4. MARINE SEDIMENTS

Summary of previous survey results

Particle size analysis for 2005 revealed a heterogeneous seabed of fine and medium sands with varied amounts of gravel, the gravel sometimes being dominant. Gravels and 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 to or within the turbine array or along the cable route between 2002 and 2005. As sites both within the wind farm array and in control areas had shown both increases and decreases in coarseness during this period there was 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 changes in sediment characteristics at each site.

4.1 GRAB SAMPLING

4.1.1 Introduction

This section does not consider the wider sedimentary environment of the NHOWF and its impacts upon suspended sediments, sediment transport and coastal processes (these being discussed elsewhere. It considers the results of the particle size of the sediments as sediment type and structure heavily influences the benthic communities which they support. Samples of the seabed taken as part of the benthic grab survey monitoring programme were analysed and their sediment characteristics described (these results have been investigated with reference to the benthic infaunal species in the next section).

The sediment characteristics of the sea bed within and around the NHOWF have previously been described as fine and medium sands with varying amounts of coarser material. Eastwards from the array towards the mouth of the Dee Estuary sediments are composed of sandier material whilst coarser sediment environments are located offshore of the wind farm and also towards the west of the development. The original baseline survey undertaken during 2001 described the area 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). The results of the sediment samples collected so far as part of the FEPA monitoring programme (2002-2005) have so far confirmed this initial site description with coarse sediments and sands being the predominant sediment types found at the monitoring sites.

Most of the predictions raised within the North Hoyle EIA were related to suspended sediments and sediment transport issues. However, in relation to the composition of sediments at the wind farm site the EIA hypothesized that:

"The presence of the turbines will lead to local alterations of current velocity, which will increase erosion forces in certain areas around the structures causing scour……finer sediments will be removed leaving sediments that will be much coarser than previously, with a greater component of stones and shell fragments. This will affect the benthic fauna able to colonise the sediment" (Innogy, 2002).

4.1.2 Methods

4.1.2.1 Field Survey

The benthic grab field surveys were undertaken during September 2006 to maximise the comparability between the previous monitoring surveys undertaken at NHOWF. The survey was undertaken using the survey vessel 'Aquadynamic' (Aquatech Ltd)
Methods used were exactly the same as those for the previous monitoring surveys with sediment samples being obtained from each of the 20 monitoring sites (see Chapter 5 for positions of monitoring sites) using a standard 0.1m^2 (10 litre) Day grab. Under standard CMACS Quality Control (QC) measures, grab samples were rejected if the volume of the returned grab was less than 5 Litres. Grabs were also rejected if the jaws were held open e.g. by loose stones or gravel on the return to surface. When samples were rejected the grab was redeployed to obtain a suitable sample for analysis. Some problems were experienced at site 14 where pebbles repeatedly blocked the grab jaws from closing causing no suitable sample to be obtained.

On return to surface, the sediment sample was allowed to drain within the grab for a few minutes. Samples were then taken from the grab using a trowel (washed in sea water between sites) and placed into labelled aluminium foil sediment trays. At all sites field notes were taken by the onboard CMACS scientist which included the estimated volume of each grab (litres), time and date of sample and the visual appearance of the sediment (Field notes are displayed within Appendix 4.

4.1.2.2 Laboratory Analysis methods

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

4.1.2.2.1 Particle Size Analysis (PSA)

Sediments were sieved using a set of Endecott BS 410 test sieves on the following sieve fractions;10mm; 5mm; 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 for each of the monitoring sites. The classification system used to distinguish sediment type and the sorting index were carried out in accordance with the methods of Buchanan (1984) (see Table 4.1 and Table 4.2). In addition, further classification was also made using the British Geological Survey Folk triangle classification system (see Figure 4.1).

4.1.2.2.2 Total Organic Carbon (TOC)

To analyse the TOC content of the marine sediments at each of the survey locations samples were first processed through a series of sieves for particle size analysis and the < 1mm fraction sub sampled. This fraction was sent to a commercial laboratory to be ashed at temperatures in excess of 550ºC. The TOC content of the marine sediments was analysed by calculating the loss on ignition from each sample.

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)

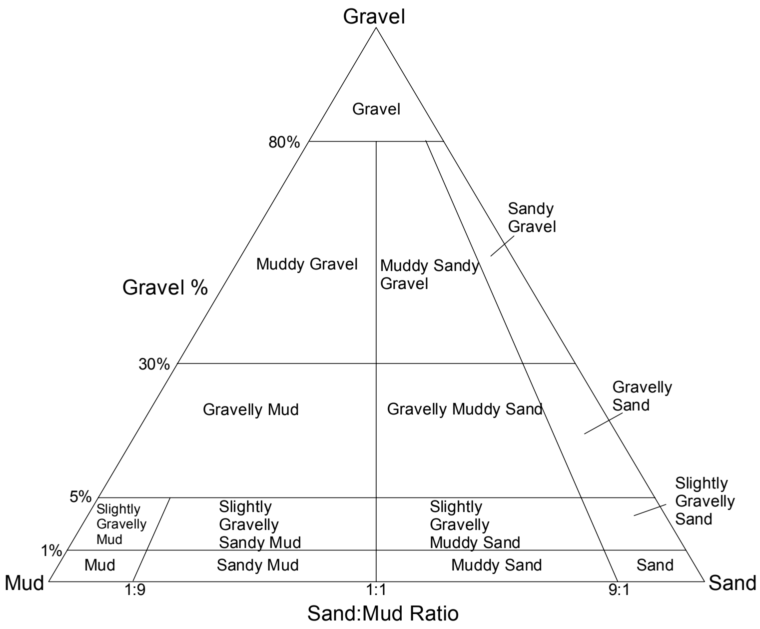

Figure 4.1 Sediment classification after Folk (1954), where "gravel" refers to particles greater than 2mm and "mud" to particles less than 63µm.

4.1.3 Results from 2006 monitoring survey

Full results from the Particle Size Analysis (PSA) of the previous monitoring year (2006) monitoring sites are presented within the Appendix 4. This results table displays the percentage of sediments retained on each sieve which was then analysed according to Buchanan's methods (Buchanan, 1984) to provide statistical data and sediment descriptions as displayed in 3 below. Table 2.4 provides a comparative of the sediment descriptions from each site during the survey years of 2002-2006.

