Impact of Suspended Sediment and Smothering on Scallops

Inch Cape Wind Farm

Inch Cape Offshore Ltd

SDIC Red Rock Power Limited

6th October 2017

Inch Cape Windfarm Limited

Author: Laila Higgins, Environmental Consultant

Document reference: 1152250

natural power

Document history

Author	Dr Laila Higgins	08/09/2017
Checked	Stuart McCallum	12/09/2017
Approved	Dr Jane Lancaster	06/10/2017

Client Details	
Contact	Tom Young
Client Name	Inch Cape Offshore Limited
Address	5th Floor, 40 Princes Street Edinburgh. EH2 EBY

Issue	Date	Revision Details
A	06/10/2017	First issue (before modelling)
B	08/02/2018	Second issue incorporating modelling
C	02/03/2018	Third issue following client comments
D	12/03/2018	Fourth issue following client comments

Local Office:

Unit 5, Horsley Business Centre
Horsley
Northumberland
NE15 0NY
Tel: +44 (0) 1661 312 100

Registered Office:

The Natural Power Consultants Limited
The Green House
Forrest Estate, Dalry,
Castle Douglas, Kirkcudbrightshire,
DG7 3XS

Reg No: SC177881
VAT No: GB 243 6926 48

Contents

1. Introduction

1.1. The Inch Cape Project

Inch Cape Offshore Limited (ICOL) is progressing the development of the Revised Inch Cape Wind Farm and associated Revised Inch Cape Offshore Transmission Works (OfTW), collectively known as the Revised Development for the purposes of this report. The Revised Development is located in the North Sea off the east coast of Angus, Scotland. It will comprise an offshore array of up to 72 Wind Turbine Generators (WTGs), connected by up to 190km of subsea inter-array cables. These will be connected to one or two Offshore Substation Platform(s) (OSPs) where power generated by the WTGs is transformed and subsequently carried approximately 83 km to the onshore landfall location at Cockenzie via Offshore Export Cables (OEC). Foundations for WTGs and OSPs will be either be mounted on gravity base structures (GBS) or piled.

The Revised Development will comprise an offshore generating station with a capacity of greater than one megawatt (MW) and therefore requires Scottish Ministers' consent under section 36 of the Electricity Act (Section 36 Consent) to allow its construction and operation. Under the Marine (Scotland) Act 2010, the Revised Development will also require Marine Licences granted by the Scottish Ministers to allow for the construction and deposition of substances and structures in the sea and on the seabed.

A Scoping Report for the Revised Development was prepared in support of a request for an opinion from Marine Scotland Licensing and Operations Team (MS-LOT) as to the scope of the information to be provided within the Revised Development Environmental Statement (ES). The Scoping Report was submitted to MS-LOT on 28th April 2017 and an opinion received on 28th July 2017.

1.2. Purpose of this Report

This document has been produced in response to the Scoping Opinion received from MS-LOT. The Scoping Report set out the approach to the Revised Development EIA, specifying which receptors and impacts should be considered. For the Natural Fish and Shellfish chapter ICOL proposed only one receptor and impact should be included within the impact assessment (the impact of construction noise on hearing specialists).

In the Scoping Opinion Scottish Ministers noted two potential impacts that may require further consideration within the impact assessment: Impact of suspended sediment and smothering on scallops and *Nephrops,* and particle motion. This paper covers the impacts of suspended sediment and smothering, particle motion is covered by a separate discussion paper.

The scoping opinion is detailed below.

Impact of suspended sediment and smothering on scallops and nephrops

The SFF raised the issue of the need for an assessment of the impact of suspended sediment in smothering species such as scallops and nephrops in their consultation response and during discussions at the stakeholder meetings.

Advice from MSS noted that the possible use of gravity base structures would require significant dredging operations and lead to increased suspended solids and increased smothering impacts. MSS note that structures such as monopoles or pin piles would not be likely to have such an effect. Adult and larval scallops have a low tolerance to smothering and to increases in suspended sediment levels although adults are able to swim and may be able to escape the impacts. The behaviour and survival of scallop larvae and their ability to settle on suitable substrate would also be affected. Adult nephrops are more tolerant to smothering and to suspended solid load increases and decreases but MSS noted that more information on larval production, larval development and juvenile nephrops behaviour is required to understand the effect on these life stages. MSS note that the dredging would also have an effect by destroying populations of nephrops and by removing sediments best suited to burrowing and that re-colonisation/recovery would be prolonged.

MSS provided advice on a suggested approach for assessing the impact of sediment on scallops and nephrops.

