Author of Paper: "Scour

			Engineer at IMDC			Around Gravity-based Wind Turbine Foundations:Prototype Measurements"
	A_Bolle_paper.pdf	pdf	Paper: "Scour around gravity-based wind turbine foundations - prototype measurements"	Sep-09	12	
Other	497_EWEC2009.pdf	pdf	Turbine Installation - First 5 MW Turbines Summary		9	
	Monitoring_windmills_2009_final.pdf	pdf	MUMM and RBINS report presenting a compilation of results of monitoring activities throughout 2008	2009	327	
	Thornton Bank Sediment.doc	doc	CEFAS Report on Sediment Information from Thornton Bank		8	
	thornton bank.jpeg	jpeg	Turbine Sructure Image			