Results obtained from the 2006 survey are consistent with findings from the previous surveys showing that the sediments of the area are generally sandy gravels (see Figure 4.2). Inshore sites 9 and 17 and the sites closest to the mouth of the Dee Estuary (12, 13 & 16) were, as expected, well/moderately sorted fine and medium sands. Sites located within the wind farm area (1, 3,4,5,18,19 and 20) were mostly poorly sorted coarse sands classified as Sandy Gravel (after JNCC). The results from the mean phi recorded at each monitoring site (Figure 4.3 and Table 4.5) also displays the finer sediments located eastwards towards the mouth of the Dee and inshore from the NHOWF with those sites located further offshore, including within the wind farm itself being of a coarser nature.

During the 2006 survey a sample sufficient for analysis was unable to be taken from site 14 due to the coarse nature of the sediment. This indicates that the sediments at this site are of a coarse gravelly nature as described at the site from the previous 2005 results.

site ID	Mean phi	Mean mm	1 std	skewness	kurtosis	Classification after Buchanan	Folk Triangles after JNCC
1	0.53	0.69	1.70	-0.76	1.56	Poorly sorted coarse sand	Gravelly Sand
2	1.76	0.30	0.68	-0.36	1.85	Moderately well sorted medium sand	Slightly Gravelly Sand
3	0.24	0.85	1.20	-0.05	0.82	Poorly sorted coarse sand	Gravelly Sand
4	-0.51	1.43	2.06	-0.02	0.74	Very poorly sorted very coarse sand	Sandy Gravel
5	-0.88	1.84	2.10	0.17	0.59	Very poorly sorted very coarse sand	Sandy Gravel
6	-0.06	1.04	2.42	-0.49	0.66	Very poorly sorted very coarse sand	Sandy Gravel
7	1.50	0.35	0.31	0.00	1.46	Very well sorted medium sand	Sand
8	-1.53	2.89	2.48	0.73	0.50	Very poorly sorted granule	Sandy Gravel
9	2.29	0.21	0.42	-0.12	1.10	Well sorted fine sand	Sand
10	1.25	0.42	1.35	-0.61	0.90	Poorly sorted medium sand	Gravelly Sand
11	0.98	0.51	1.13	-0.52	1.18	Poorly sorted coarse sand	Gravelly Sand
12	1.88	0.27	0.45	0.14	0.84	Well sorted medium sand	Sand
13	2.00	0.25	0.59	-0.09	1.03	Moderately well sorted medium sand	Slightly Gravelly Sand
14	-	-	-	-	-	-	-
15	1.57	0.34	0.53	-0.02	1.62	Moderately well sorted medium sand	Sand
16	2.04	0.24	0.80	-0.55	1.62	Moderately sorted fine sand	Slightly Gravelly Sand
17	1.99	0.25	0.47	-0.03	0.93	Well sorted medium sand	Sand
18	-0.82	1.77	1.35	-0.11	0.68	Poorly sorted very coarse sand	Muddy Gravel
19	-0.63	1.54	1.63	0.11	1.01	Poorly sorted very coarse sand	Sandy Gravel
20	-0.59	1.50	1.75	0.08	1.01	Poorly sorted very coarse sand	Sandy Gravel