If gravity base foundations are to be used the Scottish Ministers advise that for fish and shellfish ecology further work to assess the impact of sediment on scallops and nephrops is carried out. The Scottish Ministers advise that the following two pieces of work be undertaken:

- *A review of literature on effects of suspended sediments to scallops and nephrops (including different life stages); and*
- *Physical process modelling of likely spatial extent of suspended sediments from activities of concern.*

These could be used to provide a comparison with the spatial extent of the scallop and nephrops fishery, identified from commercial fisheries data (e.g. Vessel Monitoring System ("VMS") data as described by Kafas et al. (2012) and found online at Kafas et al. (2013). This would allow an understanding of the spatial extent of effects, if any, to scallops and nephrops and provide a context within which to consider them. If ICOL consider that there are no significant effects and scope this potential impact out of further assessment they must provide justification for this decision.

Kafas A, Jones G, Watret R, Davies I and Scott B (2012). Representation of the use of marine space by commercial fisheries in marine spatial planning. ICES CM I:23.

Kafas A, Jones G, Watret R, Davies I and Scott B (2013) 2009 - 2013 amalgamated VMS intensity layers, GIS Data. Marine Scotland, Scottish Government. doi: 10.7489/1706-1

The Scottish Ministers note that ICOL carried out a modelling assessment as part of the Original Development ES. This modelling system allowed the baseline environmental conditions to be modelled, against which the impacts and effects due to the development and any cumulative effects with the other Forth and Tay projects could be assessed. No significant effects were identified.

The Scottish Ministers advise ICOL to follow the approach suggested by MSS and outlined above and provide an overview of the potential impact of suspended sediment and smothering on scallops and nephrops.

In their scoping response MS-LOT specified that an assessment of the impact of suspended sediments is only required where GBS are to be used, as they represent the greatest source of suspended sediment for the Revised Development, as a result of the requirement for dredging for this type of foundation.

While scallops are found throughout the Development Area, *Nephrops* are less common as the sediments of the Development Area are less suitable for burrowing. *Nephrops* are instead predominately found in the soft muddier sediment of the offshore export cable route. This is demonstrated by the distribution of fishing for *Nephrops* as illustrated by Scotmap data for <15m vessels (Figure 1.1) and VMS >15m (Figure 1.2-1.3; Kafas *et al.*, 2013 and VMS data for demersal trawling (2011-2015)). ICOL therefore requested to Marine Scotland that as this assessment be limited to scallops, as *Nephrops* are unlikely to be impacted by sediment arising from the installation of the GBS as they are not found in the Development Area.

MS-LOT confirmed they are content with this approach in an e-mail from Sophie Humphries on 29th September 2017.

This paper serves to provide justification from ICOL to scope out any further assessment of the impacts from suspended sediment and smothering on scallops.

