Beatrice Offshore Windfarm Ltd

# Beatrice Offshore Wind Farm: Scour Assessment

Report R.1885

February 2012

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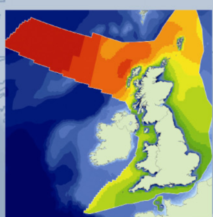


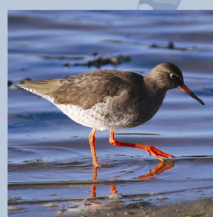

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## Summary

ABP Marine Environmental Research Ltd (ABPmer) has been appointed by Beatrice Offshore Windfarm Limited (BOWL) to consider the physical processes aspect of the Environmental Impact Assessment (EIA) for the proposed Beatrice Offshore Wind Farm.

This report follows the baseline characterisation report (ABPmer, 2011) and provides an assessment of the potential impacts of the proposed wind farm development with regard to structure scale scour in the vicinity of the turbine foundations. These effects have been assessed using the realistic 'worst-case' characteristics of the proposed development as advised by BOWL and/or as presented within the Project Design Statement (PDS) (BOWL, 2011).

This report conservatively considers the interaction between the ambient tide and wave regimes and the proposed foundation options, assuming the absence of scour protection. The methods used are appropriate for the purposes of EIA, but are not intended for use in detailed engineering design.

## Abbreviations

| | |
|---|---|
| ABPmer | ABP Marine Environmental Research Ltd |
| BOWL | Beatrice Offshore Windfarm Limited |
| CEFAS | Centre for Environment, Fisheries & Aquaculture Science |
| CMACS | Centre for Marine and Coastal Studies |
| COWRIE | Collaborative Offshore Wind Research Into the Environment |
| CPA | Coast Protection Act |
| $D$ | Diameter or characteristic length scale of structure |
| DNV | Det Norske Veritas |
| EIA | Environmental Impact Assessment |
| EMU | Environmental Monitoring Unit (Ltd) |
| $G$ | Gap between structures |
| GBS | Gravity Base Structure |
| $KC$ | Keulegan-Carpenter number |
| km | kilometre(s) |
| m | metre(s) |
| m/s | metres per second |
| MORL | Moray Offshore Renewables Limited |
| MW | Megawatt(s) |
| PDS | Project Design Statement |
| $S_e$ | Equilibrium scour depth |
| $S_{extent}$ | Scour extent |
| $S_{footprint}$ | Scour footprint |
| $\sigma_x$ | Standard deviation of x |

# Beatrice Offshore Wind Farm: Scour Assessment

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# 1. Introduction

## 1.1 Overview

ABP Marine Environmental Research Ltd (ABPmer) has been appointed by Beatrice Offshore Windfarm Limited (BOWL) to consider the physical processes aspects of the Environmental Impact Assessment (EIA) for the proposed Beatrice Offshore Wind Farm.

The BOWL application site is located in the north of the Outer Moray Firth, approximately 15 km south east of the Caithness coast, the details of which are found in the Project Design Statement (PDS) (BOWL, 2011).

The purpose of this study is to conservatively quantify the potential for scour formation for the purposes of EIA, and to provide suggestions for mitigation and monitoring requirements. This assessment utilises a variety of empirical approaches to the prediction of scour, which are inherently informed and supported by previously undertaken studies, including monitoring. This report follows and refers to the baseline assessment (ABPmer, 2011).

# 2. Aim of the Assessment

The purpose of this assessment is to quantify the estimated area of seabed that will be altered during the operational phase of the wind farm as a result of the footprint of:

- The turbine foundations; and
- Sediment scour that may develop adjacent to turbine foundations (in the absence of any scour protection).

This assessment is undertaken as a desktop exercise, considering the realistic combinations of foundation types, sizes and layouts, with respect to scour. Scour dimensions are evaluated using standard empirical relationships from the literature (as referenced in the following sections), summary engineering design information (from the developers) and the presently available understanding of the baseline metocean and sedimentary environments (ABPmer, 2011a). The findings of the present study are also consistent with industry engineering guidance (e.g. DNV, 2004), and specific research undertaken in relation to scour around offshore wind farm foundations (e.g. HR Wallingford *et al.,* 2008; ABPmer *et al.,* 2010).

This assessment uses highly conservative approaches to the characterisation of scour potential and is therefore not intended to inform detailed engineering design.

