Kyleakin Fish Feed Factory

Marine Harvest

Environmental Impact Assessment - Volume 2 of 4: Main Report

Chapter 18: Coastal Processes and Geomorphology

May 2017

Final

Contents

Appendix 18.1: Kyleakin Pier Development Hydraulic Modelling Report, RPS 2016

Appendix 18.2: Kyleakin Geotechnical Survey, ALHS 2016

Appendix 18.3: Kyleakin Pier Dredging Addendum, RPS 2017

Appendix 18.4: Response to comments made by SNH email 28th December 2016

Appendix 18.5: Response to comments made by SNH email 28th December 2016 as applied to the Addendum (see Appendix 18.3) to the report

18. Coastal Processes and Geomorphology

18.1 Introduction

This section of the Environmental Statement (ES) identifies the potential changes arising from the Proposed Development on coastal processes. These include wave climate, tidal regime, sediment pathways and how they might affect seabed morphology, in particular the morphology of sensitive habitats.

The Proposed Development will incorporate the capital dredging of an area of seabed covering approximately 5.8 hectares. Material will be removed to a minimum depth of -8.5 m Chart Datum (CD). Over the duration of the capital dredging, approximately 190,000 m^3 of material will be removed from the immediate area and placed in the quarry for re-use in the construction process (**see Chapter 2: Project Description**).

To help assess the potential changes dredging might have on coastal processes, modelling of the wave and tidal regime has been carried out. To this extent, the coastal processes chapter provides quantitative predictions of changes in wave and tidal flows derived from model outputs.

To help understand the potential effects on sediment movement from the Proposed Development a sediment transport model, informed from the outputs of the wave and flow models, has been carried out (**Appendix 18.1**). Similarly, to understand how the sediment plume generated during the capital dredging programme, could ultimately affect the marine receptors, sediment plume modelling was carried out covering several potential dredging scenarios. This predicted, amongst other things, the likelihood and extent of sediment dispersion and subsequent deposition.

An assessment was also carried out to determine the side slope stability following capital dredging i.e. the effects of coastal processes on the morphology of the dredged slope(s) and whether these would be likely to relax (slump) over time. Should 'slumping' occur then consideration would be given to the future effects this might have on coastal processes.

In March 2017, after discussions with a number of dredging contactors, it is anticipated that all dredging would be carried out by backhoe dredger (BHD), within both the inner and outer dredge areas (see **Chapter 2**). To acknowledge this change to the dredging methodology further sediment plume modelling was carried out (**Appendix 18.3**), with the conclusions being used to inform the assessment within this chapter.

18.1.1 Key Consultation Considerations

Within the Scoping Opinions received (**see Chapter 3: Development Design and Alternatives** and **Appendix 1.1: Scoping Opinion, 2016**) were several comments relating to the understanding and possible modelling of coastal processes. Marine Scotland Science (MSS) stated that '*investigations need to include all aspects of the physical environment, such as sediments (sediment plumes for example, especially considering the proximity to the MPA), hydrodynamics (for example changes to tides and currents), water quality (and subsequent effects on the flame shells), coastal processes, sea level rise mitigations, and storm surge events*.'

Scottish Natural Heritage (SNH) stated that '*assessment of indirect impacts will likely be informed by modelling of changes in water movement and resulting changes in bathymetry and bed sediment. There should be separate modelling for construction and operational phases'* (**Appendix 1.1**).

In terms of the Water Framework Directive 2000/60/EC (WFD) it was the opinion of the Scottish Environment Protection Agency (SEPA) that *'there is unlikely to be any significant impact upon hydromorphological status in this water body from these works. So long as the designated sites and Marine Protection Area are protected then the River Basin Management Plan and Water Framework Directive objectives will be fulfilled*' (**Appendix 1.1**).

During a meeting in summer 2016 (26/7/16) with Marine Scotland Licencing Operations Team (MS-LOT), SNH, SEPA and the Highland Council, Marine Harvest sought further advice from the regulators on the proposed modelling work. Written responses were received from MSS (8/8/16) and from SNH (30/7/16 and 8/8/16) in relation to the proposed modelling. In development of their modelling studies and report, RPS has been mindful of these comments. Among the comments received from SNH (30/7/16 and 8/8/16) were the need to consider propeller wash, boat wake and how changes in the dredged slopes (should they occur) would be fed back into the overall modelling. Consequently, these points are addressed within this chapter.

Following the meeting (26/7/16) further discussion was had with SEPA on the overall assessment process. It was acknowledged by SEPA that no discrete WFD assessment would be required (**see Chapter 17: Water Quality and Marine Sediment**). However, it was requested that some commentary in the ES be provided on whether there would be any significant impact on overall water body status. This would include acknowledgment of any effects on geomorphology/hydromorphology and water quality (**see Chapter 17**). Consideration should also be given to the potential effects on biota from the introduction of non-native species. It should be noted that the potential for introduction of non-native species is dealt with in **Chapter 19: Marine Ecology**; as it is these receptors which their introduction would ultimately impact.

In late December 2016 (28/12/16) SNH requested clarification on the hydrodynamic modelling studies, their findings and the consequent assessments in relation to three separate issues. These queries covered:

1. Seabed change, specifically in relation to sediment transport modelling, and why this had not been assessed from large storms i.e. 100 year storm events.

2. Why sediment plume modelling did not factor in winds stronger than Force 3 southerly, and why winds from the west or WSW were not considered.

3. Whether the potential for short-term deposition of dredged material, specifically over the flame shell bed, had been overlooked.

On the 9th January 2017 a detailed response was provided to SNH against each of these queries (**Appendix 18.4**). This response was taken into account by SNH in their advice to The Highland Council (20/01/17) in relation to determination of the planning application under the Town and Country Planning (Scotland) Act 1997 for the construction of the Proposed Development (ref: 16/03869/FUL). At which time (20/01/17) SNH withdrew their earlier objection to the Proposed Development.

To acknowledge the recent modifications to the dredging methodology (see **Chapter 2**) the previous responses to the clarifications requested by SNH (28/12/16) have been adapted and are appended for ease of reference (**Appendix 18.5**). However, where appropriate, the key content of these responses has been incorporated into this chapter.

18.1.2 Structure of Chapter

Due to the nature of the assessments (**Section18.3**) the structure of this chapter varies slightly from that of the generalised approach provided for the other technical chapters and covers:

- Legislation, Policy and Guidance.
- Methodology.
- Baseline Conditions.
- Modelling and Studies.
- Predicted Changes.
- Mitigation Measures.
- Overview.

18.2 Legislation, Policy and Guidance

Although no specific legislation is available that covers coastal processes in isolation, WFD assesses ecological status of waterbodies on a number of elements including hydromorphology and water quality (**see Chapter 17**).

Hydromorphology encompasses geomorphology and hydrology. Hence potential changes to coastal processes and how this might affect geomorphological features is a consideration of the hydromorphology element to the WFD.

The WFD was transposed into Scottish law by the ‘Water Environment and Water Services (Scotland) Act 2003’ (WEWS Act) (Scottish Executive, 2003) (**Ref 18-1**). This aims to classify surface waters according to their ecological status and sets targets for restoring/improving the ecological status of water bodies. The objectives of the Directive aim for 'Good status' for all ground and surface waters (rivers, lakes, transitional waters, and coastal waters) in the EU. Hydromorphology is one of several characteristics against which ecological status is assessed.

Marine Scotland is a designated authority under the WEWS Act (Scottish Executive, 2003)) and should ensure that marine licensing assists in the delivery of River Basin Management Planning (RBMP) objectives. River basins comprise all transitional (estuaries) and coastal water bodies extending to three nautical miles seaward from the territorial baseline. Any proposed development within three nautical miles must have regard to the requirements of WFD to ensure that all transitional and coastal water bodies achieve ‘Good Ecological Status’ and that there is no deterioration in status.

Acknowledgement is given to the general policies outlined in the Scottish National Marine Plan (Marine Scotland, 2015) (**Ref 18-2**). Within this Plan, the planning policy ‘GEN 8’ relates to coastal process and flooding and states: *‘developments and activities in the marine environment should be resilient to coastal change and flooding, and not have unacceptable adverse impact on coastal processes or contribute to coastal flooding.’*

The policy GEN 8, goes on to state: *‘marine planners and decision makers should also be satisfied that activities and developments will be resilient to risks from coastal change and flooding over their lifetime, and will not have an unacceptable impact on coastal change. They should seek to ensure that any geomorphological changes that an activity or development bring about in coastal processes, including sediment movement and wave patterns, are minimised and mitigated, bearing in mind the potential impact on commercial interests such as fisheries and conservation of the natural environment and key coastal heritage sites. Developments which may affect areas at high risk and increase the probability of coastal change should not be permitted unless the impacts upon the area can be managed effectively.’*

18.3 Methodology

The assessment approach within this ES does not attempt to assign sensitivity or value to the individual or combined elements of the coastal processes. Therefore, although it is recognised that the works (i.e. the pier extension and the dredged footprint) have the potential to alter coastal processes and affect the geomorphology, this alteration cannot be clearly defined as an ‘impact’ upon the parameter (or process). Hence no impact significance criteria are defined. Instead the assessment relies on an indication of the degree of change (or magnitude of change) which is provided and discussed. This is derived from quantification of differences between the baseline (or existing) physical parameters and those predicted from the modelling post-construction, and/or a qualitative review of how any perceived changes may affect the geomorphological receptors.

For the purposes of this chapter the criteria used to define the magnitude of change from the development on coastal processes and geomorphological features are provided in **Table 18.1.** In terms of likelihood of occurrence, a worst case approach is afforded to the predictions generated from the modelling i.e. the outputs predicted are considered likely to occur. However, the frequency of their occurrence varies and is discussed in the assessments. Changes are considered in the context of how they may differ from ‘natural variability’, this term equating to the baseline conditions.

Table 18.1 : Criteria used for defining magnitude of change to coastal processes and geomorphology.

Magnitude	Definition
Large	Changes to coastal processes in the immediate proximity, near and far field (e.g. Loch Alsh), with the scale of change much greater than the natural variability. These changes are likely to have a major effect on geomorphology over the long-term (>5 years).
Medium	Changes to coastal processes in the immediate proximity, near and far field, with the scale of change being greater than the natural variability. These changes are likely to have a considerable effect on geomorphology over the medium (1 - 5 years) to long-term.
Small	Changes to coastal processes in the near or far field, with the scale of change exceeding the natural variability but unlikely to have a detectable effect on geomorphology over the medium to long-term, or if detectable then unlikely to result in more than a minimal change in geomorphological features. Changes to coastal processes in the immediate proximity of the development, with the scale of change exceeding the natural variability and likely to have a detectable effect on geomorphological features over the short, medium or long-term.
Negligible	Changes to coastal processes in the immediate proximity of the development, with the scale of change slightly exceeding the range of natural variability but unlikely to have a detectable effect on geomorphology over the medium to long-term. Changes to coastal processes in the near or far field that are within the range of natural variability in the short, medium or long-term.

