4 MARINE SEDIMENTS

4.1 SUBTIDAL

4.1.1 Introduction

An initial baseline benthic survey for the North Hoyle wind farm location and its surrounding sublittoral environment was undertaken during August 2001 by the Centre for Marine and Coastal Studies (then University of Liverpool, now CMACS Ltd). The baseline survey and subsequent annual monitoring have covered subtidal benthic ecology and marine sediments. Subtidal benthic ecology monitoring is described in Section 4; the following section describes the results sediment particle size analyses performed on benthic samples obtained through field survey by methods described in detail in Section 4 (Benthic Organisms).

4.1.2 Methods

4.1.2.1 Laboratory Analysis

4.1.2.1.1 Sediment analysis

In the laboratory all sediment samples were dried to a constant weight using ovens set at a temperature of 70^{o}C. The sediments were then analysed chemically for Total Organic Carbon (TOC) and physically for particle size analysis (PSA).

4.1.2.1.2 Chemical Analysis - Total Organic Carbon (TOC)

To analyse the TOC content of the marine sediments at each of the survey locations a small sample of approximately 5-10g of sediment was removed from each sample prior to particle size analysis. Dilute hydrochloric acid was then used to remove inorganic carbon such as carbonates from the sediment of <1mm. A Carlo Erba analyser was then used to determine the percentage of TOC within the sediment.

4.1.2.1.3 Physical analysis - Particle size analysis (PSA)

Sediments were sieved using a set of Endecott BS 410 test sieves on the following sieve fractions;9.5mm; 5.6mm; 4mm; 2mm;1mm; 600µm; 425µm; 300µm; 212µm; 150µm; 63µm meshes. Results from sieving allowed the calculation of mean and median particle sizes and the determination of a sorting index by calculating the standard deviation of Phi. These indices were then used to determine the sediment type. The classification system used to distinguish sediment type and the sorting index were carried out in accordance with the methods of Buchanan (1984) (Table 3.1 and Table 3.2) In addition, further classification was also made using the British Geological Survey Folk triangle classification system (Figure 3.1). As this was not undertaken in previous years the data sets from 2002 and 2003 were also classified to this system and the results are discussed within Section 3.1.

Wentworth Scale (mm)	Phi units	Sediment types
>256 mm	<-8	Boulders
64 - 256 mm	-8 to -6	Cobble
4 - 64 mm	-6 to -2	Pebble
2 - 4 mm	-2 to -1	Granule
1 - 2 mm	-1 to -0	Very coarse sand
0.5 - 1 mm	0 - 1	Coarse sand
250 - 500 µm	1 - 2	Medium sand
125 - 250 µm	2 - 3	Fine sand
63 - 125 µm	3 - 4	Very fine sand
<63 µm	>4	Silt

Table 4.1 Classification used for defining sediment type (from Buchanan, 1984)

Standard Deviation of mean Phi	Classification
<0.35	Very well sorted
0.35 - 0.5	Well sorted
0.5 - 0.71	Moderately well sorted
0.71 - 1	Moderately sorted
1 - 2	Poorly sorted
2 - 4	Very poorly sorted
>4	Extremely poorly sorted

Table 4.2 Classification used defining degree of sediment sorting (from Buchanan, 1984)

4.1.2 Results

4.1.2.1 Post-construction Survey Results (2004)

Overall, the sea bed within and around the North Hoyle wind farm is considered to be composed of fine and medium sands with varying amounts of coarser material. Eastwards from the array towards the mouth of the Dee estuary sediments are sandier and coarser areas are found further offshore and to the west of the development. The original site survey carried out in July and August of 2001 described the area of the wind farm itself as highly variable over even quite short distances, but consisting largely of sand and sandy gravels with varying amounts of stone and minor clay/silt content, depending upon location (CMACS 2002; Fugro-UDI Ltd, 2001).

4.1.1.2 Particle Size Analysis (PSA)

The results from the particle size analysis, following analysis according to the method of Buchanan (1984), are displayed in Table 3.3.

The results in Table 3.3 demonstrate that there was an even distribution of medium and coarse sand over the survey site. Medium sand was found on some inshore sites (8, 9 and 17) and several offshore sites (1, 2, 4, 11, 12, 15 and 19), with mean grain sizes between 0.25mm and 0.50mm. Coarse sand was also found at an inshore site (13) and some offshore sites (3, 5, 6, 7, 10, 18 and 20) with mean grain sizes between 0.57mm and 1.28mm. Two sites were dominated by fine sand: site 14 to the west of the survey area and site 16 to the east with mean grain sizes of 0.24mm for both sites. Silt was found in the samples at most sites but at site 16 made up more than 10% of the sediment. The high level of silt at this site most likely originates from the Dee estuary to the south. Many of the sites within and near to the turbine array had a high proportion of gravels or larger particles, especially sites 6 and 20.