Change to the seabed area in the foundation's footprint (including scour) may be considered as a modification to habitat. The seabed area directly affected by scour may be modified from the baseline (pre-development) or ambient state in several ways, including:

- A different (coarser) surface sediment grain size distribution may develop due to winnowing of finer material by the more energetic flow within the scour pit;
- A different surface character will be present if scour protection (e.g. rip-rap or frond matting) is used;
- Seabed slopes may be locally steeper in the scour pit; and
- Flow speed / turbulence will be locally elevated, on average.

The magnitude of any effect will vary depending upon the foundation type, the local baseline oceanographic and sedimentary environments and the type of scour protection implemented (if needed). In some cases, the modified sediment character within a scour pit may not be so different from the surrounding seabed; however, effects relating to bed slope and elevated flow speed and (near-field) turbulence are still likely to apply. As such, depending upon the sensitivities of the particular ecological receptor, not all scouring effects necessarily correspond to a 'loss' in habitat. No further direct assessment is offered within this document as to the potential impact on sensitive ecological receptors.

# 3. Introduction to Scour

The term scour refers here to the development of pits, troughs or other depressions in the seabed sediments around the base of turbine foundations. Scour is the result of net sediment removal over time due to the complex three-dimensional interaction between the foundation and ambient flows (currents and/or waves). Such interactions result in locally accelerated time mean flow and locally elevated turbulence levels that enhance sediment transport potential in the area of effect. The resulting dimensions of the scour features and their rate of development are, generally, dependent upon the characteristics of the:

- Obstacle (dimensions, shape and orientation);
- Ambient flow (depth, magnitude, orientation and variation including tidal currents, waves, or combined conditions); and
- Seabed sediment (geotextural and geotechnical properties).

Based on the existing literature and evidence base, an equilibrium depth and pattern of scour can be empirically approximated for given combinations of these parameters. Natural variability in the above parameters means that the predicted equilibrium scour condition may also vary over time on, for example, spring-neap, seasonal or annual timescales. The time required for the equilibrium scour condition to initially develop is also dependant on these parameters and may vary from hours to years.

Scour assessment for EIA purposes is considered here for three foundation types: conical gravity base structures (GBS); jacket on pin piles or suction caissons; and jacket on gravity base structures.

The potential concerns under consideration include the seabed area that may become modified from its natural state (potentially impacting sensitive receptors through habitat alteration) and the volume and rate of additional sediment resuspension, as a result of scour.

The assessment presented here is not intended for use in detailed engineering design; however, similar methodologies to those recommended for the design of offshore wind farm foundations (e.g. DNV, 2004) have been used where available and appropriate.

# 4. Assumptions

The following preliminary scour assessment for the proposed Beatrice wind farm reports the predicted equilibrium scour depth. It assumes that there are no limits to the scour development, including time-scale or the nature of the sedimentary or metocean environments. As such, the results of this study are considered to be conservative and provide an (over-) estimation of the maximum potential scour depth. Several factors (discussed in Section A.8) may lead to naturally reduce the equilibrium scour depth, with a corresponding reduction in the area and volumes of effect.

This study makes the basic assumption that the seabed sediments are composed of uniform non-cohesive sediment. This is consistent with the baseline understanding of the Moray Firth in the vicinity of the wind farms (e.g. ABPmer, 2011). Project specific surveys (Osiris, 2011a, CMACS, 2010 and EMU 2011) indicate that seabed sediments upon the banks comprise medium to well-sorted medium sands (typically 200 to 400µm diameter), slightly gravelly sands or gravelly sands that are present in variable thickness across the sites (these surficial sediments are absent or thinner in the shallower parts of the sites but up to 30 m over the underlying glacial till at other locations). Seabed sediments were assessed to be mobile in response to the naturally present wave regime, but not to the tidal regime, except perhaps infrequently during tidal ranges greater than the mean spring condition. Water depths within the array vary from 35 to 55 m and are therefore adopted for all of the structure types being considered.

Scheme, foundation and other details are consistent with the preliminary project design information made available at the time of this assessment by the developers (BOWL, 2011 and MORL 2011). With regards to the present study, the generalised foundation types are broadly similar between the two wind farm developments; differences in foundation dimensions are represented in the range of options tested here and other differences in the design details are not considered to significantly affect the potential scour risk for EIA purposes.