The outputs from RPS coastal processes modelling work have predicted the level of change as compared to the baseline environment, during the construction (e.g. sediment plume modelling) and operation (e.g. flow, wave and sediment transport modelling) phases (see **Section 18.6**). However, where the results of the modelling do not clearly fall within the criteria defined **(**see **Table 18.1**) then professional judgement has been used to determine the magnitude of change along with a clear justification for the selection.

It is ultimately the potential effects that the predicted changes to coastal processes could have on the geomorphology which are considered. To this end, the conclusions of the modelling reports (**Appendix 18.1: Kyleakin Pier Development Hydraulic Modelling Report** (**RPS, 2016); 18.3: Kyleakin Pier Dredging Addendum** (**RPS 2017**)) have assisted in the assessment process.

The modelling results and the subsequent assessment provide an understanding on the potential for short-term changes (over the duration of capital dredging works) to the geomorphology from changes in sediment dispersion. It also provides an indication of the level of change to suspended solids within this period of activity, with the results feeding into **Chapter 17: Water Quality** and **Chapter 19: Marine Ecology.**

It should be acknowledged that the study area for this topic is mirrored by that provided in the modelling reports (see **Appendix 18.1** and **Appendix 18.3**); however, the zone of influence was found to vary slightly for each aspect. For example, changes to sediment transport (when considering a once a year storm event) were almost undetectable by the model beyond 300 m from the proposed pier, with the greatest changes occurring in the nearshore environment.

Consideration of the possible long-term changes to the seabed morphology from side-slope slumping (destabilisation) was informed by modelling (**Appendix 18.1**). The conclusions from this work are summarised in **Section 18.6**.

During the construction phase and to a greater extent the operation phase, there is potential for the propeller wash from vessel movements to scour the seabed and thus affect the geomorphology (this is also covered as a potential effect on subtidal habitats in **Chapter 19**). Within the modelling report specific consideration has been given to the issue of propeller wash generated scour and the potential for changes to seabed geomorphology.

The final conclusions from this chapter help inform specific assessments within several other chapters: **Chapter 16: Navigation, Chapter 17: Water Quality** and **Chapter 19: Marine Ecology**. Specifically, these relate to the potential for changes to hydrodynamics, sediment transport, sediment dispersion and ultimately, geomorphology that may affect receptors in each of the above mentioned chapters. To avoid repetition, cross-referencing is used within these chapters to the outputs, results and conclusions of the coastal processes chapter.

18.3.1 Model Scenarios

After completing the coastal process modelling and desk studies, several minor adjustments were made to the proposed marine works. These included:

- a minor adjustment to the orientation of the rock armour on the western side of the proposed pier structure;
- replacing the vertical wall on the eastern side of the proposed slipway with rock armour;
- introducing two 2.4 m gaps between the proposed caissons to allow for future settlement; and
- repositioning the northern boundary of the proposed dredge extent by approximately 35 m to the south.

The effect of these amendments on the coastal processes has been expertly assessed and it was concluded that these changes were non-material (see **Appendix 18.1).** Similarly, the requirement now for a long sea outfall (see **Chapter 2**) was considered by the modellers and it was also concluded that its presence would have no readily detectable changes on coastal processes during the operation of the Proposed Development.

As these modifications to the design are non-material, the hydrodynamic outputs that were presented in the modelling report and therefore the assessments made, are considered valid and suitably reflective of the Proposed Development.

Baseline and Built Scenarios

Two future representations of the development were considered for the wave, flow and sediment transport models giving rise to the following conditions represented in the models:

- a baseline case – present day bathymetry and existing pier profile;
- a ‘just after’ capital dredging scenario with pier extension completed as proposed in **Chapter 2: Project Description and Chapter 3: Development Design and Alternatives**; and
- a second future longer term representation which would acknowledge ‘slumping’ of the dredged slopes (see **Section 18.1.1**).

It should be acknowledged that following modelling of the slope stabilisation the second future scenario was no longer considered applicable **Section 18.6.3**.

18.4 Baseline Conditions

To help inform the coastal processes and geomorphology assessments, baseline data were collected from field studies. A summary of the baseline data is provided with reference to the supporting technical documents, as appropriate. Where relevant these data were used for coastal process model calibration and validation. The technical reports should be referred to for a description of the specific models used, detail on the validation and calibration of the models, and the outputs (**Appendix 18.1** and **Appendix 18.3)**.

The development sits within the Inner Sound water body but is close (~800 m) from the western boundary of the Loch Alsh waterbody. The coastal waterbodies of the ‘Inner Sound’ and ‘Loch Alsh’ have the same overall classification for status with ‘Good’ being assigned to each (**Ref 18-9** and **18-10**). Many of the parameter classifications are also the same, with particular acknowledgment given to the ‘hydromorphology’ and ‘morphology’ of each, assigned as ‘High’.

Following discussion with SEPA, on the 26th July 2016, it was agreed as a precautionary approach, that the receiving water be considered as having an annual mean concentration of suspended particulate matter of between 10 to <100 mgl^{-1}. In accordance with the classification of transitional waterbodies this would assign an intermediate turbid type to the water body, though acknowledgment is given to the receiving waters being coastal rather than transitional.

18.4.1 Geology

Sedimentary Precambrian (Torridonian, Applecross Formation) gritty pebbly sandstones dominate the solid geology of the Kyleakin headland (**Ref 18-4**). These sedimentary bedrocks were originally formed as river terrace alluvial, floodplain and estuarine deposits consisting of fine silt and clay with some organic material originating from peat bogs (**Ref 18-6**).

Local superficial deposits of raised marine deposits and marine beach deposits, each consisting of gravel, sand and silt were laid down between 2 and 3 million years ago respectively. Originally formed on marine shorelines and in shallow seas, they are now elevated above current sea levels.

Changes in sea level due to isostatic land elevation have resulted in the current raised beach and delta area found around Kyleakin. These raised shoreline features were formed at the time of the retreat of Scotland’s last ice sheet approximately 15,000 years ago. More recently they have been mined by sand and gravel extraction industries (**Ref 18-3**).

Geological SSSI Ob Lusa to Ardnish (128.7 ha, NG681246) (**Ref 18-5**) consisting of Lower Jurassic strata is located 2.3 miles to the west of the gravel pit site.

18.4.2 Geomorphology

The intertidal coastal geomorphology around the site is dominated by high energy coastal conditions in combination with supply of unconsolidated sedimentary materials stored in the local raised beach features described in **Section 18.4.1**.

The intertidal zone and near shore comprise coarse sedimentary beach deposits made up of zones of gravels and sand and gravels. A geotechnical survey undertaken by Aspect Land and Hydrographic Surveys Ltd (ALHS) (**Appendix 18.2)** provided detailed bathymetric and near shore sedimentary data using surface grab and vibrocore techniques within the proposed dredge area. Investigations revealed a surface layer of cobbles over much of the site (particularly offshore) or gravels limiting the ability to take vibrocore samples. This confirms the action of high energy currents at the sea bed, with the potential to mobilise surface sediments smaller than pebbles (<4 mm). The presence of kelp growing with the cobbles further indicates the relative stabilisation of the seabed with strong currents.

18.4.3 Seabed Sediments

As part of a geotechnical survey carried out by ALHS a combination of vibrocores and grabs were used to collect sediments in August 2016 around the existing pier and proposed footprint of the dredging works (

Figure 18.1). Particle size analysis (PSA) and sediment chemistry analyses (metals, polychlorinated biphenyls (PCB’s) and polyaromatic hydrocarbons (PAH’s)) were carried out by Environmental Scientific Group and are reported as part of a supporting technical document produced by ALHS (**Appendix 18.2 (ALHS 2016)**).

The geotechnical survey revealed that much of the offshore area was dominated by a significant surface layer of cobbles and shingle. Closer inshore there was a wider distribution of very fine to coarse sand material with localised regions capped with gravel material **Figure 18.1.**

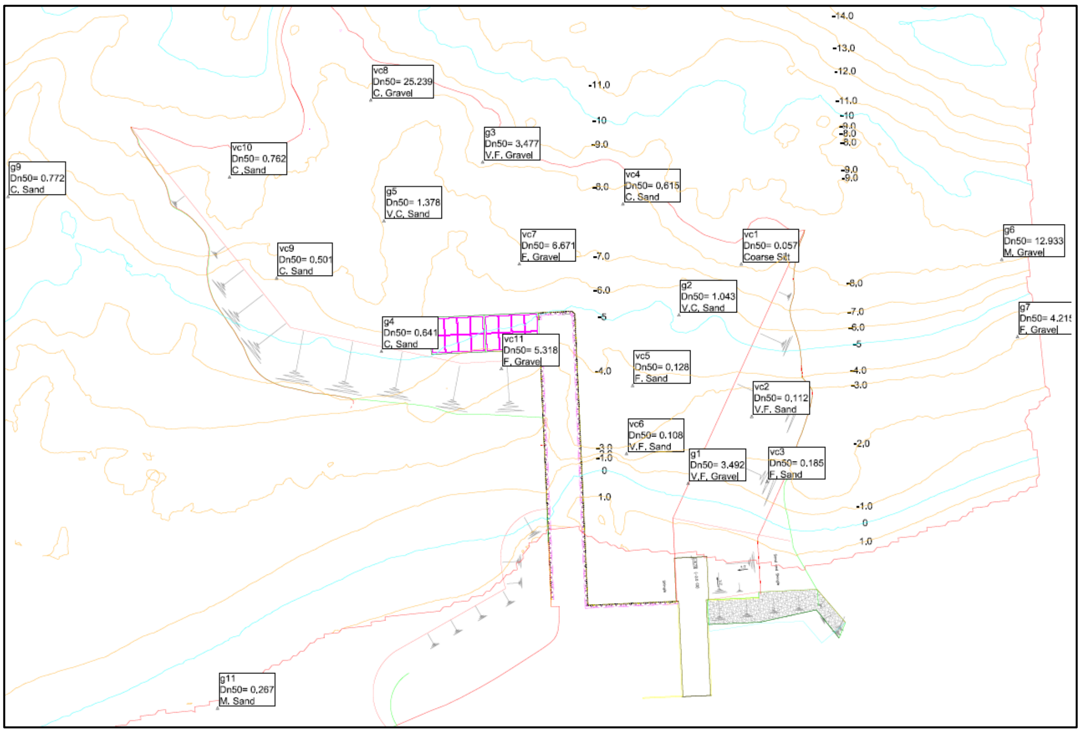

Figure 18.1 : Location of sediment sampling stations at Kyleakin and sediment classification at each point.