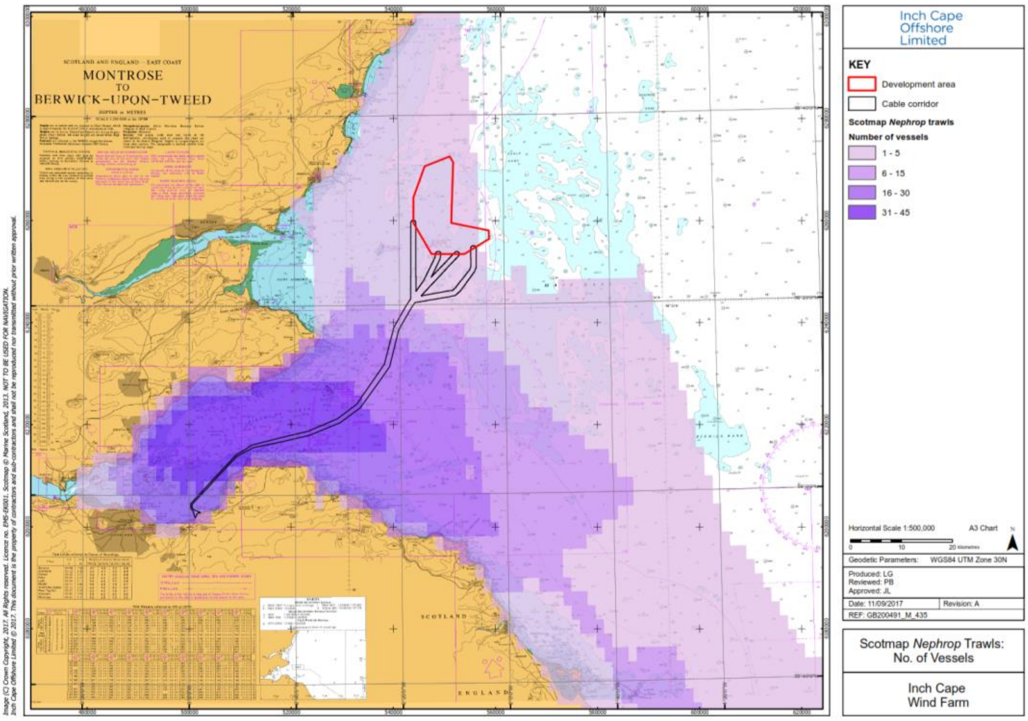


Figure 1.1: Number of *Nephrops* trawls from <15 m vessels (Scotmap, 2013)

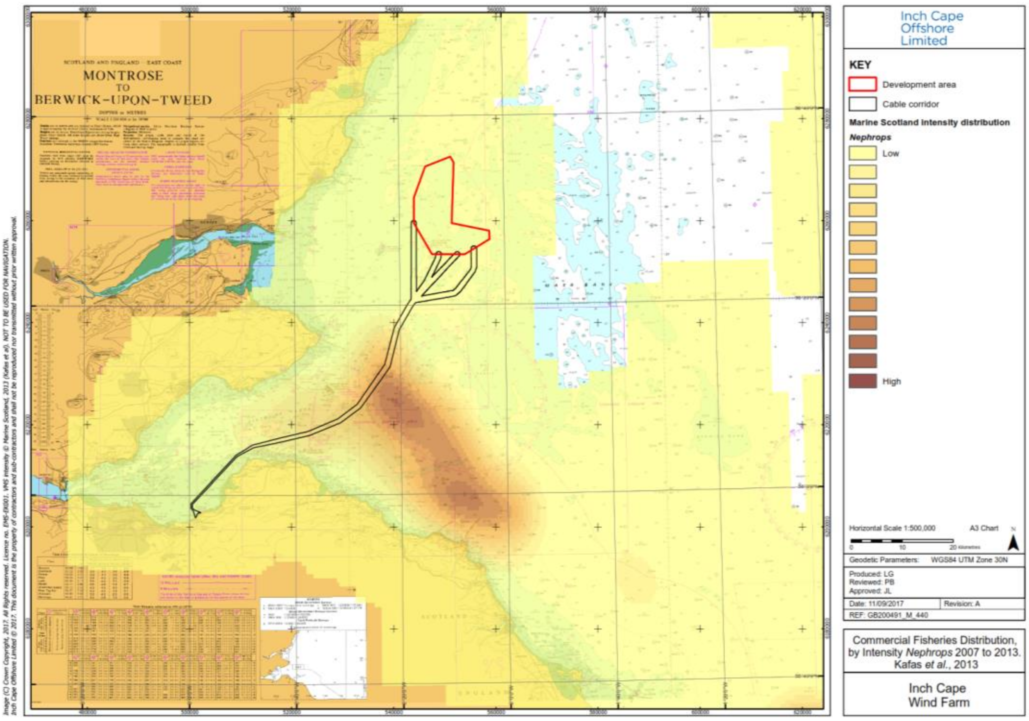


Figure 1. 2: Commercial fisheries distribution of *Nephrops* by Intensity, 2007 to 2013 (Kafas *et al.,* 2013)