Site	Mean phi	Mean mm	+/- 1 std	Skewness	Kurtosis	Classification after Buchanan	Folk Triangles after BGS
1	1.55	0.34	0.52	-0.16	1.61	Moderately well sorted medium sand	Slightly Gravelly Sand
2	1.64	0.32	0.41	-0.01	1.20	Well sorted medium sand	Slightly Gravelly Sand
3	0.37	0.77	1.31	-0.36	0.90	Poorly sorted coarse sand	Gravelly Sand
4	1.35	0.39	0.64	-0.27	1.47	Moderately well sorted medium sand	Slightly Gravelly Sand
5	0.81	0.57	1.12	-0.42	1.19	Poorly sorted coarse sand	Gravelly Sand
6	-0.61	1.53	2.40	-0.17	0.65	Very poorly sorted very coarse sand	Sandy Gravel
7	-0.26	1.20	1.65	0.25	0.67	Poorly sorted very coarse sand	Sandy Gravel
8	1.76	0.29	0.34	-0.11	0.75	Very well sorted medium sand	Sand
9	1.00	0.50	0.88	-0.43	1.04	Moderately sorted medium sand	Slightly Gravelly Sand
10	-0.17	1.13	1.54	-0.11	0.83	Poorly sorted very coarse sand	Sandy Gravel
11	1.68	0.31	0.37	0.04	0.93	Well sorted medium sand	Sand
12	1.98	0.25	0.37	0.14	2.24	Well sorted medium sand	Sand
13	0.04	0.97	2.32	-0.78	0.68	Very poorly sorted coarse sand	Gravelly Sand
14	2.05	0.24	0.48	0.23	2.10	Well sorted fine sand	Sand
15	1.31	0.40	0.73	-0.32	1.16	Moderately sorted medium sand	Slightly Gravelly Sand
16	2.06	0.24	0.92	-0.09	4.30	Moderately sorted fine sand	Gravelly Sand
17	1.81	0.28	0.53	-0.11	1.72	Moderately well sorted medium sand	Sand
18	-0.35	1.28	1.42	0.11	0.77	Poorly sorted very coarse sand	Sandy Gravel
19	1.19	0.44	0.95	-0.47	1.43	Moderately sorted medium sand	Gravelly Sand
20	-0.10	1.07	2.24	-0.58	0.67	Very poorly sorted very coarse sand	Sandy Gravel

Table 4.3 Summary Statistics for sediment data date from 2004 surveys

4.1.3 Comparison with Previous Surveys

A comparison of particle size analysis and sediment statistics between years is provided in Table 3.4. The seabed at some sites had changed sediment type between 2002 and 2004, some becoming dominated by finer sediment, some becoming dominated by coarser sediment and a few remaining the same. The sediments at sites 1, 15 and 17 were dominated by medium sand throughout the three surveys and site 17 had very uniform mean grain size between 2002, 2003 and 2004. Site 18 was dominated by very coarse sand in both years it was surveyed (2002 and 2003). Sites 2, 3 and 5 appeared to become coarser in 2003 and then finer again in 2004, sites 3 and 5 within the turbine array started as very coarse sand in 2002, became dominated by gravel and pebble in 2003 and then coarse sand in 2004. This reduction in the proportion of sandy sediment may have been as a result of wind farm construction or may have simply been the result of grab sampling what may be a patchy seabed in this area. The sediment at five sites became dominated by coarser sediment between 2002 and 2004; sites 6, 7 and 13 were all dominated by medium sand in 2002 and 2003 but in 2004 became dominated by coarse sand at site 13 and very coarse sand at 6 and 7. The seabed at site 9 changed from dominance by fine sand in 2002 and 2003 to dominance by medium sand in 2004 and site 10 changed from coarse sand in 2002 to very coarse sand in 2003 and 2004. The seabed at five sites changed from dominance by coarse sediment to finer sediment between 2002 and 2004. In 2002, site 4 had a seabed dominated by gravel, which changed to dominance by medium sand in 2003 and 2004. Sites 8 and 11 also started out with gravel as the dominant sediment in 2002, this became coarse sand at site 8 and medium sand at site 11 in 2003 and medium sand at both sites in 2004. The seabed at site 14 was dominated by pebble in 2002, gravel in 2003 and fine sand in 2004. Sites 19 and 20 were dominated by gravel in 2003 which changed to dominance by medium sand at site 19 and very coarse sand at site 20 in 2004.