Reported observations of scour under steady current conditions (e.g. in rivers) generally show that the upstream slope of the depression is typically equal to the angle of internal friction for the exposed sediment (typically 32° from horizontal for sands); the downstream slope is typically less steep. In reversing (tidal) current conditions, both slopes will develop under alternating upstream and downstream forcing and so will tend towards the less steep or an intermediate condition. For the purposes of the present study, the angle of internal friction will be used as the characteristic slope angle.

# 5. Equilibrium Scour Depth, Extent and Volume

In the present study, the maximum equilibrium scour depth ($S_e$) is defined as the depth of the scour pit adjacent to the structure, below the mean ambient or original seabed level. The value of $S_e$ is typically proportional to the diameter of the structure and so is commonly expressed in units of structure diameter (*D*).

Scour depth decreases with distance from the edge of the foundation. The scour extent ($S_{extent}$) is defined as the radial distance from the edge of the structure (and the point of maximum scour depth) to the edge of the scour pit (where the bed level is again equal to the mean ambient or original seabed level). This is calculated on the basis of a linear slope at the angle of internal friction for the sediment, i.e.:

$$S_{\text{extent}} = \frac{S_e}{\tan 32°} \approx S_e \times 1.6 \qquad \text{(Eq. 2.1)}$$

The scour footprint ($S_{footprint}$) is defined as the seabed area affected by scour, excluding the foundation's footprint, i.e.:

$$S_{\text{footprint}} = \pi\left(\frac{S_{extent}}{2}\right)^2 - \pi\left(\frac{D}{2}\right)^2 \qquad \text{(Eq. 2.2)}$$

The scour pit volume is calculated as the volume of an inverted truncated cone described by Equations 2.1 and 2.2 above, accounting for the presence of the foundation but excluding its volume.

# 6. Scour Assessment: Gravity Bases Structures

The outline design of the proposed gravity base foundation is shown in Figure 1. The foundation is characterised as a round base plate upon which sits a circular cross-section cone, tapering upwards to a monopile-like section in the middle or upper water column. Four cone base diameters (50 m, 55 m, 60 m and 65 m) are considered in the present study.

The evidence base for scour associated with GBS installations is relatively limited in comparison to that for monopiles and typically refers to oil and gas platforms which have a wide range of shapes and designs. Post-construction monitoring data from the Thornton Bank offshore wind farm (the only site to use GBS foundations so far) is not yet forthcoming in the public domain; however, these GBS structures were installed in conjunction with scour protection measures and so will likely not experience scour. Attempts to produce empirical relationships are complicated by this diversity of 'gravity base' structures.

The pattern and extent of scouring and the location of the point of maximum scouring may also vary depending upon the gravity base's relative size and shape. For the purposes of the present assessment, scour is assumed to be equally present at the predicted depth around the whole perimeter of the GBS, decreasing in depth with distance from the base edge to the ambient bed level at the angle of internal friction for the sediment (32°).

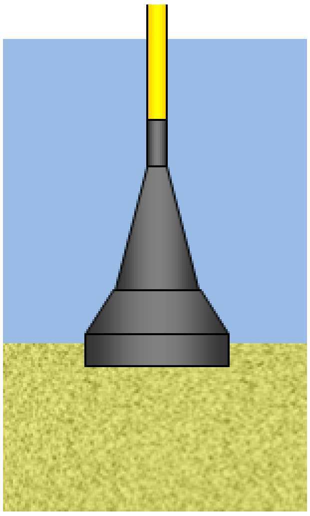

Figure 1. Outline Design of the Proposed Gravity Base Foundation

## 6.1 Under Steady Currents

Relationships for scour associated with a conical top gravity base for currents alone or waves alone are not readily available from the literature. However, Whitehouse (2004) provides relationships for a ‘girder top’ GBS, predicting equilibrium scour depth due to currents alone of

$$S_e = 0.18D \quad \text{(Eq. 2.3)}$$

(where $D$ is the base diameter of the GBS). This would yield values of $S_e$ = 9.0 m, 9.9, 10.8 m and 11.7 m for the 50 m, 55 m, 60 m and 65 m gravity bases respectively. Whitehouse (2004) concluded that the scour depth was controlled in part by the profile and slope of the conical section of the foundation, which may vary depending upon the final design chosen for the developments.