Table 2.3 Summary statistics for sediment data date from 2006 surveys

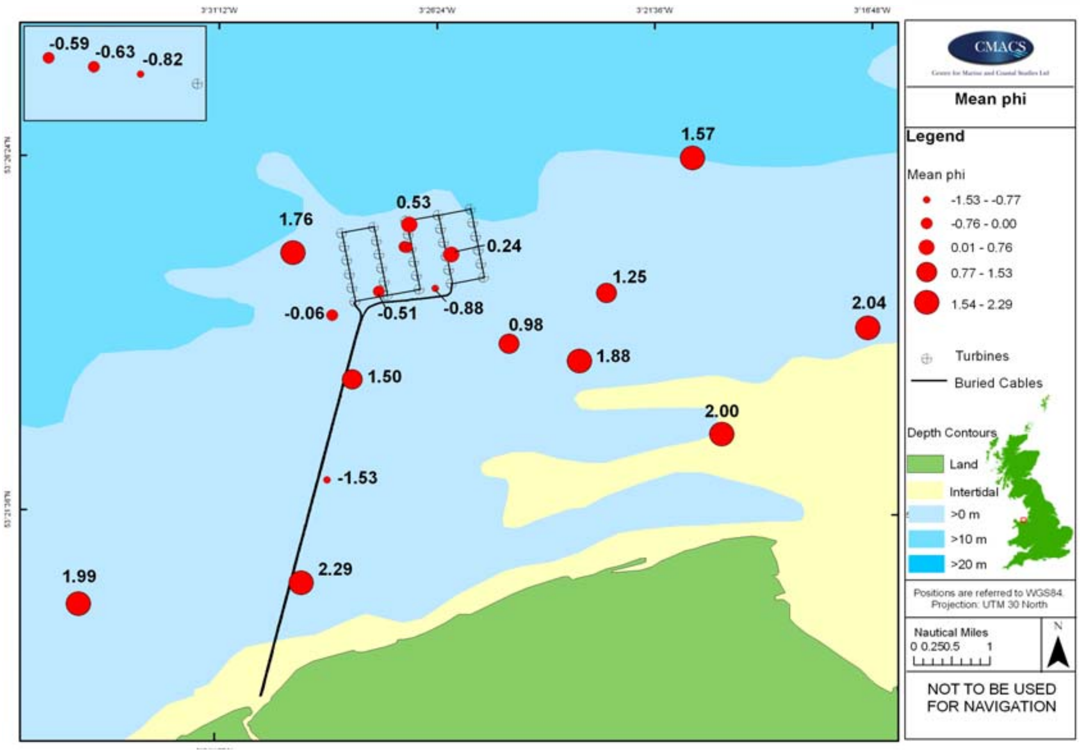

Figure 4.2: Sediment classifications according to BGS Folk triangles for 2006

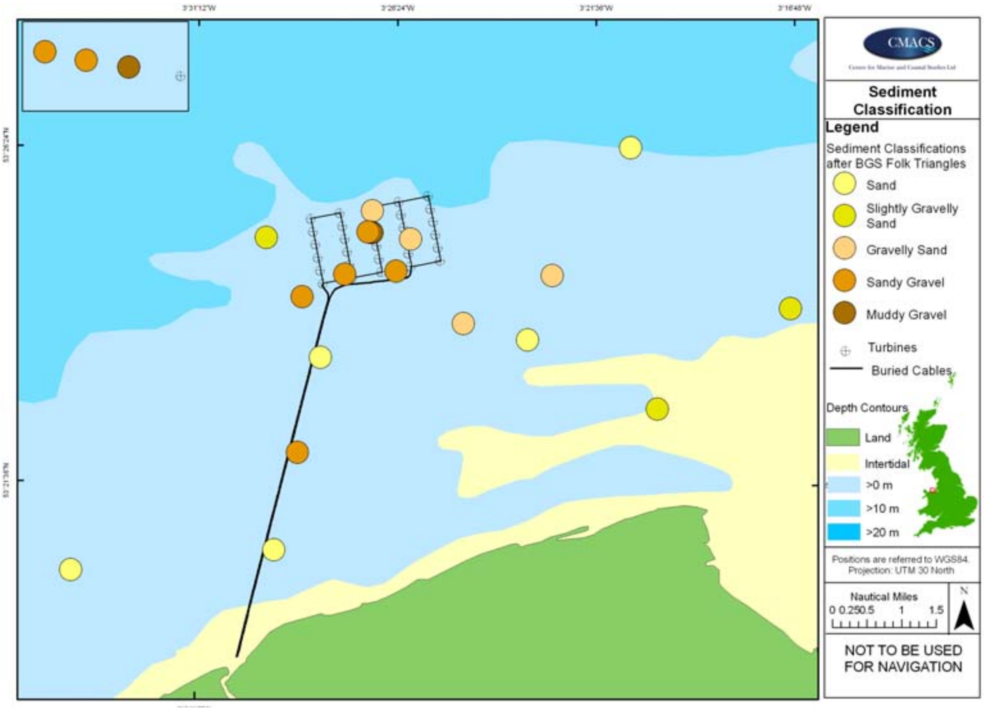

Figure 4.3: Mean Phi for 2006

Table 4.4 Sediment descriptions for sediment data from 2002 to 2006.

Site	Descriptions after Buchanan 2002	2003	2004	2005	2006	Folk Triangles after BGS 2002	2003	2004	2005	2006
1	Moderately sorted medium sand	Well sorted medium sand	Moderately well sorted medium sand	Well sorted medium sand	Poorly sorted coarse sand	Slightly Gravelly Sand	Sand	Slightly Gravelly Sand	Sand	Gravelly Sand
2	Poorly sorted coarse sand	Very poorly sorted Very coarse sand	Well sorted medium sand	Very poorly sorted very coarse sand	Moderately well sorted medium sand	Gravelly Sand	Sandy Gravel	Slightly Gravelly Sand	Gravelly Sand	Slightly Gravelly Sand
3	Poorly sorted coarse sand	Poorly sorted granule	Poorly sorted coarse sand	Poorly sorted coarse sand	Poorly sorted coarse sand	Gravelly Sand	Sandy Gravel	Gravelly Sand	Gravelly Sand	Gravelly Sand
4	Poorly sorted granule	Well sorted medium sand	Moderately well sorted medium sand	-	Very poorly sorted very coarse sand	Gravel	Sand	Slightly Gravelly Sand	-	Sandy Gravel
5	Poorly sorted Very coarse sand	Poorly sorted pebble	Poorly sorted coarse sand	Poorly sorted very coarse sand	Very poorly sorted very coarse sand	Sandy Gravel	Gravel	Gravelly Sand	Sandy Gravel	Sandy Gravel
6	Poorly sorted medium sand	Very well sorted medium sand	Very poorly sorted Very coarse sand	Very poorly sorted Very coarse sand	Very poorly sorted very coarse sand	Gravelly Sand	Sand	Sandy Gravel	Sandy Gravel	Sandy Gravel
7	Very well sorted medium sand	Very well sorted medium sand	Poorly sorted Very coarse sand	Very well sorted medium sand	Very well sorted medium sand	Sand	Sand	Sandy Gravel	Sand	Sand
8	Poorly sorted granule	Very poorly sorted very coarse sand	Very well sorted medium sand	Very poorly sorted Very coarse sand	Very poorly sorted granule	Gravel	Sandy Gravel	Sand	Sandy Gravel	Sandy Gravel
9	Well sorted fine sand	Well sorted fine sand	Moderately sorted medium sand	Well sorted medium sand	Well sorted fine sand	Sand	Sand	Slightly Gravelly Sand	Sand	Sand
10	Poorly sorted coarse sand	Poorly sorted very coarse sand	Poorly sorted Very coarse sand	Moderately well sorted medium sand	Poorly sorted medium sand	Sandy Gravel	Sandy Gravel	Sandy Gravel	Slightly Gravelly Sand	Gravelly Sand
11	Poorly sorted granule	Well sorted medium sand	Well sorted medium sand	Moderately sorted medium sand	Poorly sorted coarse sand	Sandy Gravel	Sand	Sand	Gravelly Sand	Gravelly Sand
12	Very well sorted medium sand	Well sorted fine sand	Well sorted medium sand	Well sorted medium sand	Well sorted medium sand	Slightly Gravelly Sand	Sand	Sand	Sand	Sand
13	Moderately well sorted medium sand	Well sorted medium sand	Very poorly sorted coarse sand	Well sorted medium sand	Moderately well sorted medium sand	Slightly Gravelly Sand	Slightly Gravelly Sand	Gravelly Sand	Sand	Slightly Gravelly Sand
14	Moderately sorted pebble	Very poorly sorted granule	Well sorted fine sand	Poorly sorted medium sand	-	Gravel	Sandy Gravel	Sand	Gravelly Sand	-
15	Moderately well sorted medium sand	Moderately well sorted medium sand	Moderately sorted medium sand	Well sorted medium sand	Moderately well sorted medium sand	Slightly Gravelly Sand	Slightly Gravelly Sand	Slightly Gravelly Sand	Sand	Sand
16	Moderately sorted medium sand	Well sorted medium sand	Moderately sorted fine sand	Poorly sorted coarse sand	Moderately sorted fine sand	Slightly Gravelly Sand	Slightly Gravelly Sand	Gravelly Sand	Gravelly Sand	Slightly Gravelly Sand
17	Moderately well sorted medium sand	Well sorted medium sand	Moderately well sorted medium sand	Well sorted medium sand	Well sorted medium sand	Slightly Gravelly Sand	Sand	Sand	Sand	Sand
18	*	Poorly sorted very coarse sand	Poorly sorted very coarse sand	Poorly sorted granule	Poorly sorted very coarse sand	*	Sandy Gravel	Sandy Gravel	Sandy Gravel	Muddy Gravel
19	*	Poorly sorted granule	Moderately sorted medium sand	Poorly sorted very coarse sand	Poorly sorted very coarse sand	*	Sandy Gravel	Gravelly Sand	Sandy Gravel	Sandy Gravel
20	*	Poorly sorted granule	Very poorly sorted very coarse sand	Poorly sorted granule	Poorly sorted very coarse sand	*	Sandy Gravel	Sandy Gravel	Sandy Gravel	Sandy Gravel