Site	2002 Mean phi	2003 Mean phi	2004 Mean phi	2002 Mean mm	2003 Mean mm	2004 Mean mm	2002 +/-1 s.d.	2003 +/-1 s.d	2004 +/-1 s.d	2002 skewness	2003 skewness	2004 skewness	2002 kurtosis	2003 kurtosis	2004 kurtosis
1	1.17	1.51	1.55	0.44	0.35	0.34	0.85	0.49	0.52	-0.39	-0.08	-0.16	1.22	1.35	1.61
2	0.34	-0.19	1.64	0.79	1.14	0.32	1.92	2.27	0.41	-0.73	-0.76	-0.01	0.65	0.49	1.20
3	0.33	-1.28	0.37	0.79	2.43	0.77	1.34	1.48	1.31	-0.18	0.59	-0.36	0.78	1.04	0.90
4	-1.92	1.52	1.35	3.78	0.35	0.39	1.28	0.44	0.64	0.28	0.03	-0.27	1.50	1.08	1.47
5	-0.27	-2.39	0.81	1.20	5.23	0.57	1.86	1.54	1.12	0.07	0.50	-0.42	0.64	1.13	1.19
6	1.02	1.65	-0.61	0.49	0.32	1.53	1.94	0.33	2.40	-0.34	0.25	-0.17	1.52	0.86	0.65
7	1.58	1.63	-0.26	0.33	0.32	1.20	0.32	0.33	1.65	0.15	0.19	0.25	1.28	0.97	0.67
8	-1.55	-0.80	1.76	2.92	1.74	0.29	1.92	2.42	0.34	0.79	0.11	-0.11	3.51	0.50	0.75
9	2.22	2.25	1.00	0.21	0.21	0.50	0.37	0.42	0.88	0.09	0.21	-0.43	0.86	1.08	1.04
10	0.08	-0.97	-0.17	0.95	1.97	1.13	1.79	1.44	1.54	-0.06	0.07	-0.11	0.61	0.89	0.83
11	-1.90	1.78	1.68	3.73	0.29	0.31	1.41	0.43	0.37	0.49	-0.05	0.04	1.18	1.03	0.93
12	1.96	2.33	1.98	0.26	0.20	0.25	0.29	0.42	0.37	-0.09	-0.38	0.14	1.47	1.78	2.24
13	1.78	1.85	0.04	0.29	0.28	0.97	0.65	0.50	2.32	-0.20	0.11	-0.78	1.70	0.97	0.68
14	-2.78	-1.83	2.05	6.89	3.55	0.24	0.94	2.30	0.48	0.40	0.83	0.23	3.82	0.49	2.10
15	1.41	1.30	1.31	0.38	0.41	0.40	0.60	0.69	0.73	-0.28	-0.41	-0.32	2.04	1.94	1.16
16	1.60	1.73	2.06	0.33	0.30	0.24	0.86	0.45	0.92	-0.59	0.09	-0.09	1.69	1.07	4.30
17	1.86	1.84	1.81	0.28	0.28	0.28	0.57	0.45	0.53	-0.33	-0.15	-0.11	1.86	1.13	1.72
18	*	-0.83	-0.35	*	1.77	1.28	*	1.67	1.42	*	0.17	0.11	*	0.95	0.77
19	*	-1.14	1.19	*	2.20	0.44	*	1.61	0.95	*	0.25	-0.47	*	0.94	1.43
20	*	-1.09	-0.10	*	2.12	1.07	*	1.59	2.24	*	0.08	-0.58	*	0.95	0.67

Table 4.4 Summary Statistics for sediment data date from 2002, 2003 and 2004 surveys