## 6.2 Under Waves and Combined Wave-Current Forcing

Relationships for scour associated with a conical top gravity base for waves alone are also not readily available from the literature. However, Whitehouse (2004) also provides a relationship for a ‘girder top’ GBS, predicting an equilibrium scour depth in response to waves alone of

$$S_e = 0.04D \quad \text{(Eq. 2.4)}$$

This yields values of $S_e$ = 2.0 m, 2.2 m, 2.4 m and 2.6 m for the 50 m, 55 m, 60 m and 65 m gravity bases, respectively.

Empirical results from physical model testing by Whitehouse (2004) suggest that the maximum scour depth around a conical top gravity base (broadly similar to that proposed here) under combined wave-current conditions will be

$$S_e = 0.064D \quad \text{(Eq. 2.5)}$$

This yields maximum scour depths of $S_e$ = 3.2 m, 3.5 m, 3.8 m and 4.2 m for the 50 m, 55 m, 60 m and 65 m gravity bases, respectively. This is considered to be a very worst-case scenario and the actual scour depth achieved is likely to be reduced by either the installation of scour protection or the erosion resistant nature of the underlying geology.

# 7. Scour Assessment: Jacket on Pin Piles or Suction Caissons

The outline design of the proposed jacket foundation is shown in Figure 2. Above the seabed the jacket comprises a lattice of vertical primary members and diagonal cross-member bracing, typically 1.6 m in diameter. The jacket frame will have a nominally square plan view cross-section with base dimensions of approximately 21 m, 24 m or 31 m, depending upon the rating of the turbine it is supporting.

The pin piled option is anchored to the seabed at each corner by a circular pile. The suction caisson option is anchored to the seabed at each corner by a suction caisson (a broad inverted bucket drawn into the sediment) approximately 5 m in diameter.

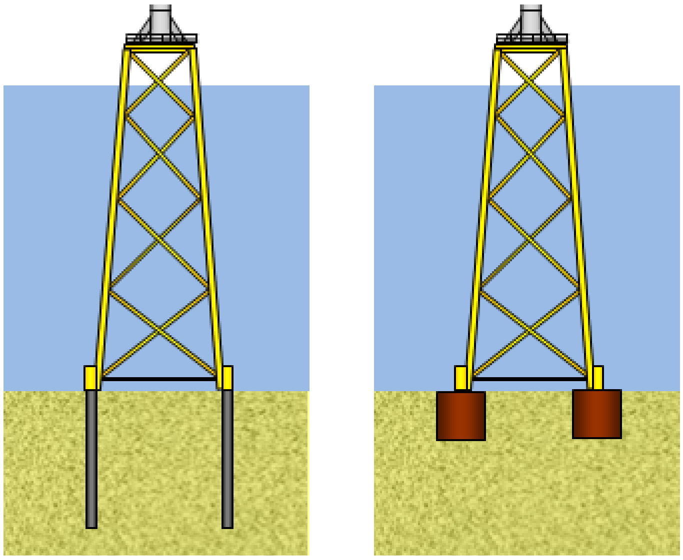

Figure 2. Outline Design of the Proposed Jacket on Pin Pile and Jacket on Suction Caisson Foundations

A jacket structure may result in the occurrence of both local and global scour. The local scour is the local response to individual structure members. Global scour refers to a region of shallower but potentially more extensive scour associated with a multi-member foundation resulting from the:

- Change in flow velocity through the gaps between members of the structure; and
- turbulence shed by the entire structure.

Global scour does not imply the presence of continuous scour at the scale of the wind farm array.

## 7.1 Under Steady Currents

Under currents alone, the equilibrium scour depth around the vertical members of the structure base can be assessed using the same methods as for monopiles, unless significant interaction between individual members occurs. The potential for such interaction is discussed below.

Compared to other more complex foundation types, scour around upright slender monopile structures in steady currents is relatively well understood in the literature and is supported by an empirical evidence base from the laboratory and from the field. Breusers *et al.* (1977) presented a simple expression for scour depth around monopiles under live-bed scour (i.e. scour occurring in a dynamic sediment environment). This was extended by Sumer *et al.* (1992) who assessed the statistics of the original data to show that:

$$\frac{S_e}{D} = 1.3 \pm \sigma_{S_e/D} \qquad \text{(Eq. 2.6)}$$

Where $\sigma_{Se/D}$ is the standard deviation of observed $S_e/D$. Based on the experimental data, $\sigma S_e/D$ is taken to be 0.7, hence, 95 % of observed scour falls in the range $0 < S_e/D < 2.7$. Based on the central value $S_e = 1.3D$ (as recommended in DNV, 2004), the maximum equilibrium depth of scour for a 1.6 m diameter vertical member close to the seabed is estimated to be 2.1 m.

