APPENDIX 4.7 VIKING WIND FARM DESIGN PROCESS

1.1 INTRODUCTION

This Appendix explains, describes and illustrates the design process developed and implemented for the Viking Wind Farm. The design process had two main objectives:

- To design a wind farm layout that achieves an appropriate balance between commercial factors (primarily construction cost and electrical productivity), and environmental impact, whilst meeting technical requirements.
- To record and explain the basis on which design decisions were made.

The report summarises the design factors, describes the design process, and illustrates the design evolution and key changes made. Please refer to figures in Volume 4b, Appendix Figures.

1.2 CONSTRAINTS AND REQUIREMENTS

1.2.1 Legal, technical & commercial factors

(a) **Land ownership**

Agreement with relevant landowners is required in order to develop, construct and operate a wind farm. The Viking Energy Partnership has negotiated leases with landowners as illustrated in Appendix Figure 4.7.1. The leased area consists of a buffer region 75m either side of the proposed track alignment, and 75m around the sites of infrastructure (turbines, masts, substations etc.) The exact extent of the leased area will be finalised prior to construction.

(b) **Wind Resource**

The electrical output of a wind turbine depends upon the wind speed at its location, typically measured as mean annual wind speed. Mean annual wind speed, and therefore wind turbine output varies locally with topography. In general, wind speed increases with altitude, with windward slopes creating a ‘speed up’ effect, and leeward slopes reducing wind speeds. The Viking site has a relatively varied topography, and hence variations in wind speed occur across the site; but it also has an extremely good wind resource, as illustrated in Appendix Figure 4.7.2a and 4.7.2b. A design objective is therefore to place turbines in locations with the greatest wind resource.

(c) **Slope gradients**

Slopes will alter the direction of wind flow locally, and this can both create turbulence and cause wind flow through the rotor at an angle which is oblique to the rotor plane. This is likely to result in undue mechanical fatigue on the turbine. Consequently manufacturers specify slopes gradients which are likely to be unsuitable for turbine locations, with 10° being a typical value for the steepest permissible slope. Appendix Figure 4.7.3 illustrates areas within the site where slopes exceed 10˚ and consequently these areas are constrained out. In addition, track gradients for turbine component abnormal loads are limited to about 8˚.

(d) **Turbine separation**

Wind turbines create downwind turbulence. This has two consequences: firstly, it can induce mechanical fatigue in other turbines located in the wake; secondly, it will reduce the output of other turbines in the wake (also known as array losses). Consequently, design criteria of five rotor diameter minimum separation downwind (550m) and four rotor diameter minimum separation across wind (440m) have been adopted as the starting position in this case, in accordance with typical manufacturer specifications. The turbine density needs to balance the benefits of increasing separation, and hence reducing turbulence and array losses, against reducing the capacity that can be installed in a given area, and hence the capacity and output of the overall wind farm. In certain circumstances the overall output of a wind farm can be increased by reducing the number of turbines and hence reducing array losses.

Turbine separations were reviewed during the course of the design process with the final layout being verified by a typical turbine manufacturer.

(e) **Number of wind turbines**

A specific economic factor of the Viking Wind Farm project is the requirement to construct and operate a sub sea cable to export power to the mainland. The cost of constructing and operating the cable is recovered by way of a Transmission Network Use of System charge (TNUoS). It is likely that the TNUoS charge for a project in Shetland will be significantly higher than for a comparable project on the mainland. Although the final details of the TNUoS are still to be determined, significant progress has been made in that direction. Initial indications in the design process were that a wind farm and cable capacity of circa 550-600MW should be economic. Review of commercially available wind turbines indicates that machines of circa 3.6MW should be both available and suitable for the Viking Wind Farm. Consequently the initial design was based upon 167 such 3.6MW turbines (giving a total installed capacity of 601MW), but an ongoing aim was to maximise the number of turbines to maximise the economic benefit of the project. Indeed, an early consultation layout design consisted of 192 turbines.