Table 4.4 Continued

Site	2002 Classification after Buchanan	2003 Classification after Buchanan	2004 Classification after Buchanan	2002 Folk Triangles (BGS)	2003 Folk Triangles (BGS)	2004 Folk Triangles (BGS)
1	Moderately sorted medium sand	Well sorted medium sand	Moderately well sorted medium sand	Slightly Gravelly Sand	Sand	Slightly Gravelly Sand
2	Poorly sorted coarse sand	Very poorly sorted very coarse sand	Well sorted medium sand	Gravelly Sand	Sandy Gravel	Slightly Gravelly Sand
3	Poorly sorted coarse sand	Poorly sorted granule	Poorly sorted coarse sand	Gravelly Sand	Sandy Gravel	Gravelly Sand
4	Poorly sorted granule	Well sorted medium sand	Moderately well sorted medium sand	Gravel	Sand	Slightly Gravelly Sand
5	Poorly sorted very coarse sand	Poorly sorted pebble	Poorly sorted coarse sand	Sandy Gravel	Gravel	Gravelly Sand
6	Poorly sorted medium sand	Very well sorted medium sand	Very poorly sorted very coarse sand	Gravelly Sand	Sand	Sandy Gravel
7	Very well sorted medium sand	Very well sorted medium sand	Poorly sorted very coarse sand	Sand	Sand	Sandy Gravel
8	Poorly sorted granule	Very poorly sorted very coarse sand	Very well sorted medium sand	Gravel	Sandy Gravel	Sand
9	Well sorted fine sand	Well sorted fine sand	Moderately sorted medium sand	Sand	Sand	Slightly Gravelly Sand
10	Poorly sorted coarse sand	Poorly sorted very coarse sand	Poorly sorted very coarse sand	Sandy Gravel	Sandy Gravel	Sandy Gravel
11	Poorly sorted granule	Well sorted medium sand	Well sorted medium sand	Sandy Gravel	Sand	Sand
12	Very well sorted medium sand	Well sorted fine sand	Well sorted medium sand	Slightly Gravelly Sand	Sand	Sand
13	Moderately well sorted medium sand	Well sorted medium sand	Very poorly sorted coarse sand	Slightly Gravelly Sand	Slightly Gravelly Sand	Gravelly Sand
14	Moderately sorted pebble	Very poorly sorted granule	Well sorted fine sand	Gravel	Sandy Gravel	Sand
15	Moderately well sorted medium sand	Moderately well sorted medium sand	Moderately sorted medium sand	Slightly Gravelly Sand	Slightly Gravelly Sand	Slightly Gravelly Sand
16	Moderately sorted medium sand	Well sorted medium sand	Moderately sorted fine sand	Slightly Gravelly Sand	Slightly Gravelly Sand	Gravelly Sand
17	Moderately well sorted medium sand	Well sorted medium sand	Moderately well sorted medium sand	Slightly Gravelly Sand	Sand	Sand
18	*	Poorly sorted very coarse sand	Poorly sorted very coarse sand	*	Sandy Gravel	Sandy Gravel
19	*	Poorly sorted granule	Moderately sorted medium sand	*	Sandy Gravel	Gravelly Sand
20	*	Poorly sorted granule	Very poorly sorted very coarse sand	*	Sandy Gravel	Sandy Gravel

* = Not sampled

4.1.3.1 Total Organic Carbon (TOC)

The 2004 TOC analysis results are displayed in Table 3.5 alongside the results from the pre-installation 2002 and 2003 construction surveys. Sites 18,19 and 20 were new sites for 2003 and therefore no data was available for 2002.

Overall, the TOC levels for 2004 are broadly similar to those levels found during the previous surveys of 2003 and 2002 with some sites showing minor increases and others minor decreases. No overall difference between those sites located within the boundaries of the wind farm or those sites located in control areas can be identified.

Site no.	%TOC 2002	%TOC 2003	%TOC 2004
1	0.04	0.01	0.04
2	0.06	0.04	0.05
3	0.08	0.04	0.07
4	0.55	0.02	0.04
5	0.07	0.01	0.04
6	0.08	0.06	0.07
7	1.02	0.01	0.12
8	0.02	0.16	0.05
9	0.17	0.04	0.07
10	0.07	0.04	0.05
11	0.05	0.01	0.04
12	0.07	0.03	0.04
13	0.12	0.01	0.06
14	0.09	0.05	0.05
15	0.02	0.03	0.04
16	0.04	0.01	0.09
17	0.12	0.06	0.06
18	*	0.07	0.05
19	*	0.01	0.07
20	*	0.04	0.05

* = not surveyed in 2002

Table 4.3 Total Organic Carbon (%) results for 2004 with comparison to 2003 construction survey and the 2002 baseline.

4.1.4 Summary

Most of the sites within the survey area had a seabed of coarse sand with some of medium sand. A few sites to the east and west of the survey area had a notable amount of silt. The coarse and medium sands were fairly evenly distributed over the survey area with no obvious inshore/offshore differences. There has not been a consistent pattern of change in dominant sediment type near and within the turbine array or along the cable route in 2004 with sediments at some sites becoming generally finer, others coarser and two sites remaining the same. As sites within the wind farm array and in control areas have shown both increases and decreases in coarseness there is no trend present that would suggest that wind farm construction, cable burial or adjustment of hydrodynamic forces due to the presence of the piles in the seabed are responsible for the changes in sediment type at each site. The original geophysical survey in 2001 described several areas of rippled and megarippled seabed and it is possible that there are different sediment types on the crests and in the troughs of these ripples. It is also plausible that the grab is sampling from different pockets of sea bed type which alter as a result of natural variation over the course of the year.