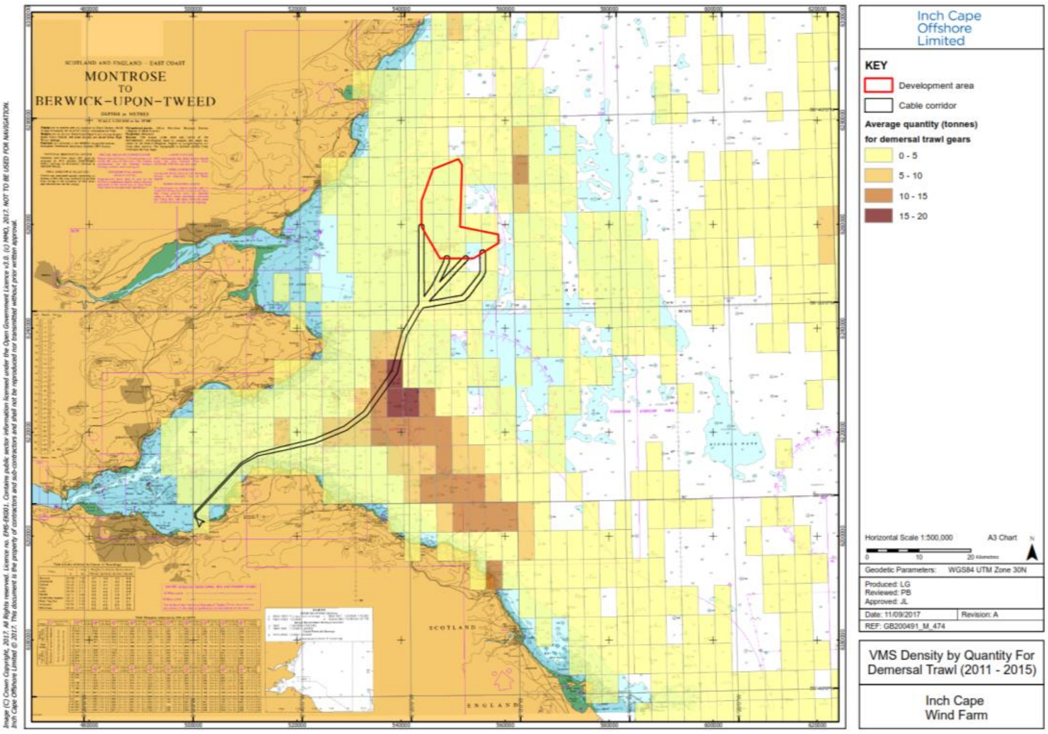


Figure 1.3: VMS Density by Quantity for Demersal Fishing 2011 to 2015 (ICES Commercial Landings)

2. Approach

This document aims to provide justification to address points raised by Scottish Fishermen's Federation (SFF) and Scottish Ministers on the impact on scallops from suspended sediment and smothering should GBS be used in the Revised Development. This has been achieved through the undertaking the following tasks:

- A literature review on the impact of on scallops at different phases of their life cycle arising from increased suspended sediment concentrations (SSC) and smothering;
- Sediment plume modelling to predict the likely spatial extent of elevated SSC and subsequent deposition arising from a worst-case scenario of 72 GBS for the Revised Development within the Development Area; and
- Establishment of the spatial distribution of scallops in the vicinity of the Development Area, as indicated by the extent of the scallop fishery derived from fisheries data.

This information was compared to the information presented in the Natural Fish and Shellfish Chapter of the Original Development ES in order to assess the validity of scoping out this impact from the Revised Development ES. This was achieved through the following steps:

- Comparison of the levels of SSC and smothering predicted from the sediment plume modelling for the Revised Development to:
  - The levels predicted in the Original Development ES;
  - The levels found to be biologically significant to the different life cycles in the papers reviewed;
- Comparison of the sensitivity of scallops used to assess the significance of the predicted impacts in the Original Development ES compared to those found in the literature review.

Validation of the commercial fisheries assessment presented in Original Development ES was beyond the scope of this study, as a new assessment will be undertaken as part of the Revised Development EIA report.

3. Findings

3.1. Literature review on sensitivity of scallops to sediment

3.1.1. Scallop biology

Scallops are bivalve molluscs, preferring sedimentary habitats comprised of sand, gravel and mud, sometimes interspersed with stones, rocks or boulders (MarLIN, 2006; Marine Scotland, 2017a). They are filter feeders, collecting phytoplankton and other micro-organisms from the water column (Seafish, 2016). Within the ICES rectangles corresponding to the Development Area (41E7 and 42E7), two species have been identified in commercial landings, the king scallop (*Pecten maximus*) and the queen scallop (*Aequipecten opercularis*), with king scallops making up the vast majority of the landings.

The king scallop (*Pecten maximus*) is a large scallop which can grow to 17 cm or more and is typically found in depths between 20-40 m, but has been found deeper than 100 m (Seafood Scotland, 2012). The minimum landing size for king scallops is 10.5 cm in length, except in the Irish Sea where it is 11 cm and Shetland where minimum landing length is 10 cm (Cappell *et al*., 2013; Marine Scotland, 2017b).

The queen scallop (*Aequipecten opercularis*, also known under synonym of *Chlamys opercularis*; Carter, 2008) is a medium-sized scallop which grows to around 8-9 cm and is found between tide marks, and to a depth of 100 m (Carter, 2008; Hayward & Ryland, 2017). The minimum landing size for queen scallops is 4 cm, with a potential increase proposed to 5.5 cm (Cappell *et al*., 2013; Marine Scotland, 2016).