1.2.2 Environmental factors

(a) **Landscape and Visual**

It is important to note that this was a coarse-grained exercise in order to help determine initial constraints to development. It was followed during the design process by a more fine-grained approach based on more detailed knowledge, site-based data and liaison with other specialist design team members, which incrementally resulted in further reductions in the extent of development and turbine numbers.

Initial landscape constraints

In order to inform the location and layout, an evaluation of the sensitivity of the landscape to the proposals was carried out by using the same methodology described in Chapter 8.

The degree of sensitivity of landscapes to change will vary in accordance with the importance of the landscape concerned and the contribution it makes (positively or negatively) to the local, regional and national landscape. An evaluation of the sensitivity of a landscape to change in relation to windfarm development was informed by a review of landscape value and scenic quality.

Landscape value is frequently addressed by reference to international, national, regional and local designations, determined by statutory and planning agencies. Figure 4.7.4a illustrates these relevant areas shown here within a 15km distance from the ultimate periphery of the proposed development.

An evaluation of Scenic Quality was also carried out over the same area. This has been mapped in Figure 4.7.4b (and is repeated in Chapter 8, Figure 8.1). Note that areas of scenic quality and landscape character areas do not necessarily coincide.

The review of landscape value and scenic quality led to an evaluation of landscape sensitivity to wind farm development. This is described in more detail in Chapter 8, but is mapped here in Figure 4.7.4c (and is repeated in Chapter 8, Figure 8.6).

The broad landscape constraints after this exercise was completed, stipulated that development should be restricted to undesignated landscape character areas of low or low-medium sensitivity to wind farm development. In this way, the proposals were directed away from being sited within or adjacent to, the most valued, scenic, smaller scale and sensitive landscapes of the Shetland Islands; instead, limiting development to those larger scale landscapes of the Mainland which, taking into account the foregoing evaluation, were considered potentially less sensitive to windfarm development.

Initial visual constraints

In order to mitigate potential impacts upon visual receptors, wherever possible the foreground screening effect of local topography and ridge-lines was utilised in order to either eliminate or reduce views of turbines. The extent of the resultant setback of turbines from potential receptors was guided by the use of Zone of Theoretical Visibility (ZTV) diagrams and also “Wind Farm” software which permitted changes in turbine locations to be correlated to wireframe projections. Unfortunately due to the local juxtaposition of settlement and topography it was not always possible to achieve this objective; for example where receptors are orientated directly towards the proposals and/or elevated, in combination with a foreground of either sea, or gently sloping hills and with no foreground ridges which could otherwise have assisted with screening.

The layout was also guided by consideration of important views from National Scenic Areas (NSAs) and other sensitive landscape areas and from Historic and Designed Landscapes, again guided by the use of “Wind Farm” software which permitted changes in turbine location to be correlated using wireframe projections.

The following general principles were also observed wherever possible:

- To create a more cohesive design, turbines were clustered in groups, but avoided situations where individual turbines combined visually to create a seemingly solid mass from certain viewpoints; and the layout also attempted to avoid outlying individual turbines;
- Valleys and valley sideslopes were avoided and turbine groups were positioned in order to reflect the form of the local landscape; in the case of the Mid-Kame Ridge, providing a strong composition reflecting the linearity of this feature;
- Existing access tracks were utilised as appropriate and elsewhere they were generally positioned to follow contours and avoid valley sideslopes and steep gradients;

- Borrowpits were sited wherever possible in locations which avoid or minimise intervisibility with receptors and are to be reinstated using existing peat topsoil and associated native seed - bank which will then be allowed to naturally regenerate.

(b) **Ornithology**

The objective of the design process with respect to birds was to minimise as far as practical the risk of collision and disturbance, prioritising species according to their sensitivity and the practicality of mitigation by design. Thus it was more practical to consider species that exhibited consistent and localised patterns of spatial activity, rather than species that were numerous and more uniformly distributed.