There was no obvious trend in TOC values between sites either for the 2004 survey or when compared to results from the 2003 and 2002 survey and it is postulated that differences represent little more than natural variations.

There is also no evidence that the distribution of drill cuttings arising from the construction process over the sea bed has acted to increase the coarseness of the sea bed sediments at the wind farm site with most of the wind farm sites (1, 3, 4 and 5) having the same sediment classification in 2003 as in 2002 (prior to any construction activity). However, the results from future monitoring surveys will help to confirm whether this is the case.

4.2 SUSPENDED SEDIMENT MONITORING

Suspended sediment concentration (SSC) monitoring was carried out during the construction phase. Further to discussion with the Licensing Authority, CEFAS and CCW, it has been agreed that no further SSC monitoring is required during wind farm operation. The results of SSC monitoring is presented in the Annual FEPA Monitoring Report for 2003-4 (June 2005).

4.3 SCOUR

The purpose of this section is to summarise the monitoring for scour effects and from the results interpreting how the actual scour effects around the foundations relate to the expected scour and how this may impact on structural integrity of the monopiles and also on the benthic environment. The full scour report for Spring 2005 has been submitted to the Licensing Authority under separate cover.

4.3.1 Introduction

Condition 9.15 of the Food and Environmental Protection Act Licence (FEPA) 1985: Part II, licence 31579/05/0 (as amended) to NWP Offshore Ltd. For the North Hoyle Offshore Wind Farm specifies:

> *"The Licence Holder must undertake a bathymetric survey around a sample of adjacent turbines (minimum of 4) within 3 months of completion of the construction of the wind farm to assess changes in the bathymetry within the array. The survey is to be undertaken immediately after construction is complete and repeated at 6 monthly intervals for a period of 3 years. This shall specifically address the need for (additional) scour protection around the turbine pylons. The Licence Holder must submit the data in the form of a report to the Licensing Authority, including proposals for scour protection measures."*

Further to that quoted above, Condition 9.16 adds:

> *"If the monitoring results carried out under condition 9.15 indicate that scour protection is not required…., the Licence Holder must seek approval from the Licensing Authority for the change in the works previously notified to the Licensing Authority. "*

Scour monitoring has been undertaken for all 30 turbine structures at regular intervals since the monopile foundations were installed, between July and October 2003, to present.

The original scope of work required the main contractor on the project, the North Hoyle Consortium (NHC), to back-fill any scour holes that were predicted to develop at the base of the monopile foundations with rock armour to stabilise the seabed.

The major functions of this protection were to :

- Provide support in the upper part of the soil layer and to prevent the development of large scour holes, which would reduce the effective pile length
- Provide protection to the cables at the seabed level.

In 2004 the decision was taken to apply rock protection to all J-Tubes and cable bights (the section of cable running from the J-Tube at seabed level to full burial depth) to a distance of up to 12m from each turbine as a precautionary measure not from scour, but to reduce mechanical damage to the J-Tubes from tidal current action and to protect shallow laid cables as they approached the J-Tubes. DEFRA were advised of this course of action under Condition 9.16 and the Licensing Authority acknowledged on the 17th March 2005.

Between July and October 2004 rock dumping took place at all 30 turbines. A total of 4187m^3 of rock was placed during 2004 around the J-tubes. This was placed on a rolling programme using the vessel Forth Guardsman. It is not currently possible to correlate the rock dump volumes with the volumes presented in Table 4.5 as rock dumping was taking place before and after the scour surveys.

4.3.1.1 Predictions of Scour Development

The North Hoyle Project Method Statement (June 2003) stated that from results of assessments and evidence from subsea inspections of the met mast structure that scour would be prevalent at the site. It also predicted that scour holes would develop to up to a maximum of 5.2m in depth assuming no scour protection was installed, the scour depth being governed in this instance by tidal currents as the horseshoe vortex becomes more strongly developed than with waves. The truncated cone shaped hole was also predicted to extend laterally up to 3 pile diameters (12m).