These species are abundant in the North Sea and the Atlantic with a geographical distribution from Norway to the Mediterranean (Carter, 2008; Marshall and Wilson, 2008). Within the coastal waters of Scotland, king scallops are found in numerous separate populations in the North Sea and to the west of the Hebrides in the Atlantic (Seafood Scotland, 2012), while queen scallops are predominantly located in the Irish Sea, particularly around the Isle of Man (Carter, 2008; Marine Scotland, 2016).

Adult scallops of both species are benthic, living on the seafloor in sand and gravel habitats, and reproduce by releasing gametes into the water column during synchronised spawning events (Le Pennec *et al*., 2003; Seafood Scotland, 2012; Marine Scotland, 2016; Agri-Food and Biosciences Institute [AFBI], 2017). For king scallops, spawning occurs between April and September and peaks in late spring, with a secondary spawning peak in late summer / autumn (Seafood Scotland, 2012). Queen scallops spawn during approximately the same period, peaking in March to May and again in autumn, and may spawn periodically during the summer (Jenkins *et al*., 2003; Brand, 2006; Marine Scotland, 2016).

Life cycles are similar for both species. After spawning, the eggs (oocytes) and larval stages are pelagic (live in the water column). The fertilised oocytes remain near the seabed for a few days until they develop the capacity to swim, becoming larvae which are lecithotrophic (possessing a yolk), and rise to the surface of the water column.

The larvae have several stages of development, starting with a trochophore stage, then grow into veligers and develop an eyespot, later developing a “foot” in preparation for their benthic life stages (Cragg, 1980; Cragg, 1991; Le Pennec *et al*., 2003). The yolk reserves are thought to last for approximately a week (Le Pennec *et al*., 2003), after which veligers resort to hunting phytoplankton and other pelagic micro-organisms. The scallop larvae are capable of active swimming, and their position in the water column largely depends on the water currents and temperature, though eyed veligers concentrate near the top of the water column, and typically near high concentrations of other plankton (Cragg, 1980; Cragg, 1991; Le Pennec *et al*., 2003).

After 3-6 weeks, the larvae settle on the seabed and metamorphose into juvenile scallops, known as spat (Le Pennec *et al*., 2003; Howarth and Stewart, 2014). The settlement of pelagic larvae in benthic environments is referred to as recruitment. The pelagic life style of the larvae allows for recruitment of new scallops both to the location they were spawned (self-recruitment) as well as to other areas (dispersal), depending on hydrographic conditions (Howell & Fraser, 1984; Lewis and Thorpe, 1994a; 1994b; Beaumont and Gjedrem, 2007).

King scallops become sexually mature at approximately 2-3 years at a shell length of 80-90 mm, and often first spawn in the autumn of their second year (Howarth and Stewart, 2014; Seafood Scotland, 2012). Queen scallops mature between 1-2 years old and approximately 40 mm in shell length (Howarth and Stewart, 2014). Small scallops attach using a byssus while larger scallops are capable of swimming freely (Hayward & Ryland, 2017).

3.1.2. Effect of sediment on scallops

Large movements of sediment are common in mobile sedimentary habitats such as sands and gravels, where storms and current fluctuations regularly shift the mobile substrate, causing changes in SSC and sediment deposition (Orpin *et al*., 2004). Smothering and increased SSC are considered separately, although it is recognised there is overlap between these impacts. The information presented below applies to both king and queen scallops unless otherwise stated.

3.1.2.1. SSC

The effects of elevated SSC have been examined in scallops particularly in relation to aggregate extraction and scallop fishing by dredging (Szostek *et al*., 2013; Howarth and Stewart, 2014). These effects vary depending on the developmental stage of any scallops present, and the activities that they would ordinarily be undertaking at that time. The key behaviours or activities that can potentially be affected by an increase in SSC are:

- Spawning;
- Settlement;
- Avoidance behaviour; and
- Feeding.

Effects on the above behaviours will be considered in relation to increased SSC.

Spawning

Scallops produce large numbers of gametes (oocytes and sperm) during spawning, and can spawn multiple times throughout the spawning season (Le Pennec *et al*., 2003). Three-year-old adult king scallops can produce 15 million oocytes in one emission (Le Pennec *et al*., 2003). Oocyte production in queen scallops can range from 3 to 6 million (MarLIN, 2006). The production of large amounts of oocytes is a strategy used by broadcast spawners, and the mortality of these oocytes and resulting larvae is extremely high (Thorson, 1950).