*NotSampled

site ID	2002	2003	2004	2005	2006
1	1.212	1.51	1.55	1.44	0.53
2	0.325	-0.19	1.64	-0.03	1.76
3	0.354	-1.28	0.37	0.40	0.24
4	-1.971	1.52	1.35	-	-0.51
5	-0.206	-2.39	0.81	-0.06	-0.88
6	1.032	1.65	-0.61	-0.35	-0.06
7	1.583	1.63	-0.26	1.35	1.50
8	-1.666	-0.80	1.76	-0.01	-1.53
9	2.219	2.25	1.00	1.75	2.29
10	0.133	-0.97	-0.17	1.71	1.25
11	-1.920	1.78	1.68	1.03	0.98
12	1.964	2.33	1.98	1.80	1.88
13	1.775	1.85	0.04	1.72	2.00
14	-2.934	-1.83	2.05	1.42	-
15	1.410	1.30	1.31	1.35	1.57
16	1.604	1.73	2.06	0.88	2.04
17	1.861	1.84	1.81	1.89	1.99
18		-0.83	-0.35	-1.08	-0.82
19		-1.14	1.19	-0.79	-0.63
20		-1.09	-0.10	-1.03	-0.59

Table 4.5: Mean Phi results for all monitoring surveys (2002-06) grey shading indicates no sample

4.1.3.1 Total Organic Carbon (TOC)

Total Organic Carbon provides a measure of how much organic content occurs within marine sediments. Sediments in open water habitats have an average range between of 0.04 to 6.6%. Hyland et al. (2000) found that extreme concentrations of TOC can have adverse effects on benthic communities with TOC levels above 3.0% being related to a decrease in benthic abundance and biomass.

TOC results from 2006 are presented within Table 4.6, alongside those from 2002-2005. Overall, the results were comparable with those from the 2005 survey ranging from a minimum of 0.36% (site 1- located within the wind farm) to a maximum level of 1.56% (Site 6- located to the immediate south-west of the array). Fluctuations in TOC levels were comparatively small bearing no significance to location regarding sites within or outside the wind farm. All of the 2006 results were well below the level of 3% suggested by Hyland et al (2000) as having an effect upon the surrounding benthos.

Site no.	%TOC 2002	%TOC 2003	%TOC 2004	%TOC 2005	%TOC 2006
1	0.04	0.01	0.04	0.28	0.36
2	0.06	0.04	0.05	0.39	0.62
3	0.08	0.04	0.07	0.41	0.46
4	0.55	0.02	0.04	No sample	0.83
5	0.07	0.01	0.04	0.41	0.43
6	0.08	0.06	0.07	1.55	1.56
7	1.02	0.01	0.12	0.21	0.41
8	0.02	0.16	0.05	1.20	0.98
9	0.17	0.04	0.07	0.44	0.54
10	0.07	0.04	0.05	0.37	0.52

Site no.	%TOC 2002	%TOC 2003	%TOC 2004	%TOC 2005	%TOC 2006
11	0.05	0.01	0.04	0.45	0.42
12	0.07	0.03	0.04	0.37	0.39
13	0.12	0.01	0.06	0.35	0.44
14	0.09	0.05	0.05	0.50	No sample
15	0.02	0.03	0.04	0.47	0.46
16	0.04	0.01	0.09	0.46	0.46
17	0.12	0.06	0.06	0.49	0.59
18	*	0.07	0.05	0.98	0.67
19	*	0.01	0.07	1.01	1.28
20	*	0.04	0.05	0.95	1.24

* = not surveyed in 2002

Table 4.6 Total Organic Carbon (%) results for 2006 with comparison to 2002-2005 surveys (Sites 18, 19 and 20 were new sites for 2003 and therefore no data was available for 2002).

4.1.4 Results from overall 5 year monitoring programme

In 2006 the sediments at most sites were consistent to those previously described there from the preceding monitoring surveys (2002-2005). For those sites located within the wind farm (1, 3, 4 and 5) the results from 2006 showed little difference in sediment types from the same sites in preceding years. Although fluctuations are evident within results for sites between the years, such fluctuations display no apparent link to the wind farm development, distance offshore, depth, or any other geographical or hydrographical factor. It is possible to attribute such changeability to the nature of the sedimentary environment along this coastline and within Liverpool Bay with a high variability being observed over relatively short-distances. Such characteristics are typical of the wave-exposed shallow water environment found at the NHOWF.

2005 and 2006 have TOC levels which are perceptibly higher than those for 2002-2004. However, it should be noted that all recorded TOC levels are considerably lower than the 3% level suggested by Hyland et al. (2000) as having an effect on benthic biomass and abundance and all are well below the maximum average levels suggested for open water habitats. Fluctuations in results are comparatively small and bear no significance to location regarding sites within or outside the wind farm.

4.1.5 Conclusion

The original baseline survey undertaken during 2001 described the sediment characteristics of the area as being 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). Results from the particle size analysis on the sediment samples collected from 2002-2006 have confirmed this initial site description with coarse sediments and sands being the predominant sediment types found at the monitoring sites.

Particle size analysis revealed a heterogeneous sea-bed of fine and medium sands with varied amounts of gravel, the gravel sometimes being dominant. Gravels and 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 to or within the turbine array or along the cable route between 2002 and 2006. As sites both within the wind farm array and in control areas have shown both increases and decreases in coarseness during this period 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 changes in sediment characteristics at each site. The original geophysical survey of 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. Such small scale variation is indicated by some of the faunal results, where significant differences occasionally occur between replicate samples taken from within a few metres of each other. It is also plausible that the grab is sampling from different pockets of sea bed type which change as a result of natural variation over the course of the year. Finally, chance variation in the number of stones picked up in any one sample, even where sediments are actually quite evenly distributed, could conceivably result in noticeable changes in the sediment as described by particle size analysis.

TOC values in 2003 and 2004 suggested little obvious pattern between sites, nor was there any clear trend when those results were compared to results from the 2002 survey, and it was previously thought likely that any differences in those years represented natural variations. However, 2005 and 2006 results are clearly higher than those from previous monitoring surveys if these results truly represent increased values they are also presumably caused by natural variations since there is no relation between the amount of increase in TOC and the wind farm or cable route, nor is there any clear relationship with possible hydrographic factors such as depth, distance offshore or east–west position. It is common for organic content of sediments to be closely linked with the fine fraction, but review of results for particle size fractions shows clearly that in this case these apparent increases are not related to the amount of very fine (<63µm) material in the samples.