Evidence from the Designer's engineering consultants, LIC Engineering A/S (report 0148-53) and other physical processes experts support the principle that scour at North Hoyle is primarily driven by tidal currents from ebb and flow tides and that this process occurs year round peaking during maximum tidal streams at spring tides. It was speculated that arisings from the drilling technique to create the monopile sockets provided additional seabed stability thus reducing the effects of scour. This material comprises crushed mudstone or sandstone sediments from the upper seabed strata.

Arisings were discharged in the water in a slurry adjacent to the foundations. The coarsest materials being deposited close to the foundation, the finer materials deposited further away. The end result has been that the seabed around the foundation piles are covered by a veneer of material, which has a mean diameter of typically 4 mm. This is generally coarser than has previously been reported for the natural seabed materials.

In LIC design report "Evaluation of Scour." Memo 0148-53, Gislason (Aug 2003) states the governing situation for erosion of the coarse material close to the foundations is maximum currents and the maximum currents in combination with waves.

It was estimated that material with a median diameter of more than 4 mm (D_{50}) is sufficiently coarse not to move underneath the strongest currents away from the piles. Adjacent to the piles smaller material will move because the pile wall generates the so-called horseshoe vortex, which amplifies the load on the sea bottom.

For a one year period, Gislason (2003) estimated that the scour depth developed by repeated action of strong currents may obtain a depth of 0.52m. A strong current with recurrence period of 50 years (0.8 m/s) will in its short duration at the peak of a tidal cycle be able to develop a scour hole of 0.66m (assuming 50 year extreme significant wave height of 6.05m).

For D_{50} = 4mm the local scour around the pile will vary from time to time, depending on strength of current and wave climate, direction etc. For coarser material the variation in the scour depth would be less.

For large waves, Gislason (Aug 2003) states the coarse 4 mm material will be mobilised on the seabed. A scour hole from the wave action does not, however, develop to great depths, because the horseshoe vortex is weaker. For instance, a maximum 1 year wave, in combination with maximum spring tidal current, will develop a scour hole of 0.4 m.

4.3.2 Scour Surveys

The main contractor issued an as-built survey report number HBC-750-NH-R002 (Dec 2003) to assess the development of scour by presenting 3D plots of each turbine foundation base and the surrounding seabed surface to 10m. No appreciable scour pits were identified in the survey carried out between August and October 2003 when each monopile had been installed for at least 30 days. The design assumption was that if scour were to develop, it would most probably do so within 14 days of installation. This survey report has been submitted to DEFRA.

The main contractor deemed that no significant scour was developing and thus no rock armour was required.

The main contractor subsequently followed this report with a visual diver inspection at each foundation between April and May 2004 to satisfy themselves as designers that no scour had since developed over the previous winter period.

Osiris Projects Ltd were then commissioned to carry out scour monitoring surveys covering all 30 turbine structures at the North Hoyle development site in Autumn 2004 and repeated subsequently in Spring 2005. These surveys were carried out over 100m square boxes, centred at each monopile location, with high-resolution swath bathymetry data (see example in Figure 4.2) acquired by running a series of parallel survey lines at 50m centres. The primary objective of the surveys was to accurately map localised variations in seabed topography, in order to monitor the effects of tidal current scour around the monopile structures, including two met mast locations at the site.

The Autumn 2004 scour survey took place between 12th August to 12th October 2004 and identified no obvious or significant scour around any of the 30 monopiles. Minor scour development has been noted from the Osiris survey text:

- Turbine 6 : shallow depression running NW-SE either side of turbine
- Turbine 14 : immediately north of the turbine structure
- Turbine 18 : NE of the turbine between the structure and cable rock armour

However, none of the quoted scour has developed beyond 0.5m depth and upon review of the two and three dimensional bathymetry plots for each turbine, many of the features considered to be scour pits are not immediately apparent. This result is compared to the predicted scour pit development of up to 2 pile diameters (i.e. 8m) in the Project Method Statement (June 2003). Clearly, such scour is certainly negligible in the context of what was predicted and closer to that predicted by LIC.

Due to the implication of scour developing through storm wave processes and also the possibility of global seabed level scour/sediment re-working; NWPO Ltd undertake a second detailed swath bathymetry scour survey for all 30 turbines in the Spring of 2005.

The Spring 2005 survey took place between 26th April and 2nd May 2005. During the survey carried out during the August-October 2004 period, rock dumping (armouring) was still in progress and this is reflected by the localised changes in seabed levels seen at many of the turbine locations during the April-May 2005 survey. For the 2005 survey Osiris were

requested to calculate volumetric comparisons with the previous surveys to establish if wider seabed levels were changing.
From the Osiris Spring survey, minor scour development from placement of the foundations appears to only have occurred at Turbines 4, 7, 14 and possibly 20. This scour is less than 0.5m in depth.