18.4.4 Bathymetry

A multibeam survey was completed and the data digitised into 2 m grid points that could be used to develop the range of numerical models that were employed throughout this study (**Appendix 18.1**). An overview of the extent and resolution of the survey data is presented in **Figure 18.2**.

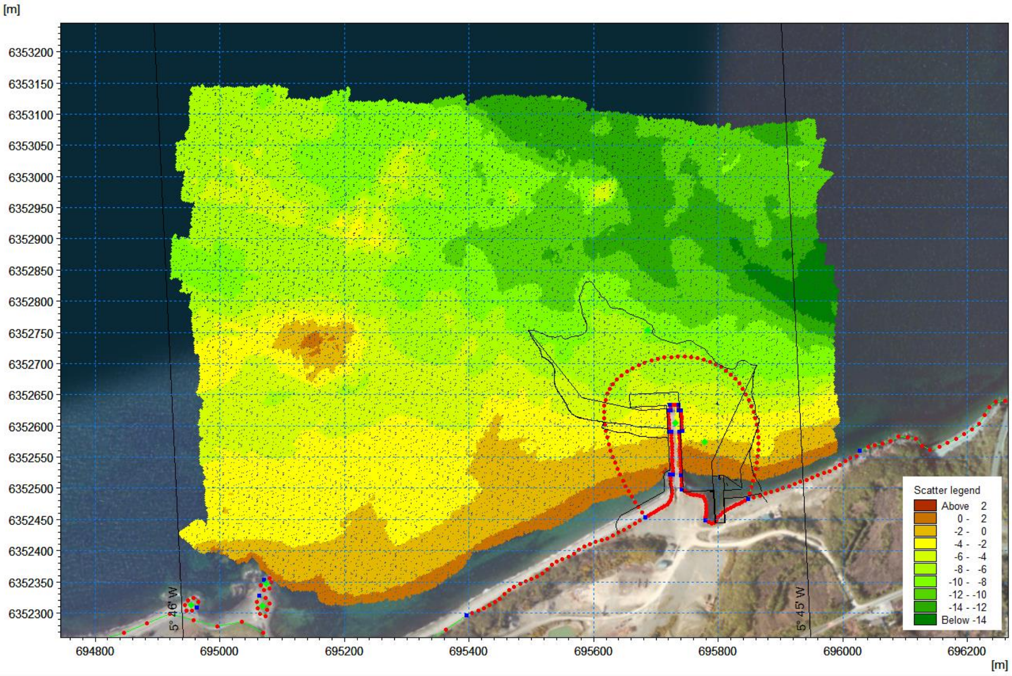

Figure 18.2 : Extent and resolution of the 2016 bathymetric survey undertaken by ALHS.

18.4.5 Tides

As with much of coastline in this area, Kyleakin is subject to semi-diurnal tides, meaning that there are generally two high waters and two low waters each day. According to the Admiralty Chart issued by the United Kingdom, Hydrography Office (UKHO) the Mean High Water Spring (MHWS) and Mean Low Water Spring (MLWS) levels are 5.3 m and 0.6 m CD respectively at the Kyle of Lochalsh which is approximately 2.5 km north-east of the study site. The Highest Astronomical Tide at the Kyle of Lochalsh is recorded as 5.9 m CD.

Tidal currents at Kyleakin are relatively complex due to the large volume of water that is forced in and out of Loch Alsh during each tidal cycle. The existing pier at Kyleakin contributes to the complexity of the tidal regime in this area by generating notable eddying effects on either side of the pier depending on the phase of the tidal cycle. The existing structure also creates a barrier along the shoreline and interrupts the littoral drift of marine sediment along the nearshore area.

Tidal stream information published by the UKHO indicates that current speeds can approach 1.5 m/s near the Skye Bridge during spring tidal conditions. Peak current speeds during typical neap tidal cycles are substantially lower at approximately 0.6 m/s.

18.4.6 Current Speeds

In July 2016, ALHS deployed two Acoustic Doppler Current Profiler (ADCP) devices over the course of a six week period to record tidal current speeds and directions at two different locations. One device was deployed to the north-west of the existing pier whilst the second device was deployed to the north-east of the existing pier; both devices were deployed near the -9.0 m CD contour. Both ADCP devices were set up to record information at 0.5 m intervals.

The data recorded by both ADCP devices across the entire month confirmed the complexity of the tidal current regime at Kyleakin. Current speeds can be as low as 0.02 m/s in one layer but as high as 0.60 m/s in another. Similar variability was observed in the current direction recordings throughout the majority of the six week deployment period.

18.4.7 Wind and Waves

Wind data for wave generation was collated from two sources. For generation of the average wave climate the data used was based on 25 years of wind speed data from the European Centre for Medium-Range Weather Forecasts (ECMWF) atmospheric model for a point at 57.5 °N, 6.0 °W. Due to the coarse nature of the ECMWF atmospheric model and the location of the data point, it is known that the wind speeds are under calculated and thus the wind speeds have been increased by 17 % (see **Appendix 18.1**).

The wind rose generated from the adjusted ECMWF data set showed that the most frequent winds come from the south to west sector. The most frequent strong winds come from the south-west to north-west sector (see **Appendix 18.1**).

The wind data prepared by the Met Office for BS EN 1991-1-4:2005 for extreme wind speeds throughout the British Isles was used as the base data set for winds influencing storm wave generation over the fetches approaching the pier site at Kyleakin.

18.4.8 Future Sea Levels

Sea levels are predicted to increase as a result of climate change and long-term monitoring of sea levels around Scotland's coastline, such as the longest individual record gauge at Aberdeen, has confirmed levels are up to 60 mm higher than those observed in the 1920's. Sea level rise is expected to differ by location for a combination of reasons and whilst forecast increases at Edinburgh by 2095 are 230 mm to 390 mm (Central Estimate) those on the west coast at Belfast for example are 245mm to 403 mm (UKCP09 projections for 2095 low to high emissions scenarios). SEPA are understood to have used the 2080 High Emissions Scenario for the National Coastal Hazard Map. The H++ scenario, a combination of sea level rise and surge that is beyond the likely range but physically plausible, resulted in a variety of estimates between 928 mm and 2500 mm.

When added to the still water extreme flood levels for this location, which SEPA indicated is 4.03 m Above Ordnance Datum (AOD), and taking account of the level of the quarry floor at the mouth of the site (6.0 m AOD) and the proposed floor levels of the building (8.25 m AOD), climate change impacts on sea levels are not expected to result in a direct risk of coastal flooding, as there is still freeboard of more than 1.56 m from the quarry floor and 3.82 m from finished floor levels. The H++ scenario would only result in an impact within the quarry itself (i.e. levels exceeded 6.0 m AOD) if the most extreme scenario played out, i.e. sea level rises of greater than 1.97 m over the lifetime of the scheme, however, these would not impact the building, as the finished floor level still provides a freeboard of 1.72 m. As a result of these freeboards when considering these unlikely scenarios, no specific mitigation for climate change on sea level rise was proposed (see **Appendix 9.1: Flood Risk Assessment**).

18.5 Modelling and Studies

The primary source of information used in the assessments is derived from focussed modelling studies carried out by RPS in 2016. It is suggested that the RPS modelling report (**Appendix 18.1**) is referred to for further technical information and key discussion points in relation to the potential changes in wave, tidal flow and sediment transport regimes. The potential short-term changes to sediment dispersion in the construction phase are summarised in this chapter.

Modelling was carried out to predict any potential changes to flow regime and wave climate as a result of the development following capital dredging works and construction of the pier and associated works. The outputs of the flow modelling were then used in a plume dispersion model to determine to what extent suspended sediment loads could increase and the subsequent sediment deposition during the excavation process (**Appendix 18.3**). The outputs of the flow and wave modelling were also used to determine changes in sediment transport during the operation phase.

In line with the comments from the consultees, specifically those received post Scoping Opinion (see **Section 18.1.1**) careful consideration has been given within the modelling report to the potential for changes (relaxation) of the dredged side-slopes in the long term (**Appendix 18.1**). Modelling of these changes has been carried out and then commentary provided on the outputs and potential measures to stabilise the slopes.

As suggested by the consultees, acknowledgment has also been made of the potential for scour (from propeller wash) and ship wake to affect the seabed. Consideration was given to these issues within the RPS modelling report (**Appendix 18.1**); however, based on the conclusions of the modellers, no directed modelling of either propeller wash or ship wake was carried out. The justification for this is provided in **Appendix 18.1** and summarised below.

Due to the requirement for outputs from flow and wave modelling to understand the sediment transport, sediment plume and consideration of propeller wash, these studies have been detailed in the order they were carried out. However, in keeping with the general format of the ES chapters, within the assessment section of this chapter, consideration is first given to those studies that relate to the construction phase and then subsequent consideration is given to studies relating to the operation phase.

18.5.1 Flow Regime Modelling

Baseline Scenario

The model was used to simulate a month of tidal conditions under the baseline (existing) conditions. Results of the numerical simulations indicated a distinct phase difference between peak current velocities and the surface elevation. Peak current velocities do not coincide with the mid-ebb and mid-flood tidal regime but are instead observed approximately 90 minutes before mid-flood and mid-ebb tides.

Under existing conditions the highest current velocities were observed during peak-flood tidal cycles when flow velocities approach 0.9 m/s at the end of the existing pier. Eddies were observed on either side of the existing pier depending on the phase of the tidal cycle.

Residual currents were also used to assess the hydrodynamic regimes. The residual current is the average current over a full tidal phase, i.e. 12.44 hours. The residual current within the immediate vicinity of the pier is generally low (approximately 0.1 – 0.2 m/s) and flows in a westerly direction (see **Appendix 18.1**). However, under storm conditions during a peak flood tide, it was found that the inshore currents flowed in the opposite direction (east) to the residual current (west) (**Appendix 18.1**).

Proposed Development Scenario

The hydrodynamic model was then re-run for the same time period as the baseline scenario using an updated model to reflect the implementation of the proposed scheme.

Under the Proposed Development scenario there is still a dominant bi-directional flow at Kyleakin that flows in a west – easterly direction, with the greatest tidal velocities observed during the peak-flood tidal cycle just beyond the end of the proposed pier structure. The overall tidal flow pattern of the proposed pier is very similar to that of the existing pier with both configurations generating eddies on either side of the pier

Outputs from the model indicated a decrease on the residual current velocities around the pier, particularly on the western side. Minimal changes in the littoral (nearshore) currents were indicated by the model, with the most obvious change being the movement of the littoral current (under storm conditions), to the west of the pier, to a flow that is turned by the proposed pier to flow west. Specific detail on the modelled changes is covered in **Section 18.6**.