It was concluded from a review of ornithological data that areas subject to the highest levels of red throated diver flight activity were likely to constitute the ornithological constraint of greatest spatial extent. Appendix Figure 4.7.5a is a map showing the relative sensitivity of red-throated divers to flight collision across the Viking Site. This map reflects the levels of diver flight activity observed during fieldwork taking account of effort. The basis of the four zones can be summarised as follows: ‘Low flight activity’, areas that were only occasionally flown over; ‘Medium flight activity’, areas that were flown over regularly but were outwith the main flight routes; ‘High flight activity’, areas that formed the main flight routes of a single pair; ‘Very high flight activity’, areas that formed the main flight routes of more than one pair.

Figure 4.7.5b shows the relative sensitivity to disturbance of birds of high conservation value on the Viking Site. This was produce by assigning an importance score to each of thirteen species ranging from 1 to 8, buffering the location of each species’ locations by an appropriate distance and then summing the scores for every part of the map and smoothing the results.

The species included in order of importance were: red-throated diver, merlin, whooper swan, whimbrel, arctic skua, arctic tern, dunlin, golden plover, common tern, greylag goose, curlew, red grouse and black-headed gull.

(c) **Noise**

The objective of the design process with respect to noise was to develop a turbine layout which would achieve compliance with the noise limits set out in ETSU-R-1997 at residential properties. In simple terms, the turbine noise at a property is a function of the distance to each turbine, the number of turbines, and the noise specification of the turbine. Noise was therefore a second order constraint spatially, tending to affect the location of turbines around the periphery of the wind farm in the vicinity of noise sensitive receptors (Figure 4.7.6).

(d) **Cultural Heritage**

The objectives of the design process with respect to cultural heritage were to:

- Avoid direct disturbance of cultural heritage sites; and
- to minimise adverse effects on the setting of cultural heritage sites.

The localised distribution of cultural heritage sites in the vicinity of the site resulted in cultural heritage being a second order constraint spatially, typically requiring micrositing in the vicinity of sites. However, Lunna House and its associated Designed Landscape proved to be a constraint of greater spatial extent both for cultural heritage and landscape character reasons.

(e) **Ecology**

The objective of the design process with respect to ecology was to minimise as far as practical disturbance to the most valuable habitats and species. The habitat on the site is relatively homogenous, and therefore did not present a significant spatial constraint. Species which were taken into account at this early stage, notably otter and fresh water pearl mussel, also present only a local constraint which would be considered during final micro-siting at the construction stage in light of more recent surveys. As it turned out, later surveys showed that the wind farm would have only minimal effects upon these species.

(f) **Water resources and peat**

The objectives of the design process with respect to water resources and peat were to:

- Minimise the risk of pollution;
- minimise adverse effects on the site's surface water hydrological regime;
- minimise adverse effects, and if practical generate beneficial effects, on the site's peatland hydrological regime; and
- minimise the risk of peat slides.

The objectives can be most readily achieved, in terms of design, by maintaining appropriate separation distances from water bodies, by designing tracks and any associated drainage that preserves or restores the natural pattern of hydrology, and by avoiding areas assessed as having a high risk of peat slide. This presents only a local constraint. Figure 4.7.7 indicates water resources which were taken into account at this early stage.

1.3 THE DESIGN PROCESS

1.3.1 Introduction

A phased approach was adopted for the design process, with each successive phase adding a greater degree of refinement. Consequently the earlier phases considered factors that shaped the general development boundary (i.e. coarse constraints), with later phases considering factors that influenced the specific development boundary, and the arrangement of development structures within it (i.e. fine constraints). Different factors may influence wind farm design to a different spatial extent from one site to another, according to local circumstances. Consequently, site data relating to technical and environmental constraints relevant to the design were considered in order to determine at which phase they should be applied, in this specific case. It should be noted that the constraints are ordered in terms of their spatial extent, and not necessarily their priority.