Secondary scour from placement of rock armour at the cable J-Tubes does seem to have occurred at Turbines 11, 12, 13, 14, 15, 16, 17, 18, 19, 21, 22, 23, 27 and 28.

The predominant process occurring across the wind farm array is that of sediment movement attributable to natural coastal processes. Residual depressions seen in late 2004 suspected to be from construction vessel activities have all been in filled by Spring 2005 and disappeared as seabed features.

Between the Autumn 2004 and Spring 2005 surveys further rock placement has taken place as a rolling programme to rock dump the J-Tubes progressed.

Of the thirty 100 by 100m survey areas, a total of 18 turbines showed a net decrease in overall sediment volume compared to the remaining 12 showing a net increase in sediment volume. The range of volume in boxes showing an increase (65-474m^3) was comparable to the range of boxes showing a volume decrease (12-430m^3). The sum difference between total volumetric increase and volumetric decrease for all turbines showed a net decrease of approximately 500m^3. This figure is in the same order of individual box volume changes since the last survey and therefore suggests it is within the range o natural variability.

Turbine / Met Mast No.	Net Volume Change in 100m x 100 m Area between Aug -Oct '04 (m³)
1	+169.5
2	+392.5
3	+145.0
4	-108.0
5	-107.0
6	-102.0
7	-138.0
8	+263.0
9	-171.5
10	-253.5
11	+304.5
12	-12.5
13	-345.0
14	+65.5
15	+408.5
16	-198.5
17	+474.5
18	+401.5
19	-54.5
20	-313.0
21	-119.5
22	-267.0
23	-430.0

24	+100.0
25	+261.5
26	-205.5m³
27	-393.5m³
28	-171.0m³
29	-293.5m³
30	-22.5m³
Met Mast 1	+24.0m³
Met Mast 2	-607.0m³

Table 4.5 Summary of Seabed Volume Changes within the 100m x 100m survey boxes.

There is no particular pattern to explain these changes in seabed volume except to say that, when mapped out; the trend lines across the wind farm array appear to be in a SW-NE orientation, suggesting that the changes reflect natural sediment movement across the site from linear features such as sand waves and megaripples.

Future surveys will provide further data to support the evidence that appreciable foundation/ rock placement scour has not developed at North Hoyle.

4.3.3 Results Interpretation

A recent study by Cooper (2005) has collated the majority of available data from North Hoyle and for both pre-construction and post-construction periods to develop an informed view on the scouring effects around the wind farm monopile foundations.

A detailed description of the local seabed is now available from swath bathymetry, and accompanied by a more detailed resolution of the seabed sediments. A key observation is the highly heterogeneous sediment composition over relatively short distances, providing variable contributions of sands and gravels, as well as wide variation in gravel particle size.

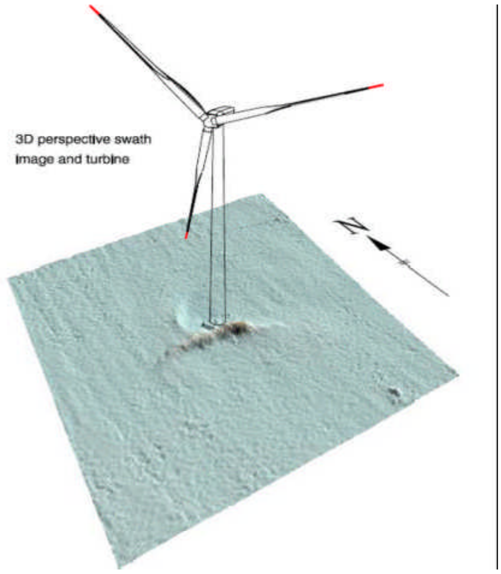
Since construction took place, a single oceanographic event has occurred (over the winter of 2003/4) which provided wave conditions equivalent to the predicted 1 in 1 year peak wave event during a winter storm. A 2004 scour survey has allowed the seabed response to be observed following this key event and compared to the original design estimates of equilibrium scour depth.

Thresholds for sea bed mobility indicate that currents alone only create live bed conditions for the sandy material, with large storms required to exceed thresholds for both sands and gravels. The largest gravels are immobile and are generally regarded as a lag deposit.

During the surveys carried out during the Autumn 2004 period, rock dumping (armouring) was still in progress and this is reflected by the localised volumetric changes in seabed levels seen at many of the turbine locations during the Spring 2005 survey.