18.5.2 Wave Modelling

Wave modelling was done to determine the wave height under a variety of storm events. The outputs of the wave modelling feed directly into the sediment transport model. As a potentially regularly occurring event, the one in one year model was used to determine differences between the existing and the proposed pier scenarios (acknowledging the dredged extent). This would allow a useful, if conservative, determination of potential sediment transport during these storm events; these being the upper end of what could be considered a regular event.

A one in one year event is the correct standard for general sediment transport simulations as one in 100 year events are extremely rare and of short duration. Changes in sediment transport tend to be important over longer periods of time thus the one in one year events are more appropriate than one in 100 year events. However, for such items as structural or bank stability extreme events are more appropriate and one in 100 year events were considered in the analysis of these items (**Appendices 18.1** and **18.4**).

Baseline Scenario

The average wave rose for a point just north-west of the pier based on the 25 years of wind records is shown in **Figure 18.3**. It will be seen from this figure that whilst the most frequent waves come from the westerly sector, the largest waves approach the pier site from 300° and 330° sectors.

Previous wave climate studies of this area have demonstrated that the waves generated in the Atlantic, which propagate over long fetches and move into the inner sound from 315° to 45°, are highly modified by the relatively narrow section of the Inner Sound to the extent that the wave climate at the existing pier is dominated by wind waves generated over short fetches (RPS, pers. comm). Thus long period swell does not reach the pier site at Kyleakin.

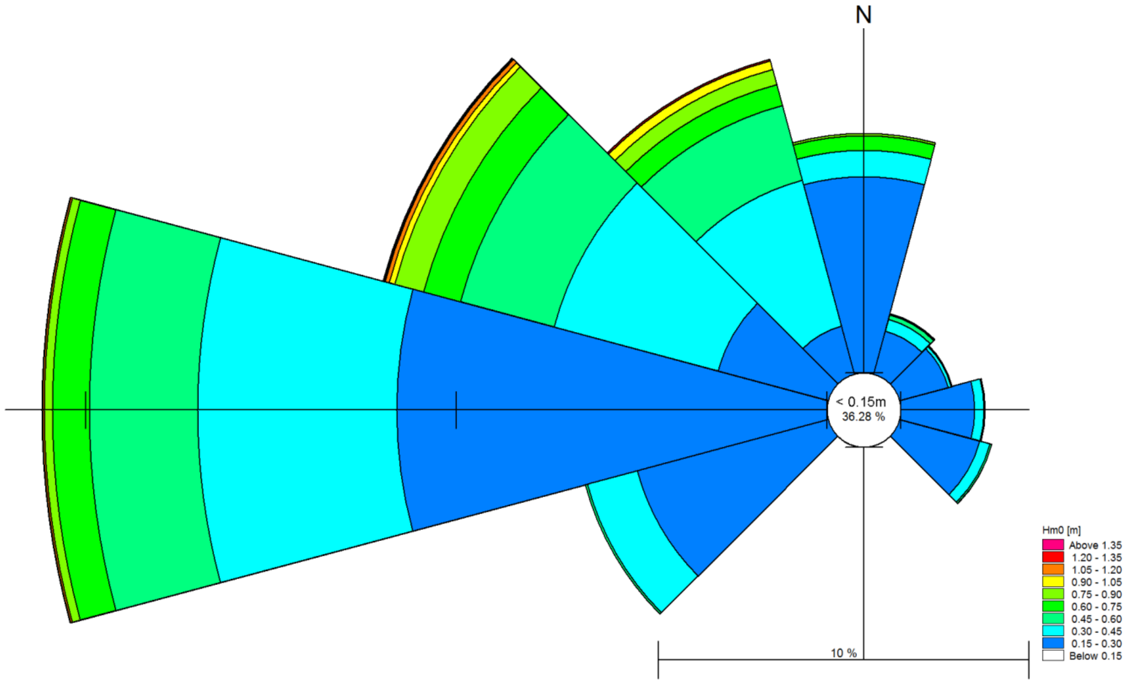

Figure 18.3 : Average wave climate rose at a point just north-west of pier site.

Tidal levels were placed in the storm wave simulations as given in **Table 18.2**. All the storm wave simulations included storm surge.

Table 18.2 : Tidal levels used in storm wave simulations.

Storm Direction (Degrees)	1 in 1 year storm water level (m CD)	1 in 100 year storm water level (m CD)
15 to 120	5.30	5.30
225	5.80	6.30
240	5.80	6.30
255	5.80	6.30
270	5.80	6.30
285	5.65	6.00
300	5.50	5.80
315	5.35	5.50
330	5.30	5.30
345	5.30	5.30
360	5.30	5.30

One in 100 year

The largest waves will approach the proposed pier from the north-west direction during a storm from 300°. It will be seen that waves with heights in excess of 3.0 m can approach the site during extreme one in 100 year return period events.

During this event the wave model predicted that wave reflections from the structure will increase the storm wave heights locally along the berthing faces of the pier (**Figure 18.4).**

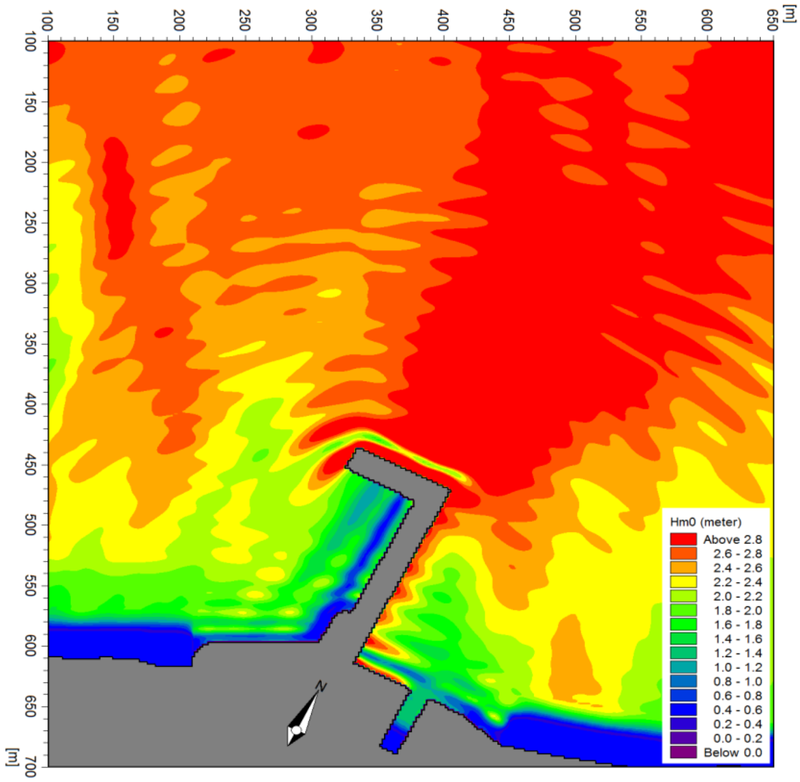

Figure 18.4 : Storm wave patterns (upper) and wave heights (m) around the proposed pier during a one in 100 year storm event from 300° at mean sea level

One in one year

Following wave modelling, the differences in wave height between the baseline and proposed development were found to be generally restricted to the area immediately adjacent to the pier with exceptions from 240 and 270 °N directions. Under a one in one year storm from 270 °N, a minimal increase in wave height (0.05 m to 0.15 m) was predicted to extend about 150 m to the north of the pier. While under a one in one year storm from 240 °N, a small reduction in wave height (0.05 m – 0.15 m) is predicted to occur to the east and extend to the base of the Skye Bridge (**Appendix 18.1**).

18.5.3 Sediment Transport Modelling

The sediment transport study has taken a conservative approach to investigating the impact of the proposed pier on the stability of the seabed within the vicinity of the proposed works, by simulating the transport of sediment under typical one in one year storm conditions. Details of this and the model can be found in **Appendix 18.1**.

As detailed in **Appendix 18.1** the sea bed to the north of existing pier is generally composed of coarse material with baseline levels of suspended sediment in the water column being very low. Consequently the main movement of sediments in the area results from waves breaking along the coast, particularly on the sections of shoreline that have fine beach material.

Only the larger waves in the overall wave climate generate littoral currents of sufficient strength to produce significant longshore sediment drift. The waves capable of driving longshore sediment drift approach the pier from the north and east (see **Appendix 18.1)**.

As there is a very limited supply of beach material on the coast to the east of the pier (**Appendix 18.1**), the only sediment drift at the existing pier will be along the western shoreline from a south westerly direction.

18.5.4 Sediment Plume Modelling

Dredging activities have been planned to increase the depth of the seabed within the immediate vicinity of the proposed pier to -8.5 m CD with slopes of 1:7 to meet existing seabed levels (**The BHD** is expected to operate on a 24/7 until the dredging has been completed. Based on this assumption it is expected that the BHD will take 28 days to complete the dredging of the outer area and 56 days to complete the dredging of the inner area (**Table 18.4)**.

In order to be conservative a Force 3 wind from the south was applied over the entire dredging period. Given the length of the dredging period it is likely that winds will actually come from a range of directions with variable strengths during the period thus it was considered that the use of a Force 3 southerly wind over the entire period is appropriate and conservative.

It is assumed that approximately 190,000 m^3 of material will need to be dredged from the study site. The composition of the seabed was derived from the results of a geotechnical survey (see **Section 10.4.3**), represented by gravel material in the outer area of the proposed works and fine to coarse sand within the inner area (**The BHD** is expected to operate on a 24/7 until the dredging has been completed. Based on this assumption it is expected that the BHD will take 28 days to complete the dredging of the outer area and 56 days to complete the dredging of the inner area (**Table 18.4)**.

In order to be conservative a Force 3 wind from the south was applied over the entire dredging period. Given the length of the dredging period it is likely that winds will actually come from a range of directions with variable strengths during the period thus it was considered that the use of a Force 3 southerly wind over the entire period is appropriate and conservative.