There also continues to be little evidence that the distribution of drill cuttings over the sea bed during construction has acted to noticeably increase the coarseness of sea bed sediments at the wind farm site with the majority of the monitoring sites having the same or very similar sediment classification post-construction (2003-06) as for pre-construction (2002).

From these results, the EIA hypothesis that the sediments within the wind farm would coarsen due to the presence of the turbines has not been found to be correct as sediment characteristics have remained the same and any fluctuations between years has been observed across all sites (including control locations) and not just limited to those either within or near-field to the NHOWF. It should be highlighted that the EIA conclusions were for the near-scale impacts to turbine (sub 50m) and that the relevant sampling sites completed for the monitoring programme were placed just beyond this zone at 65m from the pile centre (this was due to the survey vessel being unable to approach too close to the turbine to grab within this 50m zone due to safety restrictions around the newly installed turbine). However, this is not believed to have affected the monitoring programme as the results from the geophysical monitoring programme indicate that there is no difference between sea bed material between the range of 50-65m from the this turbine. It can therefore be postulated that there is no difference between the sediment type over this distance.

4.1.6 Limitations of monitoring programme

Given the close association between benthic communities and sediment types, if this monitoring programme were to be undertaken again, it is recommended that sediment sub samples from each faunal grab replicate should be taken and this sub-sample used for particle size analysis and TOC. This allows results to be directly compared to the faunal communities they support as they come from the same grab rather than have one grab for each sampling station.

4.2 SUSPENDED SEDIMENT MONITORING

Annex 1, clause 1 of FEPA Licence 31579/05/0 (as amended) specifies:

> "….The following monitoring is required in order to confirm predictions. Monitoring will use Optical Backscatter Sensor (OBS) instrumentation, and will comprise three fixed moorings (see below for locations) plus selected water column profiling, during construction, of any sediment plume. Full calibration of the sensors will be required (see below for details), and should be included in a report and presented to CEFAS. Instrument deployment will be for a period of at least four weeks, and will be provided concurrently at each site during the pre-construction, construction and post-construction periods."

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 was presented in the Annual FEPA Monitoring Report for 2003-4 (June 2005) and summarised below.

SSC monitoring of pre-construction and construction monitoring took place between 17 March 2003 and 23 April 2003. The 38 day period covered all installation drilling and piling activities for 3 monopiles as follows:

Turbine number	Monopile drill and pile dates
1	6 & 12 April
2	13 & 16 April
3	22 & 25 April

The monopile for turbine number 6 was installed on 22 and 25 April and so drilling and piling on 22 April was also included in the monitoring period.

4.2.1 Location of fixed Moorings

The turbidity unit positions were chosen to permit measurement of near and far-field sediment release and control levels.

SS1 Towards the Point of Ayr (near mouth of Dee estuary), at a distance of one tidal excursion from the boundary of the licence area and within the predicted suspended sediment plume to determine far-field levels of SSC.

SS2 Adjacent to the existing anemometry mast at the south-eastern corner of the proposed North Hoyle Wind Farm licence area to measure near-field effects of SSC.

SS3 A point outside the predicted area of the sediment plume west of the Licence area, and off-axis of the dominant flood-ebb direction to provide a 'control' measure of natural levels of SSC.

4.2.2 Overview of Results

Peak SSC were highest at SS1, the site nearest the Dee estuary, and lowest at the most offshore site, SS3. The following summarises maximum and mean SSC at each site over the construction monitoring period:

SS1: MAX 281 mg/l, mean 39 mg/l
SS2: MAX 104 mg/l, mean 19 mg/l
SS3: MAX 74 mg/l, mean 8 mg/l

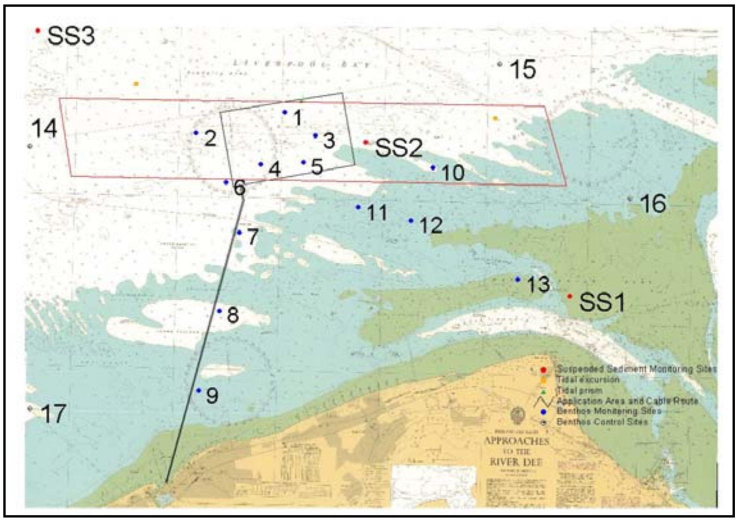

Figure 4.4: Locations for monitoring of sediment (subtidal [benthos] & suspended concentrations)

At all sites, but most noticeably at SS1, a clear pattern was evident: suspended sediments were mobilised during flood and ebb tides and settle out of the water column at high and low water. There was also a semi-lunar tidal influence evident with suspended sediment levels increasing at all 3 sites with increased tidal range (and hence current strength).

At each site there were occasional short-term peaks in suspended sediment concentration. For example at SS3 on 3 April suspended sediment concentration increased from less than 10 mg/l to more than 60 mg/l for a short period. Such short-term peaks in sediment moving across the sensors are most noticeable at SS3, which shows relatively little semi-lunar variation but would be apparent at all three sites over neap tides. Thus neap tides provide the best opportunity to identify peaks in suspended sediments from monopile installation activities.

4.2.3 Comparison with Baseline Data and Assessment of Construction Impacts

Before construction activities began and while they were ongoing, the background pattern of suspended sediment mobilisation on flood and ebb tides and the semi-lunar tidal influence is clear in these data. These same patterns were evident in the baseline data (Figure 4.5).

Weather conditions can mask the semi-lunar cycle and this was evidenced by an extended period of elevated suspended sediments caused by strong winds from the west after 8 March 2003. The following provides a comparison of maximum and mean SSC:

	Maximum mg/l (before/during)	Mean mg/l (before/during)
SS1	199/281	50/39
SS2	155/104	40/19
SS3	65/74	15/8

A comparison of pre and during-construction SSC monitoring revealed that the difference between suspended sediment levels at SS1 (near Dee estuary) and SS2/3 (near-field and control site respectively) was more marked after 18 March 2003.