The initial phases of the design process considered only turbine locations. Additional development elements, such as tracks, anemometers, and sub-stations, were considered later, since their locations will primarily be influenced by turbine location.

The design process involved 8 phases, each phase being supplemented by a review of consequences of later changes on earlier phases.

1.3.2 Phase 1 – Technical Factors

Phase 1 considered only the land ownership boundary and slope gradients as constraints, and wind resource and turbine spacing as optimisation factors. Figure 4.7.8 presents the turbine layout that resulted from running proprietary wind farm optimisation software. This layout comprised 192 turbines.

1.3.3 Phase 2 – Macro landscape and visual constraints

Phase 2 constrained out areas identified as coarse landscape and visual constraints. Figure 4.7.9 presents the resultant turbine layout. The important changes in this iteration included reducing the number of turbines in the Collafirth quadrant from 20 to twelve in response to the requirements of visual receptors at Lunna and Voe; moving turbines in north-east nesting significantly further from receptors around Dury Voe; and reducing the spread of turbines in north and south Delting and south Kergord. The resultant layout consisted of 167 turbines.

1.3.4 Phase 3 – Macro Red Throated Diver constraints

In addition to previously considered factors, Phase 3 constrained out areas with the highest levels of red throated diver activity. Figure 4.7.10 presents the resultant turbine layout. At this stage the number of turbines in Collafirth was further reduced to eight, and the turbines linking South and North Nesting (across a significant area of red throated diver activity) were deleted. The resultant layout consisted of 160 turbines.

1.3.5 Phase 4 – Key viewpoint optimisation (1)

Two issues raised prominently in the public consultation exercise were views from settlements in the vicinity of the site, and the perceived extent of the wind farm. In addition, SNH identified the designed landscape at Lunna House as an important visual receptor. Consequently key visual receptors were identified for design purposes[1] to address these issues as follows:

- Lunna House;
- Voe;
- Aith;
- Brae;
- Laxo; and
- Weisdale.

Wire frames of the Phase 3 layout were produced for each viewpoint, in order to inform the Phase 4 revisions.

In the course of Phase 4, a number of turbines were relocated to the Kergord quadrant from other quadrants, necessitating a major redesign there. Prior to optimising the visual composition of the Kergord quadrant, the design was also revised with the objective of establishing a greater separation from the area of greatest red throated diver flight activity.

[1] These viewpoints were selected for design purposes; additional viewpoints have been selected for environmental impact assessment purposes

Figures 4.7.11 to 4.7.16 illustrate the views from these locations before and after Phase 4 revisions.

1.3.6 Phase 5 – Micro constraints

In addition to previously considered factors, Phase 5 considered constraints which may affect layout on a local rather than site level.

(a) Detailed bird constraints

Red-throated diver activity data were reviewed to ensure that turbines were sited in the best locations for divers at the detailed level, following the macro constraints evaluation which had taken place at Phase 3. This allowed detailed micro-siting of turbines near areas of diver activity. Similarly, the location of breeding merlin territories was reviewed with the objective of establishing exclusion zones for areas near to territory centres.

(b) Noise

A noise model was run to establish whether the layout would meet the noise objectives. No changes resulted from this process.

(c) Cultural heritage

The layout was reviewed against cultural heritage constraints[1]. As a result of this review one turbine was deleted near Laxo Burn.

(d) Water resources

Advisory buffer zones were developed according to stream orders, as follows:

1. 1st order stream: 75m
2. 2nd order stream: 50m
3. 3rd order stream: 25m

Turbines were relocated to achieve the advised buffer zone, or where this was not feasible, to ensure that as great a separation from water bodies as practical was achieved.

(e) Peat slide risk

The turbine locations were reviewed against high level peat slide risk assessment and peat depth maps[2].

(f) Ecology

The turbine locations were reviewed against habitat maps. Although the layout impinges on some areas recognised as being of high ecological value, no feasible alternative locations were identified and hence no changes were made.