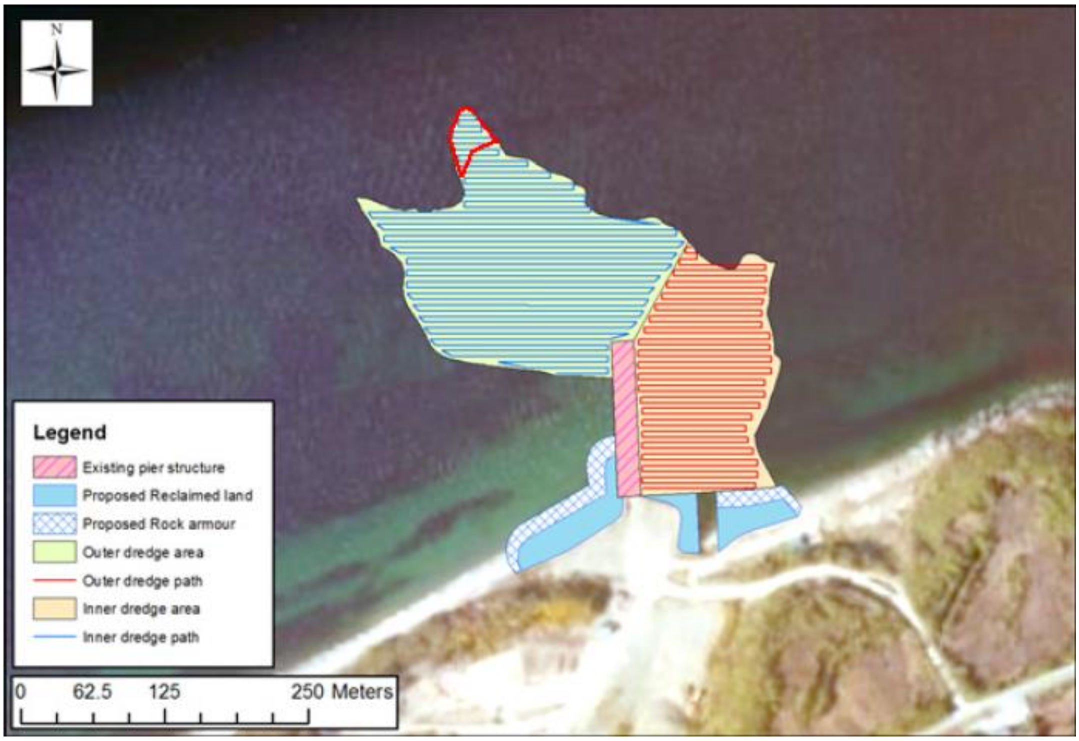

Figure 18.5 : Overview of dredging requirements showing outer and inner dredge areas. Area in northwest, outlined in red, will no longer be dredged.

To accurately reflect the heterogeneous nature of the proposed dredge material, RPS applied different sediment characteristics to the outer and inner dredge areas before undertaking any numerical modelling. Based on the hydrographic and geotechnical surveys of the area, it was assumed that approximately 85,500 m^3 and 104,500 m^3 of material would have to be dredged from the outer and inner areas respectively. Composition of bed material in these areas is provided in **Table 18.3**. Further detail is given in **Appendix 18.3.**

Table 18.3 : Composition of bed material within the inner and outer dredge areas at Kyleakin

Dredge Area	Capital Dredge Requirments (m^3)	% material <1000µm	% sand material (1000-63 µm)	% silt material (<63 µm)
Outer	85,500	46	42.5	3.5
Inner	104,500	80	60	20
Total	190,000			

Following discussions with potential dredging contactors it is anticipated that all dredging would be carried out by backhoe dredger (BHD), within both the inner and outer dredge areas, with material being offloaded at a temporary jetty (see **Chapter 2**). Based on the capital dredge requirements of both the outer and inner dredge areas, the duration of the total capital dredging programme using the BHD for both areas was assumed to be 84 days with the split between the outer and inner areas as shown in **Table 18.4**.

Table 18.4 : Assumed duration of backhoe dredging within outer and inner area of dredging extent.

Scenario	Dredging Method		Dredging Duration (Days)		
	Outer Area	Inner Area	Outer Area	Inner Area	Total
1	BHD		28	56	84

The BHD is expected to operate on a 24/7 until the dredging has been completed. Based on this assumption it is expected that the BHD will take 28 days to complete the dredging of the outer area and 56 days to complete the dredging of the inner area (**Table 18.4)**.

In order to be conservative a Force 3 wind from the south was applied over the entire dredging period. Given the length of the dredging period it is likely that winds will actually come from a range of directions with variable strengths during the period thus it was considered that the use of a Force 3 southerly wind over the entire period is appropriate and conservative.

Wind driven currents are primarily surface currents and thus only affect surface plumes. In stronger winds wave action tends to mix the surface layer with the overall water column and thus the sediment plume is more affected by the tidal currents than a surface current. Added to this is the fact that there is minimal overspill during the backhoe dredging operations planned for the development (see below) so surface plumes will not dominate the losses to the water column from the dredging operations. Therefore, the application of a Force 3 southerly wind over the entire dredging period is appropriate and conservative.

The material introduced into the marine environment as a result of BHD dredging operations can be represented by two source terms: the loss of material near the bed during the digging operation; and, the loss of material from the bucket as it breaks the surface. The losses at the BHD bucket were taken as 3 % of the sand and silt material in the inner and outer areas. These losses were simulated by introducing half of this quantity in the bottom layer of the numerical model and the other half in the top layer of the numerical model. Further details on the sediment plume modelling are provided in **Appendix 18.3.**

18.5.5 Side Slope Modelling

The stability of the proposed dredged 1 in 7 slopes on the eastern side and western side of the berthing area were investigated using a variety of Mike21 wave and sediment transport models (see **Appendix 18.1**). Over the eastern area, the existing surface is comprised of fine or very fine sands and for the purposes of the modelling, a Dn50 grain size for the slope material has been taken as 0.1 mm.

Over the western area, the seabed surface is comprised primarily of coarse sand with mean grain diameters of 0.5 mm to 0.6 mm. However, the material also contains sediments sizes up to 10 mm diameter and for the purposes of the modelling; a Dn50 grain size for the slope material has been taken as 0.5 mm.

It should be noted that a one in 100 year return period storm from 300 to 330 °N has been used in combination with spring tide flows. The 300 to 330 °N storm direction was chosen as these conditions tend to produce the most extreme conditions at the pier and this therefore would represent a worst case scenario. However it should be realised that this condition is unlikely to be experienced over the operational lifetime of the pier.

The seabed around the existing Kyleakin Pier is generally composed of a surface layer of cobble and gravel, and in many places the natural slope of this bed material is considerably steeper than 1 in 7. It is considered that the proposed capital dredge will produce a considerable amount of gravel and cobble material which can then be used to provide a protective cover layer across the 1 in 7 dredged side slopes in the same manner as the natural seabed in large parts of the Kyleakin Pier area.

Modelling and analysis was carried out for the stability of the eastern bank covered with cobble sized material using the Boussinesq wave, tidal and STP_Q3 model programs.

Further details on the modelling are provided in **Appendix 18.1** with a summary of the results given in **Section 18.6.3**.

18.5.6 Propeller-Wash and Wake

The Navigation Risk Assessment (**Appendix 16.1 (ABPmer, 2016)**) showed that as vessels arrive and depart from the development they will reduce speed significantly before turning. Similarly the departure of vessels will be carried out at slow speed as they manoeuvre into the main channel.

Propeller Wash (scour effects)

Within the modelling report (**Appendix 18.1**) consideration of scour on seabed morphology from propeller wash was carried out for both the construction and operation phases of the work.

During the construction phase the vessels used will comprise work boats, barges and tugs. Consideration was given to the propeller wash of tugs, these being the most powerful vessels operating in the construction phase, and also the hopper barges used to unload material from the backhoe at the temporary jetty.

In the operation phase consideration was given to the passage route of vessels over the seabed and where this passage overlapped with the assumed position of the flame shell bed (**Section 18.6.3**).

Wake Generated Waves

During vessel movements in the operation phase the wake generated waves would be considerably smaller than those generated by the one in one year storms modelled (**Section 18.6.3**) or even by the passage of large vessels transiting through the main channel. Given these considerations, the effect from wake generated waves on geomorphological features is scoped out of further consideration. Subsequently, the much reduced vessel movements, comparatively, during the construction phase are also scoped out.

18.6 Predicted Changes

18.6.1 Introduction

The capital dredging required to construct the berthing area has the potential to temporarily alter the suspended sediment loads during excavation activities, with the potential to increase sediment deposition rates. The potential for these plumes to affect water quality is covered in **Chapter 17: Water Quality.**

During operation, the extension of the pier and the dredged area adjacent to the pier have the potential to change the local hydrodynamic processes and therefore affect the geomorphology and subsequently, indirectly, a number of the ecological and/or environmental receptors (see **Chapter 19: Marine Ecology**).

In addition to the above, consideration has been given to the potential effects of propeller wash (scour) from vessel movements in the construction and operation phase. Furthermore, the stability of the side slopes and thus the potential for side slope 'slumping' in the operation phase has been considered and the conclusions of the models summarised (**Appendix 18.1**).

The details of how any changes identified in the hydrodynamic processes and geomorphology could potentially affect marine environmental receptors are covered in subsequent chapters, along with an assessment of the potential impacts (see **Chapters 16, 17 and 19**). To this end, specific recognition is given in the text of this section to allow other environmental topics to refer back to relevant issues of interest.

Of particular interest from these studies is the understanding of how processes may indirectly affect sensitive features. To the north of the development is a well-developed and very large flame shell bed which is one of the qualifying features of the Lochs Duich, Long and Alsh MPA, while to the east of the development is Lochs Duich, Long and Alsh SAC designated for its reefs.

Specific acknowledgment is given to the Scoping Opinions of the consultees (**Appendix 1.1**: **Scoping Opinion, 2016)** and in particular that of SNH: *'Once the extent and scale of impacts have been predicted and quantified these can be assessed against known sensitivities of flame-shell beds'.* Further comments were made by SNH in a subsequent email in early August 2016; *'it may be useful to review any information on water flow at existing flame shell beds, and impacts from water flow on similar sensitive habitats to help understand implications of any changes'.*

Given the above, careful consideration has been given to the flame shell bed in relation to hydrodynamic processes and hence specific comments are made within this section and within the associated technical reports (**Appendices 18.1 and 18.3**). Consequently, these will be cross-referred to in **Chapter 19: Marine Ecology,** as appropriate.

18.6.2 Construction

During the capital dredging work there would be a temporary increase in sediment dispersion and sediment deposition, as a result of the generated sediment plumes. Dredged material will not be disposed at sea (see **Chapter 2** and **Kyleakin BPEO (2016)**), therefore only the sediment plume generated during the excavation process is considered.

Generation of the sediment plume during the backhoe dredging activity has considered the loss of material near the bed during the digging operation; and, the loss of material from the bucket as it breaks the surface. The now minimal overspill from the settlement ponds, compared to that required for the Trailer Suction Hopper Dredger operations previously considered (**Appendix 18.1)**, would be so small that they are not considered further within the plume modelling (see **Appendix 18.3**).

The potential for scour from propeller wash during the construction phase is acknowledged, with specific consideration given to the potential for scour in the outer dredged area at the nearest point to the -9.5 m CD contour.

Sediment Dispersion (Excavation)

This section covers the potential for short-term increases and subsequent changes in suspended sediment concentrations (SSCs) generated from the excavation of material. Consideration is given to the potential for change to seabed geomorphology as a result of sediment deposition. For further detail on the SSCs and sediment deposition please refer to **Appendix 18.3**.