A key observation from the scour surveys is the presence of drill cutting mounds to the south of each pile, and where presently observed, some minor scouring to the north of piles. Further mounds relate to rock armouring around the J-tubes and have variable volume and form.

A review of scour depths has shown that scour estimates for the combined wave and tide case equate well to the presently observed scour depths. This is despite a mixed sediment composition and the presence of the drill cutting mounds and rock armour.



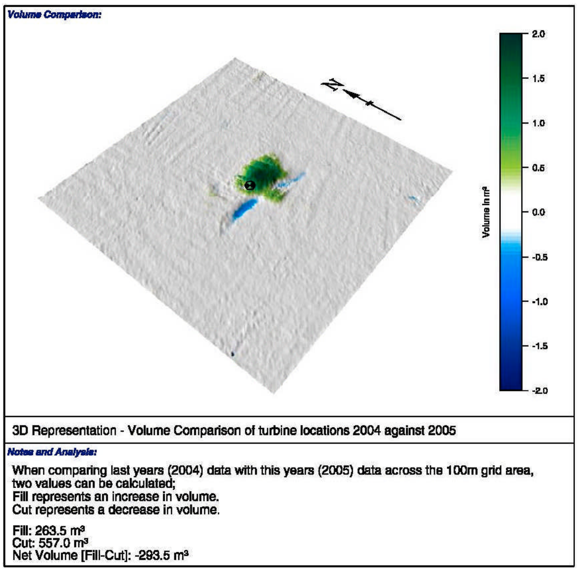


Figure 4.2 3D side scan image of WTG 29 (left) with corresponding changes in seabed volume between October 2004 and April 2005 (right).

The second high-resolution post-scour survey undertaken in Spring 2005, has further confirmed the stability, form, volume and content of the rock armour and to confirm that scouring has remained within the design estimate at less than 0.5m.

Scour could also be plausible as a result of strong tides and 'in-combination' storm waves on a seasonal basis peaking in more severe winter storms. Therefore, it had been suggested that, as no appreciable scour has developed from tidal action, the best time of year to measure any other scour development effects would be after the winter period when reworking of sediment from scour effects would have been apparent after winter storms.

Following submission of the Autumn 2004 scour survey results, DEFRA has recently confirmed that no scour monitoring is deemed necessary in Autumn 2005:

"We have consulted with our marine scientists at CEFAS and we agree that it would appear that minimal scour has occurred. We can confirm that a late summer survey is unnecessary."

The next scheduled survey will therefore be in Spring 2006.

4.3.4 Summary

From the North Hoyle Environmental Statement and The Project Method Statement Rev 2 (June 2003) it has been widely recognised that the dominant factor in mobilising soft re-workable surface sediment (i.e. sands) at North Hoyle was the action of tidal current (ebb and flood tides). Based upon surveys and subsequent assumptions, backed by coastal processes expert opinion, and from the latest set of surveys; it can be concluded that, to date, no long term scour is developing at the North Hoyle Offshore Wind Farm.

The Licence condition 9.15 requires NWPO Ltd to undertake scour surveys on a 6 monthly basis. There appears to be no scientific value in carrying out a survey at the end of the summer period in 2005 (the next timetabled survey slot) which merely reflects a regime of normal tidal processes, where is has already been established that scour (to the degree predicted prior to construction) has not occurred. Therefore, NWPO Ltd requested that the Licensing Authority reconsider the frequency of survey requirements from bi-annually to annually starting in Spring 2005.

NWPO Ltd propose to undertake subsequent scour surveys for the remainder of the Licensing period.

Bomel (Jan 2004) modelled ultimate limit state analysis for 2 typical monopile structures using the assumption that 2m depth scour pits will develop during the course of the wind farm design life. Bomel (2004) concluded that the North Hoyle monopiles for both mudstone and sandstone substrates, based on the design basis, would have an acceptable performance in respect of axial capacity, lateral response and loading-induced stresses. Hence, given the maximum scour development seen to date is less than 0.5m depth, scour is unlikely to affect the structural integrity of the monopile foundations.

Scour development is less than that anticipated / predicted in the Project Method Statement and in line with the design assumptions made by LIC.

Based upon bottom and side scan sonar survey pre- and post-construction, there has been no perceptible global scour or change in seabed bathymetry. Bathymetry depth change trends across the wind farm array, from Osiris 2004-5 surveys, appear to be in a SW-NE orientation, suggesting that the changes reflect natural sediment movement across the site from linear features such as sand waves an megaripples.

Environmental implications are effectively negligible as no distinct scour pits have developed. Placement of rock around the J-Tubes will provide a stable substrate for organisms to grow and improve biodiversity.