This is likely to be due to a combination of strong westerly winds and riverine inputs having the strongest effect in shallow coastal waters. Since mean SSC at all sites were lower it is evident that the suspended sediment regime was more dynamic in late March/April than February/early March. The neap tide after monopile installations began was not affected in this manner and so provided the best opportunity to identify specific construction impacts.

The first drilling/piling activity took place over 6 April 2003 at turbine number 1. There were no peaks in suspended sediment concentration at SS2 that show near field effects of sediment release from the monopile installation activities exceeding normal background patterns (Figure 4.5 provides a detailed analysis of data from SS2 alone during monopile installations).

SS2 was approximately 4 km from turbines 1 and 6 and 3 km from turbines 2 and 7. All four monopiles that were installed were within a single tidal excursion and the line between these turbines and SS2 is also equivalent to the known direction of tidal movement on flooding tides (80o). Any significant suspended sediment plumes would therefore have been detected.

There were individual peaks in suspended sediment concentration visible in Figure 4.6, which may be related to construction activities, particularly drilling. However, similar and bigger events occur outside these times (shaded areas on chart), including prior to construction activities, and it is also evident that the background semi-lunar and tidal patterns were not in any way masked by the on-site works.

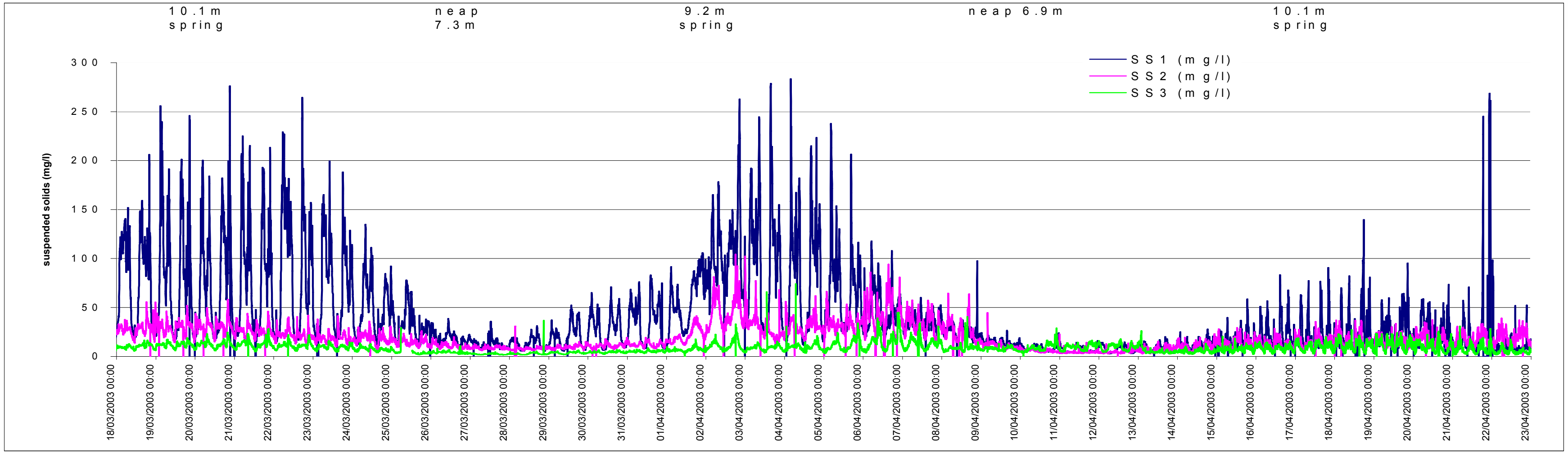

Figure 4.5 (above) Overview of data from each turbidity sensor

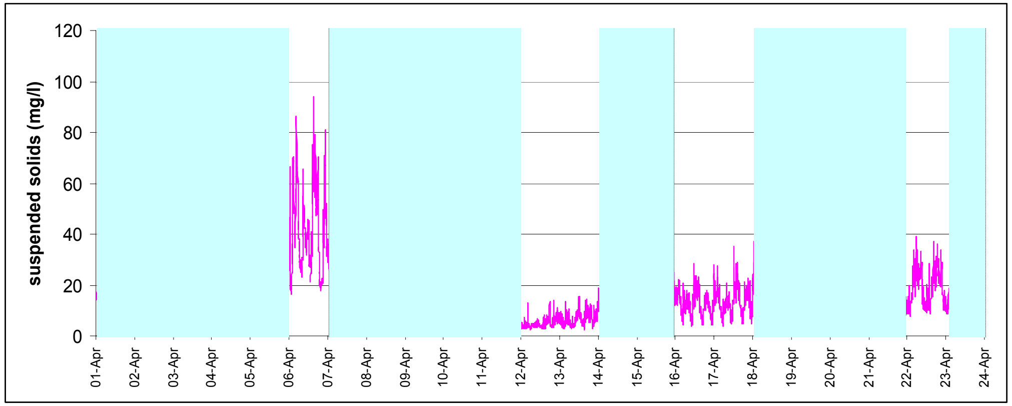

Figure 4.6 SSC at SS2 (near field site). Shaded areas had no monopile installation activity, unshaded areas represent days on which drilling/piling took place (2003).

4.2.4 Modelling Predictions

The Environmental Statement predicted that SSC at high water springs at each station would be as follows:

Station	Background (mg/l)	'Worst case scenario construction impact' (mg/l)
SS1	<30	<30
SS2	<20	<30
SS3	<10	<10

At high water on the spring tide immediately before monopile installation work began (noon on 2 April 2003) and on the following spring tide after works began (11:00 on 17 April) the SSC at each station were as follows:

Station	Actual Background (mg/l)	Actual during-construction (mg/l)
SS1	60 – 70	<10
SS2	30 – 40	<10
SS3	<10	<10

The above pattern was also repeated on successive high waters during and after monopile installation works. This suggested strongly that there was no overall detectable increase in suspended sediment load in the local environment as a result of monopile installation works. The relatively high background levels also show clearly the importance of weather conditions as the overriding influence on SSC.

4.2.5 Conclusions

The dominance of natural processes in driving SSC was evident in data obtained before and during the construction period. Both daily and semi-lunar tidal patterns drive SSC at the site but increased wind speed, mediated through elevated wave height, can also be significant.

There was no detectable increase in sediment load, either localised peaks or more generalised increases in background concentrations, as a result of the monitored monopile installations. It is possible, however, to make an assessment of the relative impact of construction activities on suspended sediment loads by making some precautionary (i.e. pessimistic) assumptions:

Elevations of SSC in excess of 10 mg/l should be readily detectable. For the purposes of this exercise it was assumed that construction activities did raise SSC by 10 mg/l. It is known that natural events routinely elevate suspended sediments by in excess of 200 mg/l. Thus monitored monopile installation activities had an impact of less than 5% above background levels. In reality the actual impact is believed to be very much smaller since the total material available for suspension was less than 1000 m3 over the entire installation process. This compares favourably with the prediction in the NHOWF Environmental Statement that the additional contribution to SSC in the mouth of the Dee estuary would be less than 10%.