It is important to note that it is common practice for dredging contractors to account for the effect of sediment deposition during the dredging programme by making very minor adjustments to the final target dredge depth.

As such, only material beyond the dredge extent should be considered when assessing sediment plume deposition levels.

Backhoe dredging

Specific consideration was given to the model outputs for SSC generation during the spring tidal conditions when the backhoe dredger (BHD) is nearest to the -9.5 m CD contour and within the inner dredge area i.e. where the percentage of fine material is greatest.

Based on the simulation results it was found that within the confines of the dredge area, the typical total increase in SSCs due to the losses at the BHD bucket do not generally exceed $30mgl^{-1}$ and where they do, increases are highly localised (<200 m^2) and very short in duration. Under normal tidal conditions there were no increases in SSCs greater or equal to 10 mgl^{-1} beyond either the overall dredge extent or the -9.5 m CD contour.

Furthermore, the average increase in SSCs over the entire dredging campaign (84 days) indicated that there would be no changes in SSCs >10 mgl^{-1} either within or beyond the overall dredge extent.

It was found that the deposition of material is strongly influenced by the residual tidal current regime which generally transports material in a westerly direction, although some material is predicted to settle to the east. Results demonstrated that sediment deposition as a result of the BHD dredging campaign did not exceed 0.10m and that deposition levels across the majority of the study area were represented by values ranging from 0.05 cm to 5 cm, though values of 5 cm were generally confined to the immediate proximity of the dredged area and a small localised patch several hundred metres to the west. It was also apparent that within 50m of the assumed boundary of the flame shell bed, the deposition of sediment was below 0.05 cm (**Figure 18.6**). The model did not predict any deposition occurring to the north of the dredged area or over the flame shell bed.

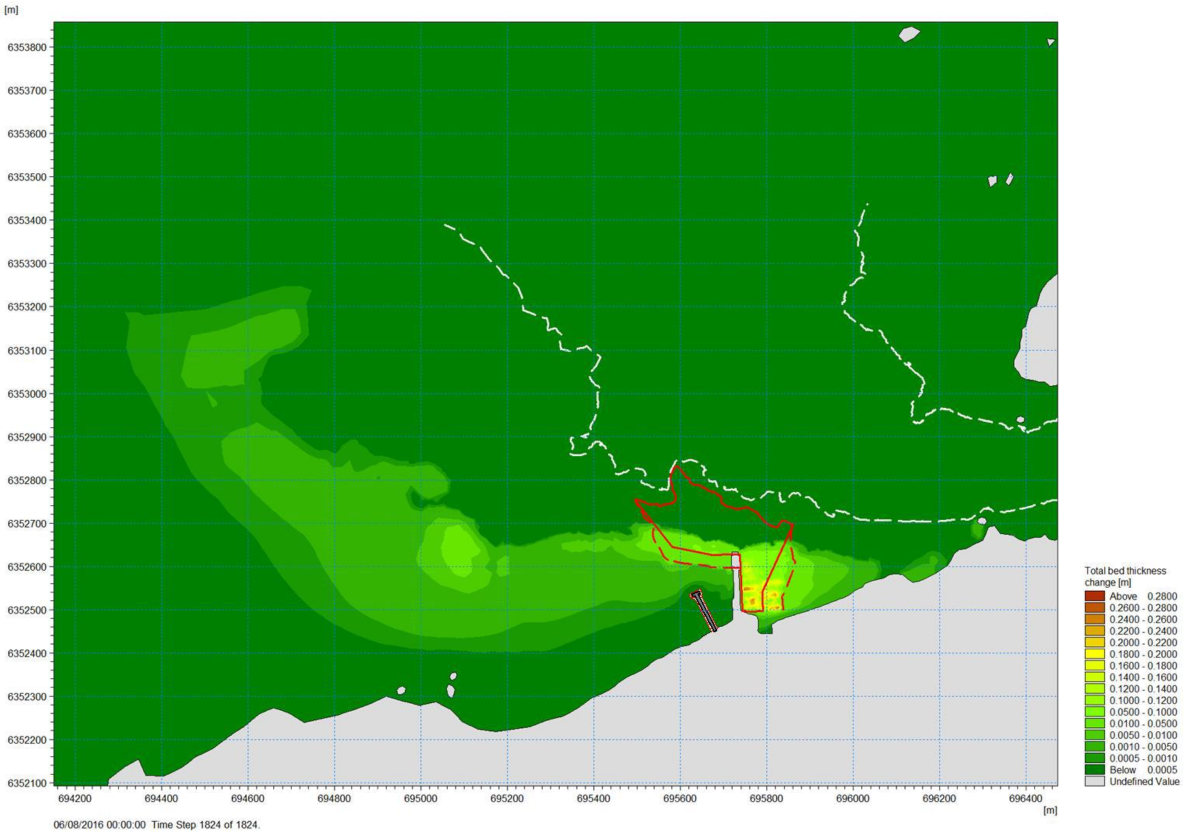

Figure 18.6 : Deposition levels at the end of the 84 day BHD dredging campaign. The white hashed line represents the -9.5 m CD contour and thus the assumed boundary of the flame shell bed.

Acknowledgement is given to the comparatively small increase, as compared to baseline values, in SSC's over the duration of the dredging works. It is also acknowledged that increases in SSC's are not predicted to occur much beyond the immediate proximity of the development.

Most of the area affected by sediment deposition would experience <5 cm of deposition, with deposition occurring up to 1.4 km west of the Proposed Development. However, beyond about 600 m deposition levels are <1 cm. As much of this material will likely be remobilised over successive tidal cycles, it is considered that changes to seabed geomorphology are unlikely to be readily detectable over the medium to long term once dredging work has ceased.

It was suggested by SNH (see **Section 18.1.1**) that maximum SSCs and deposition should also be acknowledged and details of these are provided in **Appendix 18.5**. These outputs showed similarly minimal changes in SSCs and deposition beyond the dredging extent.

The output showing 'maximum deposition' encompasses the depth of sediment over the area at any time during the dredging operation (**Figure 18.7**). Consequently, this includes material that settles on to the seabed at slack water before being subsequently re-suspended by the increasing tidal flow.

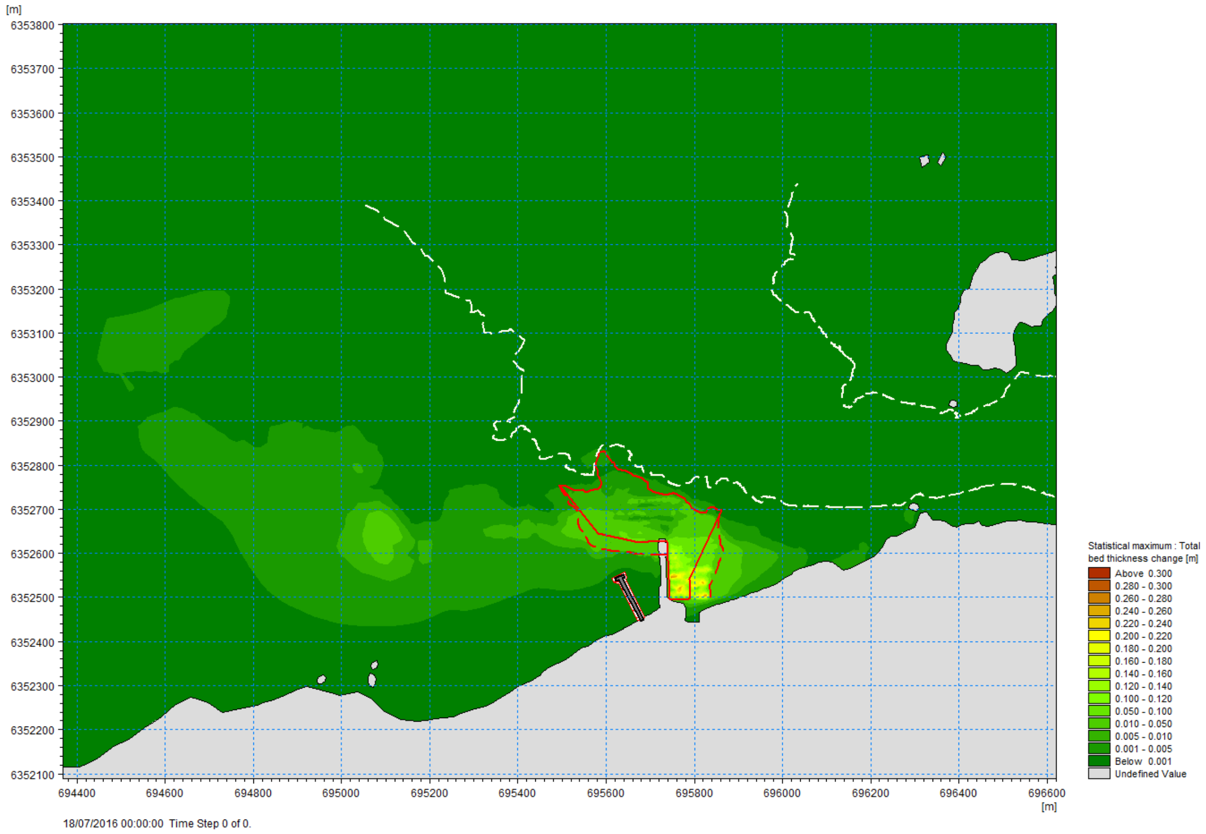

Figure 18.7 : Maximum deposition depth envelop during the 84day BHD dredging campaign

A comparison can be made between the maximum deposition depths plot (**Figure 18.7**) and the deposition depth plot at the end of the simulation (**Figure 18.6**) to see the areas where temporally deposited sediment has been re-suspended.

However, even consideration of maximum deposition rates (assuming no resuspension of material) showed only minimal increases in deposition beyond the immediate proximity of the dredged area. While a very small amount of material (<2 mm) was found to deposit over a highly localised area of the flame shell bed (**Figure 18.7)** this would only occur for a short-time during the turn of the tide i.e. at slack water. Effectively this shows that the flame shell bed area is totally dispersive for the dredged plume material generated by the capital dredging works.

It should also be noted that subsequent to the completion of the dredge scenario modelling, the decision was taken to reduce the extent of the dredge area at the north western corner of the dredged area (**Figure 18.5**). This reduction in the area, which extends close to the flame shell bed, will further reduce the level of temporary deposition at the south western edge of the flame shell bed.

Given the minimal changes to the levels of SSCs and sediment deposition, the latter leading to barely detectable changes in geomorphology, an assessment of **small** is given against the magnitude of change for sediment dispersion during excavation.

Propeller Wash

During the construction phase vessel movements will be minimal, as compared to the operation phase (see **Chapter 16: Navigation**).