Suspended sediments have been shown to impact the gametes of other species to varying extents, (Davis, 1960; Auld and Schubel, 1978; Kang, 2012; Ricardo *et al*., 2016) with a reduction in oocytes recorded between 0% in copepods (Kang *et al*., 2012) and 50% in corals (Ricardo *et al*., 2016) at SSC of 100 mg.l^{-1}, but this has not been specifically studied in scallops. Hard clams (*Mercenaria mercenaria*) showed a variable response to concentration and sediment type, showing relative tolerance to silt for both oocytes and larvae, where 750 mg.l^{-1}concentration produced no negative effect, and 400 mg.l^{-1} concertation produced 100% mortality for oocytes and 100% survival for larvae (Davis, 1960). Clay, chalk and Fuller's earth however showed significant negative impacts to growth and survivability of larvae at concentrations >250-500 mg.l^{-1}, whereas oocytes were more tolerant (Davis, 1960).

Stress can induce spawning in invertebrate animals, including scallops (New England Fishery Management Council, 1993; Heasman *et al*., 1995; Guijarro-Garcia *et al*., 2007), which could increase oocyte production in affected areas. Resulting larvae produced in this manner can be underdeveloped or self-fertilised (oocytes fertilised by sperm produced by the same individual), resulting in higher mortality of larvae, longer maturation times and reduced overall size (Beaumont and Budd, 1983).

Impacts on fecundity is related to reduced gonad development, caused by a decrease in food intake and an increase in elimination of inorganic particles (Lo, 2009).

Settlement

Both juvenile and adult scallops in general exposed to higher levels of SSC for long periods (several days to weeks) demonstrate reduced growth rates compared to those exposed to lower concentrations (Bricelj & Shumway, 1991; Szostek *et al*., 2013; Howarth and Stewart, 2014). Settling larvae and spat are more sensitive to impacts relating to increased SSC as impacts to growth would also affect the development of organs, including gonads. Juvenile king scallops exposed to low SSC (<100 mg.l^{-1}) and high SSC (200-700 mg.l^{-1}) for 18 days responded by increasing "clapping" rate (as a means of clearing unwanted particles), and though high SSC reduced growth rates, high SSC did not affect mortality (Szostek *et al*., 2013).

Avoidance behaviour

Both the pelagic larvae and adult scallops are capable of free swimming and can, to an extent, avoid unfavourable conditions (Moore and Trueman, 1971; Cragg, 1980; Howell & Fraser, 1984; Howarth and Stewart, 2014; Hayward & Ryland, 2017). During one tagging study, adult king scallop did not migrate further than 30 m from their release point (Howell & Fraser, 1984). Studies have shown animals generally remain in the same bed (Gibson, 1956), or travel less than 1-2 km of the release site (Barber and Blake, 1991), however it has been noted that movement to other areas would likely increase as a result of disturbance. Queen scallops are known to be more mobile than king scallops though this has not been quantified (Howarth and Stewart, 2014).

Scallops, including king and queen scallops, possess eyes arrayed along the edges of their valves, which are used for predator avoidance and feeding (Land, 1965; Speiser and Johnsen, 2008). Increased SSC will reduce visibility and could delay predator avoidance. It is also important to note that vision-based predators will also be impaired, thus reducing the risk of predation.

Veligers spread throughout the water column live off their yolk reserves until it is exhausted, then tend to migrate to the top of the water column (Cragg, 1980; Le Pennec, *et al*., 2003). The impact on vision-based activities will be limited due to their reliance on pressure to orientate (Cragg, 1980). Within the water column, predation by vision-based predators will also be reduced. Migration to the seafloor for settlement and metamorphosis is determined by temperature, pressure and water currents (Cragg, 1980; Le Pennec, *et al*., 2003; Beaumont and Gjedrem, 2007), however late-stage veligers (pediveligers) seek out suitable habitat to settle (AFBI, 2017), and may avoid areas of high SSC, altering settlement patterns.

Feeding

Filter Feeding

Scallops filter feed on phytoplankton and other micro-organisms. Increased sediment suspension can increase the concentration of sediment being collected by the scallop, diluting food particles and requiring expulsion of material (AFBI, 2017). It can also damage feeding apparatus of filter feeders, and result in a subsequent reduction in growth rates (Bricelj and Shumway, 1991). Many species of scallop show selectivity in food choice, for example distinguishing between different algal species (Shumway *et al*., 1997), and have been shown to respond to an increase of SSC by increasing their food selectivity, discarding non-food particles either by flushing the shell (shell claps) (Last *et al*., 2011), or excreting particles as pseudofaeces as shown in the deep-sea scallop (*Placopecten magellanicus*) (Macdonald and Ward, 1994). Other species have shown significant responses to increased SSC (Ellis *et al*., 2000), while others show greater tolerance (Bricelj and Malouf, 1984). The characteristics of the organism, properties of the sediment and length of exposure time appear to be significant factors in determining the magnitude of the impact (Beecham, 2008).