In the case of currents, inter-member interaction has been shown to be a factor when the gap, G, to pile diameter ratio (*G/D*) is less than 3. In this case, limited experiments by Gormsen and Larson (1984) have shown that the scour depth might increase by between 5 and 15 %. However, in the case of the present study the gap ratio for members at the base of this jacket structure is much greater than 3, and so no significant in-combination effect is expected.

Empirical relationships also presented in Sumer and Fredsøe (2002) indicate that global scour (measured from the initial sediment surface to the new sediment surface surrounding local scour holes) for an array of piles similar to a jacket (2x2) can be approximated as $0.4D$ (i.e. approximately 0.64 m based on a 1.6 m cross-member or corner pile diameter).

Together, the predicted maximum scour depth at the corner piles (2.1 m) and the global scour (0.64 m) is conservatively consistent with evidence from the field reported in Whitehouse (1998), summarising another report that scour depths of between 0.6 and 3.6 m were observed below jacket structures in the Gulf of Mexico (although these were potentially constrained from the maximum possible scour depth by environmental factors).

## 7.2 Under Waves and Combined Wave-Current Forcing

The scour mechanisms associated with wave action are limited when the oscillatory displacement of water at the seabed is small relative to the length-scale of the structure around which it is flowing. This ratio is typically parameterised using the Keulegan-Carpenter (KC) number:

$$KC = \frac{U_{0m}T}{D} \qquad \text{(Eq. 2.7)}$$

Where $U_{0m}$ is the peak orbital velocity at the seabed and $T$ is the corresponding wave period. Sumer and Fredsøe (2001) found that for $KC < 6$, wave action is insufficient to cause significant scour in both wave alone and combined wave-current scenarios. Values of the $KC$ parameter were calculated for a 1.6 m diameter jacket member or pin pile from the extreme wave conditions for the Moray Firth sites (Table 1 originally reported in ABPmer, 2011a)

Table 1. Extreme omni-directional wave conditions considered

| Return Period (years) | Significant Wave Height (m) | Peak Wave Period (s) |
|---|---|---|
| 10:1 | 6.7 | 8.8 |
| 1:1 | 8.0 | 9.6 |
| 1:10 | 8.9 | 10.1 |
| 1:50 | 9.2 | 10.3 |

The value of $U_{0m}$ for given (offshore or deep water) wave conditions depends upon the local water depth, which varies from 35 to 55 m within the site; the effects of shoaling and wave breaking have been ignored in the present study (a conservative assumption). Typical values of $KC$ in the deepest parts of the Moray Firth application sites (50+ m) remain below the critical value of 6 under all of the wave conditions shown in Table 1. However, in the shallowest parts of the site (35 m), the 1 in 10 year return period storm and greater may result in a small additional contribution to scour.

The depth of wave induced $S_e$ can be estimated using the following empirical relationship from Sumer *et al.* (1992)

$$\frac{S_e}{D} = 1.3\left(1 - e^{-0.03(KC-6)}\right) \qquad \text{for } KC > 6 \qquad \text{(Eq. 2.8)}$$

The resulting equilibrium scour depth is only <0.2 m during the largest wave events and much smaller for others. As such, little or no significant additional scour is predicted to result from waves, either alone or in combination with currents.

# 8. Scour Assessment: Jacket on Gravity Base

The outline design of this structure is shown in Figure 3. The jacket part is essentially similar to that described in the previous section. The gravity base plinth is a solid circular plate, essentially similar to that described in a previous section, excluding the conical top.

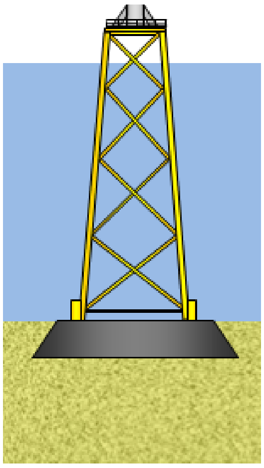

Figure 3. Outline Design of the Proposed Jacket on Gravity Base Foundation

## 8.1 Under Steady Currents

Using Equation 2.3 for a 'girder top' gravity base structure, the equilibrium scour depth due to currents alone is estimated as $S_e$ = 9.0 m, 9.9 m, 10.8 m and 11.7 m for the 50 m, 55 m, 60 m and 65 m gravity bases, respectively.