---

[1] The setting of Lunna House was considered in the visual optimisation stage

[2] interpolated from sample peat probing transects

(g) **Turbulence analysis**

Draft Layout 5 was analysed using a computational fluid dynamics model to check that turbines would not be subject to unacceptable turbulence intensity or wind inflow angles. A number of minor changes resulted from this process, principally connected with avoiding downwind turbulence effects on nearby turbines. The changes were then subjected to review in relation to earlier design constraints to ensure that no conflicts had arisen as a result of these changes.

(h) **Key viewpoint optimisation (2)**

The key design viewpoints used for Layout 4 were reassessed using the draft Layout 5, and changes made as necessary to meet the landscape and visual objectives. Once again, the changes were subjected to review in relation to earlier design constraints to ensure that no conflicts had arisen as a result of these changes.

Following the Key Viewpoint Optimisation and the Micro Constraint Analysis the number of turbines had been reduced still further to 150. The final turbine layout is shown in Figure 4.7.17.

1.3.7 Phase 6 – Tracks

The track layout was designed to take account of the Track Layout Design Strategy (Appendix 4.1), and other local environmental constraints. The peatland design strategy aimed to minimise the adverse effects of track construction on peatland hydrology, and, where practical, to improve the peatland hydrology. The strategy is based upon implementing a hierarchy for peat condition and topography, summarised in order of routeing preference, as described in Appendix 4.1.

Draft Layout 6 was also reviewed in terms of birds, cultural heritage, water resources, peat slide risk and ecology before the layout was finalised.

The final track layout is shown on Figure 4.7.17.

1.3.8 Phase 7 – Additional infrastructure

(a) **Anemometers**

Anemometers are to be located in areas that are representative of wind conditions encountered within the turbine array, and ideally are located outwith the array. The locations proposed for the anemometers have been reviewed in terms of birds, cultural heritage, water resources, peat slide risk, ecology and landscape and visual impact. As a result of this review the locations were left unchanged but the design of the masts was changed from guyed to unguyed, to reduce collision risk to birds. Anemometer locations are shown on Figure 4.7.17.

(b) **Construction compounds**

Construction will require a main construction compound and lay down area, and satellite compounds to service each quadrant. It is proposed to site the main construction compound at Sella Ness, since there are existing hardstanding areas to accommodate both construction compound and main laydown areas. The requirements for the satellite compounds are the existence of a reasonably flat and level site, and that they can be established relatively early in the construction (near the main access points). The sites proposed have been reviewed in terms of birds, cultural heritage, water resources, and ecology. Construction compound locations are shown on Figure 4.7.17.

(c) **Borrow pits**

Borrow pits need to be sited in areas of suitable rock quality and availability, and in locations which are convenient for construction. The final choice of borrow pit locations will be made by the civil contractors, informed by site investigations, but the potential sites proposed have been reviewed in terms of birds, noise, cultural heritage, water resources, peat slide risk, ecology, and landscape and visual effects. Locations for borrow pit "areas of search" are shown on Figure 4.7.17.

(d) **Sub-stations / control buildings**

Sub-stations and control rooms need to be located:

- On a suitable level site;
- away from areas of flood risk;
- in reasonable shelter;
- in a reasonably accessible place;
- within or close to the turbine array, to minimise 33kV cabling distances;
- as close as practical to the convertor station to minimise 132kV overhead line / underground cable distances.

It was decided that the preferred option is to have a local sub-station servicing the Delting quadrant; another servicing South Nesting; and other parts of the wind farm to be serviced by a larger substation adjacent to the convertor station at Upper Kergord. This option balances the benefits of local subs-stations against the environmental benefit of concentrating the electrical infrastructure in a single location. The proposed sub-station sites have been reviewed in terms of birds, noise, cultural heritage, water resources, ecology, and landscape and visual effects.

1.3.9 Final Review and Ground Truthing

The final stage in the design process was to revisit the design from first principles to ensure that all constraints had been accounted for and that no new constraints arose when the final layout design was surveyed on the ground.