Hunting by veligers

The pelagic eyed veliger stage also possesses an eyespot, and are known to hunt for phytoplankton and other micro-organisms (Le Pennec *et al*., 2003). Increased SSC would likely decrease visibility and increase mobility as a result of avoidance behaviour, therefore the effort required to find food will increase, impacting larval growth and development, as demonstrated for other species of mobile zooplankton (Hansen *et al*., 1991).

3.1.2.2. Smothering

Adult and juvenile Scallops

Benthic organisms present contrasting tolerances to burial, with mortality rates dependant on size and species (Hinchey *et al*., 2006; Kotta *et al*., 2009; Last *et al*., 2011; Hendrick *et al*., 2016).

Hendrick *et al*. (2016) found the mortality rate of adult queen scallops (*Aequipecten opercularis*) measuring approximately 5.4 cm in width was 35% in sediment depths <2 cm, increasing to 57.4% at 5 cm depth and 64.8% at 7 cm depth (Last *et al*., 2011; Hendrick *et al*., 2016). Survival was largely dependent on their ability to emerge from the sediment and individuals that could not free themselves after 32 days died (Hendrick *et al*., 2016). This research supports the conclusion that survival rates decrease with increasing sediment depths.

As survival is strongly linked to a scallop's ability to emerge from burial (Last *et al*., 2011; Szostek *et al*., 2013; Hendrick *et al*., 2016), smothering presents a greater risk to small individuals and juveniles which attach to the sediment using byssus threads (Hayward and Ryland, 2017) compared to the larger, free-swimming adults. Minchin (1992) noted that scallops as small as 1 mm in length were capable of detachment from the substrate, however most remained attached until they were between 4-13 mm in length.

Similar to queen scallops, mortality in juvenile king scallops has been shown to increase with depth of sediment and length of time it takes them to emerge, as well as increase in response to a reduction in particle size (Szostek *et al*., 2013). For medium and coarse sediment types, mortality was 0-20% for all sediment depths, and represented individuals that failed to emerge after 8 days (most emerged within a day, if not almost immediately). For fine sediment types, mortality was 0% for 1 cm burial depth, increasing to between 60-70% for 3 cm and 5 cm depth (Szostek *et al*., 2013). This also supports the conclusion that increasing burial depths reduce survival rates.

There is no specific data available measuring the tolerance of adult king scallops to burial, though Marshall and Wilson (2008) suggest burial in sediment to a depth >5 cm should be fatal. It is important to note that king scallops can grow to 17 cm across or greater, and as a result are likely to be stronger and more capable of freeing themselves than queen scallops as used by Last *et al*. (2011) and Hendrick *et al*. (2016), increasing the proportion of the population that would survive burial of the same depth. Hendrick *et al*. (2016) also demonstrated mortality was not complete for queen scallops buried 7 cm deep.

Nevertheless, as a conservative estimate, burial by sediment deeper than 5 cm for longer than 16 days should be considered to be fatal for all organisms (Marshall and Wilson, 2008; Last *et al*., 2011; Hendrick *et al*., 2016). Adult king scallops buried shallower than 5 cm of sediment are considered to be able to lift themselves clear of deposited sediments (Marshall and Wilson, 2008), however it is reasonable to propose that this is a relatively conservative value considering the size of an adult king scallop.

Once unburied, scallops are free to either swim away to find more favourable conditions, or remain and resume normal behaviour (spawning, avoidance behaviour, and filter feeding).

Oocytes and Pelagic Larvae

Smothering will not be a significant risk for oocytes and pelagic larvae. Larval dispersion is strongly influenced by local hydrographic conditions, and they do not have to settle in the location they were spawned (Beaumont and Gjedrem, 2007). Where scallop density is lost due to smothering, recruitment from the water column in affected areas would not be prevented. However, the larvae can be selective of the location they choose to settle, and excess sediment or incorrect grain size on the surface can act as a deterrent, particularly in relation to silt (AFBI, 2017).

3.2. Predicated sediment levels

Sediment dispersal modelling assessment was carried out to predict SSC levels and sediment deposition depths as a result of the Revised Development (Appendix A).