The movement of the backhoe, as mounted upon a spud-leg barge, would likely be achieved by the spud leg dredger “walking” itself incrementally backwards in a line across the dredge area, using movement of one of its legs at a time. It is anticipated that two hopper barges will be employed, with one alongside the dredger and one alongside the discharge berth at any particular time. Within a given 24 hr period it is anticipated that there would be approximately 7 vessel movements per day. The hopper barges will have a draft of approximately 3 m to allow for shallow water operations.

Acknowledgment is given to the shallow draft of these construction vessels, specifically the hopper barges. Over the short-term duration of the dredging operations there will be continuous movement of barges between the temporary jetty and the dredged area. However, owing to the shallow draft and slow speed of these vessels coupled with the very short distance of each movement, propeller wash from these vessels is unlikely to result in any significant effect on the seabed. It is also recognised that the water velocities due to the propeller wash generated by the hopper barges, will be less than the tidal velocities currently experienced in the area.

The most powerful vessels operating outside the dredged area are likely to be tugs. However, specific consideration was given to tug movements over the -9.5 m CD contour; with calculations assuming that the vessel would be manoeuvring slowly, such as when manoeuvring caissons towards the site. Assuming a worst case, these calculations demonstrated that the maximum near bed velocity due to propeller wash will be approximately 0.984 m/s. This velocity is comparable with existing near bed tidal velocities observed across the study site during typical spring tides which have been demonstrated to be in the region of c.1.0 m/s. in this area which for a typical spring tide has a near bed velocity of about 1 m/s. Thus it is expected that construction vessels will not disturb the seabed to sea landward of the -9.5 m CD contour.

Given the reasons outlined above it is not expected that propeller wash would have any readily detectable effect on the seabed outwith the dredged area. Given the above, it is considered that any changes to the geomorphology would be within the range of natural variability and consequently an assessment of **negligible** has been given for the magnitude of change. Furthermore, there will not be any detectable effect from propeller wash on the flame shell bed.

18.6.3 Operation

Maintenance Dredging

Consideration of the requirement for future dredging was carried out by RPS (**Appendix 18.1**). It is worth noting that the suspended sediment loading in the waters around the Kyleakin Pier is very low. The strong tidal flows in the area provide unfavourable conditions for settling of fines which is evidenced by the generally coarse substrata found in the area.

The prominent feature of the sediment transport regime at Kyleakin is a movement of material along the shoreline from south-west to east; consequently the existing pier currently acts like a groyne by arresting this longshore transport. The proposed caisson structure at the end of the existing pier will enhance the performance of the existing pier in retaining sediment to the western side of the pier.

Acknowledging the above, it is expected that maintenance dredging requirements will be very small and that rapid infilling of the dredged area under storm conditions is unlikely to occur. However, it is expected that some sedimentation will occur, particularly in the corners of the dredged area, as a result of ship movements remobilising fine material in this area. Owing to this highly localised deposition, it is anticipated that maintenance dredging would be carried out using an excavator mounted on the quay in combination with some occasional local ploughing within the dredged basin area.

Based on the outputs of the sediment dispersion modelling for capital dredging (see above) and the sediment transport modelling during the operation phase, the very limited requirement for maintenance dredging, the significantly smaller volume that would require dredging (compared to the capital dredging works) and the highly localised dredging requirement (immediately adjacent to the pier), an assessment of **negligible** has been given for the magnitude of change for sediment dispersion during excavation.

It is assumed that maintenance dredged material would be stockpiled in the quarry and reused as will be done for the capital dredged material.

Coastal Processes

Flow Regime

Following the outputs of the flow modelling the conclusions were:

- Beyond the immediate vicinity of the pier directional changes to the current were minimal.
- Changes to the current velocity were rarely observed to exceed 0.1 m/s with the greatest changes occurring during the peak-flood and peak-ebb flows at full spring tide.
- During the peak-flood and peak-ebb phases, existing current velocities were predicted to decrease by 0.06 – 0.08 m/s, with these occurring in a localised area around the pier, predominantly in the nearshore.
- Increases in current velocities were predicted in both the peak-flood and peak–ebb, although these were only predicted to exceed 0.1 m/s over a very small area close to the end of proposed pier during the peak-ebb.
- A small increase in current velocity (0.04 – 0.06 m/s) is predicted to occur during the peak-ebb flow of a spring tide just beyond the northern extent of the dredged area. These changes in the current velocity are not predicted to overlap and thus affect the body of water over the assumed flame shell bed area.
- Changes in current velocity at low water (spring) were almost undetectable except alongside the end of the pier.
- Changes in current velocity at high water (spring) were evidenced by decreases immediately adjacent to the pier. The exception was a small increase (0.04 - 0.06 m/s) approximately 300 m to the west of the pier.
- Changes in the residual tidal flow did not exceed 0.06 m/s with most changes represented by decreases in the area immediately adjacent to the pier. A few hundred metres to the west and east of the pier changes were predicted to increase by 0.02 – 0.04 m/s over localised areas.
- During a north-westerly storm event changes to littoral flows were predicted over a large area to the west of the pier; however, these changes were largely the result of relatively small increases in current velocity (<0.06 m/s). A very small increase in littoral flow current velocity (0.02 – 0.04 m/s) was predicted, during a north-westerly storm event, however, this is not predicted to overlap and thus affect the body of water over the assumed flame shell bed area.
- In summary, all predicted changes to current velocities were less than 0.1 m/s. The exception was over a highly localised area immediately adjacent to the northern end of the pier where changes exceeded ±0.14 m/s for approximately one hour over a peak-ebb spring tidal cycle.

Careful consideration is given to the baseline residual current velocities found around Kyleakin (**Appendix 18.1**), these being around 0.1 to 0.2 m/s near to the pier. Modelling of the tidal flows post construction showed that the residual currents varied little; with a slight increase in residual currents to the west and east of the proposed pier. Changes to the direction of the currents are minimal though some are noticeable immediately to the west of the pier.

It is acknowledged that the changes in flow velocities predicted by the modelling are minimal when compared to the baseline flow regime of this high energy water body. The greatest changes are only expected over peak-ebb and peak-flood tides for approximately one hour in a tidal cycle.

Consideration of the above leads to an assessment of **small** for the magnitude of change to the flow regime. This is based on predicted flow changes generally occurring around the immediate proximity of the pier, with minimal changes in the near to far field, and where these changes were experienced they would occur over a very small time window in any given lunar tidal cycle. The limited and generally localised changes predicted are considered unlikely to have a more than minimal effect on geomorphology; however, this is considered further in sediment transport section (see below).

Wave Regime

The greatest changes to the wave climate are predicted to occur during storm events from 240° when wave heights decreased by up to 0.65 m on the lee side of the existing pier structure. Increases of 0.65 m were predicted but over a highly localised area alongside the southeast corner of the existing pier (**Appendix 18.1**). Beyond the immediate proximity of the pier, changes to the wave climate do not generally exceed ±0.25 m during storm events from the other modelled directions (270°, 300° and 330°). Beyond the nearshore area and immediate proximity of the pier, minimal increases of 0.15 m over the dredged extent are recorded from 270°. During storms from 240°, decreases of ±0.15 m in wave height can be observed in the far field, at the base of the Isle of Skye Bridge.

Acknowledgement is given to the relative infrequency of these storm events, and the likely short duration any such storm event would last for in a given period. Although most of the predictions show relatively minimal changes (±0.25 to ±0.65 m), some of these changes were predicted further afield than the area adjacent to the pier, albeit with minimal changes (**Section 18.5.2**).

Given the above, this leads to an assessment of **small** for the magnitude of change to the wave conditions following construction of the proposal. This is based on predicted changes to wave conditions generally occurring around the immediate proximity of the pier, with minimal changes in the near to far field. The limited and generally localised changes predicted are considered unlikely to have more than a minimal effect on geomorphology; however, this is considered further in sediment transport section (see below).

Sediment Transport

Changes to sea bed levels after a storm event from the north-westerly sector found that the morphological response of the sea bed to the storm had a similar pattern irrespective of the scenario (baseline or proposed scheme), with a build-up of sediment predicted immediately to the west of the pier. However on the eastern side of the pier, material in the area just beyond the proposed side slope is transported towards the shore by littoral currents. This results in a build-up of material in the nearshore area.

Comparison of the differences in bed level changes between the two scenarios found that the majority of the differences are within the nearshore area of the proposed structure, with no changes extending more than ~10 m north of the pier. Consequently no changes are predicted to occur on or adjacent to, the flame shell bed (**Figure 18.8)**.

Minor changes were predicted to the left of the proposed revetment, with differences of ±0.2 m resulting from the new quay extension deflecting the direction of the littoral currents, and thus representing a minor displacement of sediment. To the east of the proposed pier structure, the re-graded side slopes are predicted to result in minor bed level changes. However, these changes are generally within the nearshore area proximal to the development.

It was concluded from the outputs of the sediment transport modelling (see **Appendix 18.1**) that even adopting a conservative approach under one in one year storm conditions, that virtually all the bed changes are contained within the upper surf zone of the site where waves would be breaking. Subsequently only minimal changes to the sediment transport regime would occur beyond the immediate vicinity of the works.

Following the conclusions of the modelling an assessment of **small** is given for the magnitude of change on sediment transport following construction of the proposal.