4.3 SCOUR

The purpose of this section is to summarise the monitoring for scour effects around monopile foundations. Results have been interpreted to assess 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 2007 has been included in Appendix 4.2.

Summary of previous survey results

The data from the Spring 2006 survey indicated movement of sediment was occurring for the majority of the turbine survey boxes. However, it is thought that the predominant process occurring across the wind farm array is that of sediment movement attributable to natural coastal processes and the changes in seabed levels found in the recent study are likely to be the result of these processes.

From an analysis of the 2006 volume comparison plots, minor scour development within a 10m radius of the foundation structures may have occurred (up to circa 2^{m3}) at the following turbines: 19 and 20, with less obvious decreases at 04, 08, 12, 15, 18, 24, 26, 28. Turbines 25, 29 and 30 may also show some secondary scour around the placement of rock armour. However for all of these positions, general movement of sediment is occurring across the survey box and changes in seabed levels could equally be attributable to natural sediment processes.

4.3.1 Introduction

Condition 9.15 of the FEPA 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. No rock protection was deployed due to the lack of scour hollows.

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 to reduce mechanical damage to the J-Tubes from tidal current action and to protect shallow laid cables as they approached the J-Tubes. Rock dumping was not required for scour protection purposes due to the lack of scour development. Between July and October 2004 rock dumping took place at all 30 turbines. A total of 4187^{m3} of rock was placed during 2004 around the J-tubes.

In August 2005 a 5m section of cable near WTG 30 was covered with 200 25kg grout bags to cover a free cable span approximately 18m from the bellmouth at WTG30. The side scan for this particular survey box in 2006 highlighted an area of increased volume which corresponded to area that was covered in grout bags, but no associated scour is apparent. Evidence of the cable span covering was evident in the survey box drawing.

4.3.2 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. The truncated cone shaped hole was also predicted to extend laterally up to 3 pile diameters (12m).

Evidence from 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.

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 D50 = 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.

4.3.3 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.

The main contractor deemed that, shortly after installation, 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 2004, 2005, 2006 and 2007. The first year of surveys were conducted in both Spring and Autumn, however, following submission of the Autumn 2004 scour survey results, DEFRA confirmed that scour monitoring was only necessary once a year and hence it wasn't deemed necessary to carry out further Autumn monitoring surveys unless future scour became evident.

The 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.

Osiris scour surveys have been conducted on the following dates:

- 2004 : 12th August to 12 October 2004
- 2005 : 26th April to 2nd May 2005
- 2006 : 5th April to 16th April 2006
- 2007 : 19th April to 24th April 2007

The scour surveys carried out between 2004 and 2005 identified no obvious or significant scour around any of the 30 monopiles. None of the quoted scour had 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 were not immediately apparent. This result is considered negligible compared to the predicted scour pit development of up to 2 pile diameters (i.e. 8m) in the North Hoyle Project Method Statement (June 2003).

Between the 2004 and 2005 surveys, rock placement took place as a rolling programme to rock dump around J-Tubes bellmouths to protect surface laid cables in transition to full burial. This was reflected by localised changes in seabed levels seen at many of the turbine locations during the Spring 2005 survey.

Osiris were requested to calculate volumetric comparisons in 2006 with the previous surveys to establish if wider seabed levels were changing.

Table 4.5 shows the volumetric changes in seabed at each of the thirty 100 by 100m survey areas since 2004. Between 2005 and 2006 half the turbines showed a net increase in overall sediment volume. The range of volume in boxes showing an increase (142.5-1662$^{m3)}$ was comparable to the range of boxes showing a volume decrease (33.3-1219^{m3}). However, it is evident that the maxima (highest gains and highest losses) are higher in magnitude than those of the previous year. The sum difference between total volumetric increase and volumetric decrease for all turbines showed a net increase of approximately 2400^{m3}. This compares with a net loss of 700 ^{m3} the previous year between 2004 and 2005. Both met masts exhibited a loss in sediment in the last year (albeit negligible in the case of Met Mast 1).

Comparing overall volume changes between 2004 and 2006 (over a 2 year period) a total of 17 turbines showed a net increase in overall sediment volume compared to the remaining 13 showing a net decrease in sediment volume. The range of volume in boxes showing an increase (32-1831^{m3}) was comparable to the range of boxes showing a volume decrease (5-1554^{m3}). It is evident that Met Mast 2 100m x 100m box has exhibited a loss in sediment for two consecutive years. However, negligible losses have occurred adjacent to the structure. The result here suggests that Met Mast 2 is situated in a more dynamic sedimentary environment than Met Mast 1.

The sum difference between total volumetric increase and volumetric decrease for all turbines between 2004 and 2006 showed a net increase in sediment of approximately 1700^{m3}. This demonstrates that in the three years this analysis has taken place, the net volumes across all survey boxes are in the same order of magnitude as individual box volume changes and therefore suggests it is within the range of natural inter-annual variability. It should be noted that a similar volumetric comparison to that that undertaken in the previous two years was not undertaken for the 2007 data due to the lack of substantive change in volumes since 2006. Any analysis would have caused large statistical errors in attempting to attribute volume differences. Therefore, it is assumed that little volumetric change has occurred in the last survey period.

Turbine / Met Mast No.	**Net Volume Change (m³)**		**Overall Volume Change (m3) (2004-2006)**
	Autumn '04 to Spring '05	Spring '05 to Spring '06	
1	+169.5	+ 1662.0	+ 1831.5
2	+392.5	+ 1003.9	+ 1396.4
3	+145.0	+ 1189.8	+ 1334.8

4	-108.0	+ 1118.0	+ 1010.0
5	-107.0	-420.7	-527.7
6	-102.0	+ 142.5	+ 40.5
7	-138.0	-49.1	-187.1
8	+263.0	-295.7	-32.7
9	-171.5	-160.0	-331.5
10	-253.5	-930.7	-1184.2
11	+304.5	+ 409.5	+ 714.0
12	-12.5	-1004.8	-1017.3
13	-345.0	-1209.0	-1554.0
14	+65.5	-33.3	+ 32.2
15	+408.5	-1190.1	-781.6
16	-198.5	-457.8	-656.3
17	+474.5	-138.1	+ 336.4
18	+401.5	-134.3	+ 267.2
19	-54.5	-367.4	-421.9
20	-313.0	-1219.0	-1532.0
21	-119.5	+ 699.3	+ 579.8
22	-267.0	+ 336.4	+ 69.4
23	-430.0	-377.9	-807.9
24	+100.0	+ 639.2	+ 739.2
25	+261.5	-57.5	+ 204.0
26	-205.5	+ 878.1	+ 672.6
27	-393.5	+ 388.4	-5.1
28	-171.0	+ 413.8	+ 242.8
29	-293.5	+ 1394.4	+ 1100.9
30	-22.5	+ 177.8	+ 155.3
Met Mast 1	+24.0	-19.9	+ 4.1
Met Mast 2	-607.0	-652.3	-1259.3

Table 4.6 Summary of Seabed Volume Changes between 2004 and 2006.