## 8.2 Under Waves and Combined Wave-Current Forcing

Using Equation 2.4 for a 'girder top' gravity base structure, the equilibrium scour depth due to waves alone is estimated as $S_e$ = 2.0 m, 2.2 m, 2.4 m and 2.6 m for the 50 m, 55 m, 60 m and 65 m gravity bases, respectively.

Using Equation 2.5 for a 'conical' gravity base structure (likely an over-estimate in this case), the equilibrium scour depth due to waves and currents combined is estimated as $S_e$ = 3.2 m, 3.5 m, 3.8 m and 4.2 m for the 50 m, 55 m, 60 m and 65 m gravity bases, respectively.

# 9. Factors Affecting Equilibrium Scour Depth

As summarised in Whitehouse (1998), a number of factors are known to influence equilibrium scour depth for monopiles, contributing to the range of observed equilibrium scour depths. These factors include the:

- Frequency and magnitude of ambient sediment transport;
- Ratio of structure diameter to water depth;
- Ratio of structure diameter to peak flow speed;
- Ratio of structure diameter to sediment grain size; and
- Sediment grain size, gradation and geotechnical soil properties.

In particular, the relatively low energy tidal current regime within the Moray Firth, which limits both the frequency and magnitude of sediment transport, actually maximises the scour that can potentially develop (i.e. corresponding to that provided by the relationships used here), as the scour hole is not simultaneously being (partially) in-filled by ambient sediment transport.

The above factors have been considered in the context of the Moray Firth application sites and were not found to significantly affect the predicted values for EIA purposes. As exemplified above, the effect of these factors where they do apply is to reduce the depth, extent and volume of the predicted scour, hence providing a less conservative estimate.

# 10. Time for Scour to Develop Around the Foundation Options

Using empirical relationships from Whitehouse (1998), and making the assumption of a mobile uniform non-cohesive sediment substrate, the time required for the majority of scour pit development around all foundations is estimated to be within the order of 6 to12 hours under flow conditions sufficient to induce scour. (Near) symmetrical scour will only develop following sufficient exposure to both flood and ebb tidal directions. Waves typically do not cause rapid initial scour directly but can increase the rate of initial scour development.

# 11. Summary of Results

Based on the analysis undertaken above for the three foundation types, Table 2 summarises the key results of the first-order scour assessment contained in the preceding sections. Results conservatively assume maximum equilibrium scour depths are symmetrically present around the perimeter of the structure or jacket members in a uniform and frequently mobile sedimentary environment. Derivative calculations of scour extent, footprint and volume assume an angle of internal friction = 32°. Scour extent is measured from the structure's edge. Scour footprint excludes the footprint of the structure. Scour pit volumes for gravity base and jacket on gravity base foundations are calculated as the volume of an inverted truncated cone, minus the structure volume; scour pit volume for the jacket foundations are similarly calculated but as the sum of that predicted for each the corner piles.

Values for single foundations are scaled up in Table 3 by the anticipated total number in the BOWL application site to summarise the total seabed area directly affected by each foundation type, with and without the presence of scour.

Equivalent values for the MORL development site are given in Table 4. The worst case number of turbines and development footprint on the seabed is derived from a combination of information provided by MORL regarding turbine numbers and foundation size, and conservative assumptions made by BOWL regarding the likely extent of scour protection. Whilst it is accepted that the worst case presented here may represent an overestimate of the number of turbines and development footprint, it is considered to be a sufficiently conservative approach for the purposes of cumulative assessment. Combined values for the BOWL and MORL application sites together are shown in Table 5.

Table 3 to Table 5 show that scour can significantly contribute to the total footprint of the impact of foundations on the seabed within the site boundary. However, the area of effect as a proportion of the wind farm site(s) as a whole remains relatively small and is a much smaller proportion again of all the available seabed area of this type in the regional area.