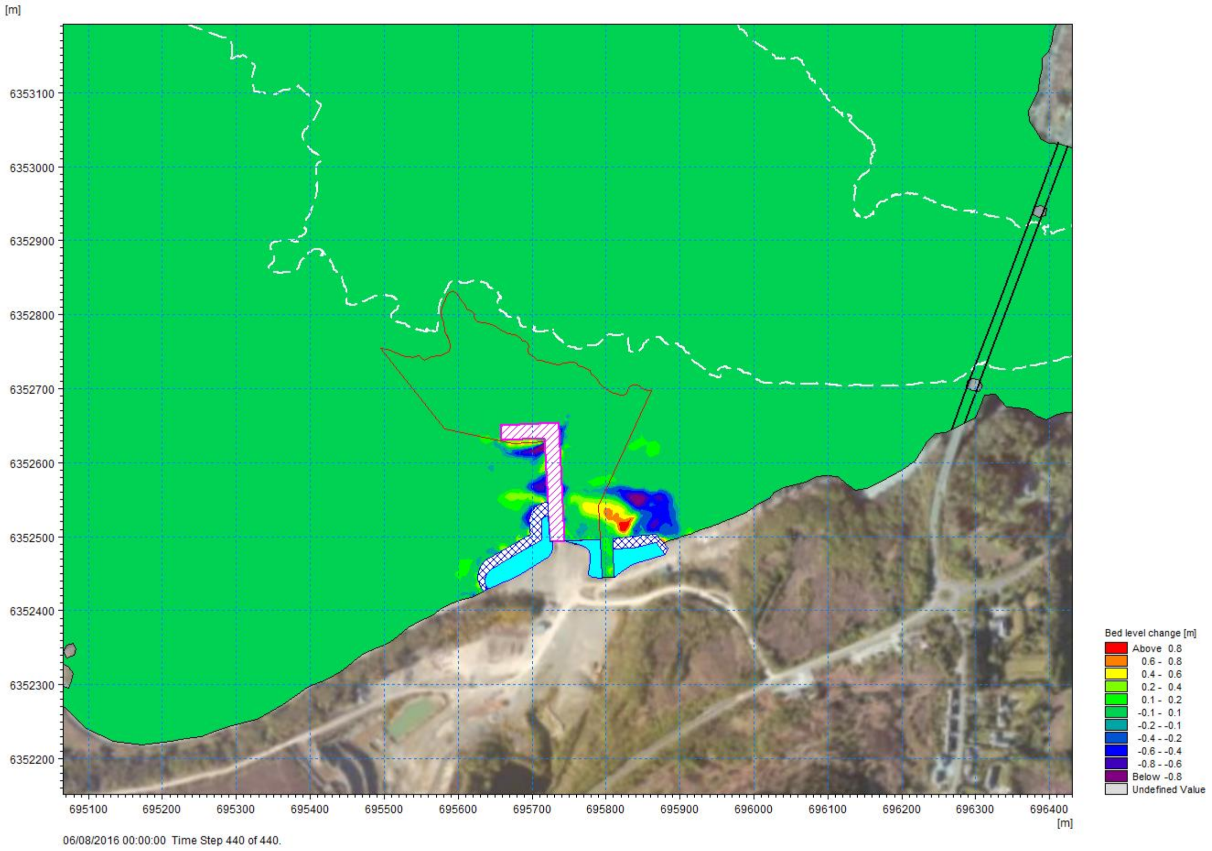

Figure 18.8 : Difference in bed level change after a four day one in one year storm from the north-west sector. Changes are given as those predicted from the proposed pier minus those predicted from the existing. The white hashed line represents the -9.5 m CD contour and thus the assumed boundary of the flame shell bed.

Side Slope Stability

Eastern Slope

A Boussinesq wave model was run for one in 100 year return period storm waves with the water levels set at mean sea level, to simulate how storm waves would be modified due to wave refraction, diffraction and wave reflections around the proposed pier area (**Appendix 18.1**).

It was found that wave reflection from the outer caisson structure and the quay wall as well as diffraction of the waves around the north eastern corner of the pier will have an effect on the wave climate at the proposed one in seven dredged slope to the east of the pier. In addition it was found that under storm conditions, a wave driven current would be generated to the east of the pier.

From the combination of the wave height and wave driven current it was concluded that these processes would destabilise the one in seven slope on the eastern side of the pier (**Appendix 18.1**). Calculations were carried out to assess the stability of the same bank if covered with cobble sized material. The model output showed that even under one in 100 year storm conditions and spring tide flows, the cobble material prevented sediment movement on the bank and thus maintain its slope.

Thus it was concluded that the one in seven side slopes with a layer of cobble sized material would provide a stable bed form for the eastern boundary of the dredged area at Kyleakin Pier.

Western Slope

The western slope is comprised of naturally graded gravel type material with grain diameters in excess of 4 mm and up to 10 mm. The modelling outputs showed that the coarser parts of the sediment grading on the slope will naturally armour the surface of the slope so that it remains stable in the long term. This conclusion was determined under a one in 100 year storm scenario.

Assessment

Under the one in 100 year storm conditions modelled it was found that the provision of cobbles on the eastern slope and the natural grading of the sediment on the western slope would prevent destabilisation of the slopes even during extreme storm events. Given that 'slumping' of the slopes would consequently be prevented, the magnitude of change on the seabed geomorphology is assessed as **negligible**.

Given that changes to the slope stability would be prevented for the reasons given above, there was no requirement to acknowledge these changes in a future (longer-term) post construction scenario (**see Sections 18.1.1** and **18.3.1**).

Propeller Wash

The navigation study showed that vessels will approach the proposed Kyleakin Pier from the north **(Appendix 16.1 (ABPmer, 2016)**). The sea bed to the north of the development is composed of exposed bed rock and cobbles together with occasional boulders. During storm conditions it can be exposed to relatively strong tidal conditions with storm waves in excess of 2.5 m. In addition, the area has been traversed by shipping for many years with regular movements of container ships through the Kyle Akin channel. Consideration by RPS indicated that the propeller wash from ships approaching the proposed pier would not result in any measureable bed erosion seaward of the -8.5 m CD contour (**Appendix 18.1**).

However, as the ships approach the berths they will require the use of both the main engines and thrusters to safely come alongside the proposed new quays. It is anticipated that the ships will come alongside the proposed new 160 m long berth bow first, i.e. bow in towards the shoreline. Information gathered during geotechnical surveys demonstrated that bed material along this quay is comprised primarily of sand and thus scour protection should be installed along at least the outer half of the berth to prevent the propeller wash eroding a hole in the bed around the draft end of the ship and depositing the material in the inner part of the berth.

Scour protection may also be required along parts of the inner section of the 160 m berth if ship masters find they frequently need to use thrusters to safely approach or leave this berth. Scour protection may be added to this area at a later date if it is found that high thruster use is required for navigational purposes. The berth along the north face of the proposed quay extension will also require scour protection from ship propeller wash as the vessels approach and leave this berth. In addition, during severe storms wave reflections from this structure will result in locally high scour currents at the base of the wall, particularly adjacent to the eastern end of the berth.

Given the above, it is considered that any changes to the geomorphology would be highly localised and occur only in the immediate proximity around the berths and therefore over the dredged area. Following from this, an assessment of **small** has been given for the magnitude of change on geomorphology from propeller wash.

18.7 Mitigation Measures

Assessment for coastal processes and geomorphology, during the construction phase of the Proposed Development, resulted in a **small** magnitude of change against sediment dispersion during capital dredging. In the operation phase a **small** magnitude of change was assessed for effects on tidal flows, wave regime, sediment transport and propeller wash. All other potential effects were assessed as **negligible.**

The potential impacts of these changes to the coastal processes and geomorphology on the receptors is covered in **Chapter 16: Navigation, Chapter 17: Water Quality** and **Chapter 19: Marine Ecology**. As discussed previously, no impact significance criteria are assigned against the changes to the coastal processes and geomorphology (**Section 18.3**). For this reason, reference should be made to each of the subsequent chapters for the detail of mitigation measures specific to an identified significant environmental effect resulting from potential changes from coastal processes and geomorphology.

A number of mitigation measures are recognised throughout the construction and operation phases of the development which are specific to coastal processes and geomorphology. These constrain the magnitude of change and add greater confidence to the assessments.

The following mitigation measures are proposed:

- The dredging contractor will liaise with the local Harbour Authority to request information on any proposed or ongoing dredging within the area during the programmed dredging period for the development.
- Ensuring the dredged area is the minimum possible to allow full operation of the development, whilst limiting the footprint.
- Ensuring the pier extension is the minimum footprint possible to allow planned operations whilst limiting the footprint.
- An Environmental Clerk of Works will be present on site during construction, to supervise the implementation of the appropriate environmental safeguards.

Before any dredging works commence a dredging Method Statement will be produced by the successful contractor for approval by Marine Scotland. This will include details of monitoring.

To provide assurance of the modelling predictions and the assessments, a general monitoring programme is proposed to assess the changes to coastal processes and geomorphology during the construction phase. Following agreement with the Marine Scotland it is envisaged that monitoring would include turbidity and/or suspended solid concentrations during dredging activities.

18.8 Overview

This chapter has considered potential for changes to the physical marine environment using flow, wave and sediment plume modelling in both the construction and operation phases. Within the modelling, consideration has also been given to the potential effects from one in 100 storms during the operation of the Proposed Development. It should be noted that the potential for coastal flood risk is considered within the Flood Risk Assessment (**Appendix 9.1**).

The overall changes to coastal processes as a result of the proposed pier are predicted to be minimal. While clear changes were predicted, these were generally in the nearshore area and proximal to the Proposed Development. This is not unsurprising as the extensions to the existing pier, which already projects 160 m into the sea, are not perpendicular to the prevailing flows.

Given the results of the modelling and the assessments, and in line with the opinion of SEPA (**Appendix 1.1**), it is concluded that the Proposed Development would not have a significant impact upon the hydromorphological status of the coastal waterbodies of the ‘Inner Sound’ and ‘Loch Alsh’. Therefore the WFD classification given to ‘hydromorphology’ and ‘morphology’ quality element would remain the same (High).

While there is an overlap of the Proposed Development and some of the coastal processes changes modelled, it is not considered that these changes would have a detectable effect on the qualifying features of the Lochs Duich, Alsh and Long MPA or SAC (see **Chapter 19: Marine Ecology**).

18.9 References

Ref 18-1 Scottish Government (2003) *Water Environment and Water Services (Scotland) Act 2003*. [Online]. [Accessed: 12 May 2016]. Available from: http://www.legislation.gov.uk/asp/2003/3/introduction.

Ref 18-2 Marine Scotland (2015). *Scotland’s National Marine Plan: A Single Framework for Managing Our Seas.* Edinburgh: the Scottish Government.

Ref 18-3 Howe, J.A., Dove, D., Bradwell, T., Gafeira, J., 2012. Submarine geomorphology and glacial history of the Sea of the Hebrides, UK. *Marine Geology*, 315-318, 64-76.

Ref 18-4 Stephenson and Merritt (2006) Skye – A landscape fashioned by geology SNH. [Online]. [Accessed November 2016). Available at: http://www.snh.org.uk/pdfs/publications/geology/skye.pdf.

Ref 18-5 Ob Lusa to Ardnish Coast, Isle of Skye (Hettangian, Sinemurian and Pliensbachian) SSSI

Ref 18-6 British Geological Society – Bedrock and Superficial deposits, Land and Offshore datasets http://mapapps.bgs.ac.uk/geologyofbritain/home.html (Accessed 11th November 2016)

Ref 18-7 http://mapapps2.bgs.ac.uk/geoindex_offshore/home.html (Accessed 11th November 2016)

Ref 18-8 http://portal.oceannet.org/search/full/catalogue/bgs.nerc.ac.uk__MEDIN_2.3__4cac87d2-7cbf-4270-8182-472c84150309.xml (Accessed 11th November 2016)

Ref 18-9 SEPA, 2014. *Inner Sound waterbody (200491).* Scotland: SEPA.

Ref 18-10 SEPA, 2014 *Loch Alsh waterbody (200352)* Scotland: SEPA.