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.

In 2007 the survey area boxes identified minima and maxima seabed depths between -6.3m below chart datum and -11.0m below chart datum. This is compared to corresponding depths in the previous year's survey of -6.3 and -11.1m below chart datum, respectively. The 2007 scour survey has not revealed any significant changes in depth or volume within any of the survey boxes. When compared to 2006, change occurred to such a small degree it was decided that volumes could not be calculated accurately due to the small numbers and percentage errors in the calculation. In the absence of numerical data to compare with the data in Table 4.7, visual references to sediment gains and losses was assessed using the volumetric comparison boxes in the scour report (Appendix 4.2) between 2006 and 2007. From this inspection, the following changes were evident:

Net Volume Increase (WTG No.)	Net Volume Decrease (WTG No.)
7	29
10	
12	
13	
14	
15	
19	
20	
30	

Table 4.7: 2006 to 2007 visual comparison of volume changes.

It is worth noting that the majority of boxes showing accumulation in the past year had previously exhibited losses between 2004 and 2006, indicating a reversal of the trend previously seen. All other turbine boxes either exhibited negligible or undetectable changes, or differences between gains and losses within the box were indistinguishable. The 2007 survey indicates that sedimentary processes within the North Hoyle site have stabilised compared to previous years, and that net accretionary processes have occurred in the 12 months since the last survey. This is affirmed by overall shallowing of the deeper parts of the survey areas in 20 out of 30 turbine survey boxes caused by thickening of seabed sediments.

The 2007 survey has provided further data to support the evidence that appreciable foundation/rock placement scour has not developed at North Hoyle.

4.3.4 Results Interpretation

Following submission of the Autumn 2004 scour survey results, DEFRA confirmed that no scour monitoring was deemed necessary in Autumn 2005.

The previous surveys had confirmed the stability, form, volume and content of the rock armour and confirmed that scouring had remained below the design estimate at less than 0.5m. This most recent study has further confirmed that scouring from both turbine structures and rock placement is entirely absent.

From an analysis undertaken in the previous FEPA report (2006), volume comparison plots, minor scour development within a 10m radius of the foundation structures may have occurred (up to circa 2^{m3}) at the following turbines: 19 and 20, with less obvious decreases at 04, 08, 12, 15, 18, 24, 26, 28. Turbines 25, 29 and 30 may also show some secondary scour around the placement of rock armour. However for all of these positions, general movement of sediment is occurring across the survey box and changes in seabed levels could equally be attributable to natural sediment processes.

Analysis of the latest 2007 survey results has not revealed any scour development at the turbine monopiles or related rock protection. Turbines 3 and 5 (and possibly 12 and 28) show indications that rock armour may have settled slightly since the last survey, but no secondary scour was evident. It was also noted that a build up of sediment adjacent to structures had caused the rock armour to blend into the surrounding seabed at turbine 10 and similarly a build up of sediment was noted south east of turbine 14.

The data from the Osiris Spring 2006 and Spring 2007 surveys indicate that movement of sediment is occurring for the majority of the turbine survey boxes. However, it is thought that the predominant process occurring across the wind farm array is that of sediment movement attributable to natural coastal processes and the changes in seabed levels found in the studies are likely to be the result of these processes. Small bedforms were noted at a number of survey boxes in the side scan plots (notably at turbines 13 and 19) and volumetric comparison plots clearly showed changes in seabed depth resulting from sediment movement within the survey boxes.

The comparative lack of change in seabed levels in the 2007 study suggests that stability or equilibrium has been reached following the 3 years since construction took place. Generally, survey boxes exhibited a narrowing of range between maxima and minima seabed depths (27 out of 30 WTGs).

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. In the period since the last survey in April 2006, four large wave events were recorded by the North Hoyle wave rider buoy (wave height in excess of 5m) representing storms in excess of 1-in-1 year events. With this in mind it is notable that no further scouring appears to have occurred.

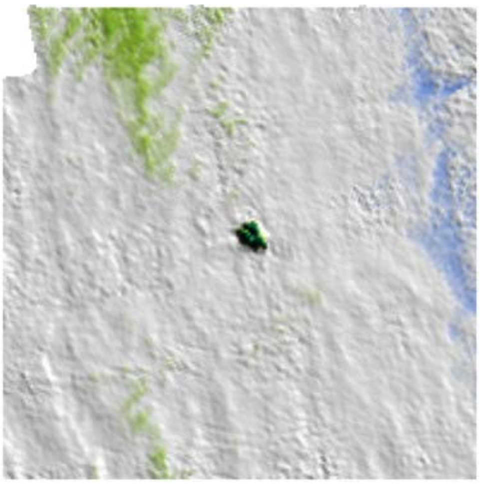

Figure 4.7 3D side scan image of WTG09 showing volume changes since April 2006. The image mostly likely indicates the passage of NNW-SSE trending sand waves. (green = accretion, blue = erosion).

Based upon the latest scour survey results and the absence of any scour at any of the structures surveyed, it is proposed that no further scour surveys are undertaken.

4.3.5 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.

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.

Bathymetry depth change trends across the wind turbine survey boxes, from Osiris surveys, appear to be in a N-S or NW-SE orientation, suggesting that the changes reflect natural sediment movement across the site from linear features such as sand waves and megaripples. Numerous volumetric comparison plots in 2007 provided evidence of sediment movement within the survey boxes consistent with the bedforms shown in the side scan plots.

Scour development was not recorded in 2007 and any previous scour noted was not apparent in the latest survey due to infilling and general accretionary processes.

Environmental implications are effectively negligible as no distinct scour pits have developed. Placement of rock around the J-Tubes has generally remained in-situ with potential movement occurring at 4 locations.

Based upon the most recent survey, it is proposed not to undertake further scour monitoring at the NHOWF. It is concluded that no further scour monitoring is necessary and that the licence condition has been closed out.