Table 2. Summary of predicted maximum scour depth assuming uniform, erodible sediment

| | Foundation Option | | | | | | |
|---|---|---|---|---|---|---|---|
| | Monotower and Gravity Base or Tubular Jacket and Gravity Base | | | | Tubular Jacket and Pin Piles or Tubular Jacket and Suction Caissons | | |
| | 50m | 55m | 60m | 65m | 21 m | 24 m | 34 m |
| Equilibrium Scour Depth (m) | | | | | | | |
| Steady current | 9.0 | 9.9 | 10.8 | 11.7 | 2.1 | 2.1 | 2.1 |
| Waves | 2.0 | 2.2 | 2.4 | 2.6 | *Insufficient to cause scour* | | |
| Waves and current | 3.2 | 3.5 | 3.8 | 4.2 | 2.1 | 2.1 | 2.1 |
| Global scour | 0.0 | 1.0 | 0.0 | 0.0 | 0.6 | 0.6 | 0.6 |
| Scour extent from foundation* (m) | 14.4 | 15.8 | 17.3 | 18.7 | 3.3 | 3.3 | 3.3 |
| Scour footprint* ($m^2$) | 2,914 | 3,526 | 4,196 | 4,925 | 206 | 206 | 206 |
| *Structure footprint ($m^2$)* | *1,963* | 2,376 | *2,827* | *3,318* | *8* | *8* | *8* |
| Scour volume** ($m^3$) | 12,136 | 16,153 | 20,971 | 26,663 | 2,894 | 3,559 | 6,299 |
| * Based upon the scour depth for steady currents. Footprint and volume values per foundation | | | | | | | |

Table 3. Total footprint of the different foundation types with and without scour: BOWL Offshore Wind Farm

| | BOWL Foundation Option | | | | | |
|---|---|---|---|---|---|---|
| | Monotower and Gravity Base or Tubular Jacket and Gravity Base | | | Tubular Jacket and Pin Piles or Tubular Jacket and Suction Caissons | | |
| | 50m (3.6 MW) | 60m (6 MW) | 65m (7 MW) | 21 m (3.6 MW) | 24 m (6 MW) | 34 m (7 MW) |
| Number of foundations* | 277 | 166 | 142 | 277 | 166 | 142 |
| Footprint on seabed of all foundations ($m^2$) | 543,888 | 469,354 | 471,200 | 2,228 | 1,335 | 1,142 |
| *Proportion of site area (%)* | *0.414* | *0.357* | *0.359* | *0.002* | *0.001* | *0.001* |
| Footprint on seabed of all foundations + scour ($m^2$) | 1,351,103 | 1,165,948 | 1,170,533 | 59336 | 35,559 | 30,418 |
| *Proportion of site area (%)* | *1.028* | *0.887* | *0.891* | *0.045* | *0.027* | *0.023* |

Table 4. Total footprint of the different foundation types with and without scour: MORL Offshore Wind Farm

| | MORL Foundation Option | |
|---|---|---|
| | Monotower and Gravity Base or Tubular Jacket and Gravity Base | Tubular Jacket and Pin Piles or Tubular Jacket and Suction Caissons |
| | 50m (Combination of 3.6 and 5 MW turbines) | 21 m - 34 m (3.6 - 7MW) |
| Number of foundations* | 420 | 420 |
| Footprint on seabed of all foundations ($m^2$) | 824,668 | 3,378 |
| *Proportion of site area (%)* | *0.278* | *0.001* |
| Footprint on seabed of all foundations + scour ($m^2$) | 2,048,604 | 89,967 |
| *Proportion of site area (%)* | *0.690* | *0.030* |

Table 5. Total footprint of the different foundation types with and without scour: BOWL and MORL Offshore Wind Farms

| | Foundation Option | | | | | |
|---|---|---|---|---|---|---|
| | Monotower and Gravity Base or Tubular Jacket and Gravity Base | | | Tubular Jacket and Pin Piles or Tubular Jacket and Suction Caissons | | |
| | 3.6 MW | 6 MW | 7 MW | 3.6 MW | 6 MW | 7 MW |
| Number of foundations* | 697 | 586 | 562 | 697 | 586 | 562 |
| Footprint on seabed of all foundations (m2) | 1,368,556 | 1,294,022 | 1,295,868 | 5,606 | 4,713 | 4,520 |
| *Proportion of total site area (%)* | *0.319* | *0.302* | *0.302* | *0.001* | *0.001* | *0.001* |
| Footprint on seabed of all foundations + scour (m2) | 3,399,707 | 3,214,552 | 3,219,137 | 149,303 | 125,526 | 120,385 |
| *Proportion of total site area (%)* | *0.794* | *0.750* | *0.751* | *0.035* | *0.029* | *0.028* |

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