The assessment was carried out using a worst-case estimate of dredging requirements, including all worst-case tolerances, of 40,000 m^3 of material to be excavated from each GBS location (72 locations in total). The assessment employed a cumulative impact model and was based on the continuous disposal of dredged material from the fall pipe of a trailer suction hopper dredger at a rate of 314.82 $kg.s^{-1}$ and at a distance of 5 m above the seabed (Partrac Ltd, 2018, Appendix A).

The model was run for 16 days accounting for the prevailing tidal currents, and flood and neap tides. Results were presented in time sliced snapshots of 48 hours at distances of 100 m, 250 m, 500 m and 1000 m away from the point of release.

The conclusions of the modelling are summarised as follows:

- There is a strong tidal axis observed along north-north-east (NNE) and south-south-west (SSW). SSC and deposition levels are greater in a SSE direction from each disposal point compared to NNE. SSC levels locally increase slightly during neap tides versus spring tides, while SSC travels further during spring tides compared to neap tides.
- SSC is predicted to peak at 200-500 $mg.l^{-1}$ above background levels (maximum observed was 330 $mg.l^{-1}$) over an area of approximately 100 m^2. Concentrations are expected to drop to 100 $mg.l^{-1}$ within 100 m of discharge point and <5 $mg.l^{-1}$ at 500 m. The maximum distance travelled by sediment is 5 km from source.
- Due to the coarse nature of the excavated material, deposition is expected to occur rapidly at the release site. SSC expected to drop to background levels (<5 $mg.l^{-1}$) almost immediately (< 1 hour).
- All SSC expected to return to background levels within 2 days of material disposal.
- The maximum predicted sediment deposition depth is 5.9 m. Sediment depths will reduce to 61-110 cm at 100 m from source, 17-19 cm at 250 m, and <5 cm at 500 m distance (north/south). The area affected by a deposition depth >5 cm is approximately 6.08 km^2.

3.3. Distribution of scallops from fisheries data

Using data collected by Marine Scotland between 2007 and 2011 (Kafas *et al*., 2012), and more recent 2009 to 2013 (Kafas *et al*., 2013), VMS data (MMO) on the scallop dredging activity for the over 15 m fleet and (2016) VMS data (ICES) on the scallop dredging activity for the over 12 m fleet, the spatial extent of the scallop fisheries in and around the Development Area have been plotted. From this, it can be seen that scallop fishing clearly overlaps with the Development Area. The extent of the scallop fishery is further discussed in Section 4.1.

Landings figures for ICES rectangles 42E7 and 41E7 (which overlap the Development Area) obtained from the MMO revealed that the vast majority of scallops landed were king scallops between 2011 and 2016. Of these rectangles the highest catches were found to have occurred in 42E7. Between 2011 and 2016 no queen scallops in were landed in 42E7, and with only 288 kg landed in 41E7 during this period (in 2012). This is not to say that queen scallops are absent in the area, but more likely they are not of high commercial value compared to king scallops. It is also worth noting that the maximum growth length for queen scallops (<9 cm) is less than the minimum landing size for king scallops (>10.5 cm, previously 10 cm), and might result in the latter species being targeted preferentially in this area for practical reasons in addition to commercial potential.

4. Validation of existing baseline

4.1. Presence of scallops and extent of fishery

Fishing patterns indicate that king scallops are still present in the area and continue to be commercially exploited and while landings of queen scallops are uncommon (not commercially exploited) they are likely to be present throughout the Development Area.

A new commercial fisheries baseline has been gathered for the Revised Development EIA, hence validation of the original baseline is not required, however details have been presented in this section which compare any changes which may have occurred with the distribution of this fishery, as an indication of the presence of scallops.

Between 2011-2016, average annual landings of scallops 42E7 and 41E7 where the Development is located were £529,645 and £240,262 respectively. The majority of scallop landings in the Forth and Tay region[1] came from ICES squares to the north east of the Development Area, particularly rectangles 42E8 and 43E8, which are located further offshore. Over this period rectangle 42E8 alone recorded average annual scallop landings of £1,418,659 and this rectangle had the second highest average landings of scallops (by value) in Scotland.

Prior to this, scallop landings were higher in both rectangles 42E7 and 41E7 and the Forth and Tay region (Figure 4.1). Scallop fishing in the 42E7 and 41E7 underwent rapid expansion during the period 2001-2007, before decreasing until 2011. Since 2011, landings have steadily increased, however remain less than half of their peak levels in 2007.

[1] Comprising of ICES rectangles 43E&, 43E8, 42E7, 42E8, 41E6, 41E7, 41E8, 40E7 and 40E8.

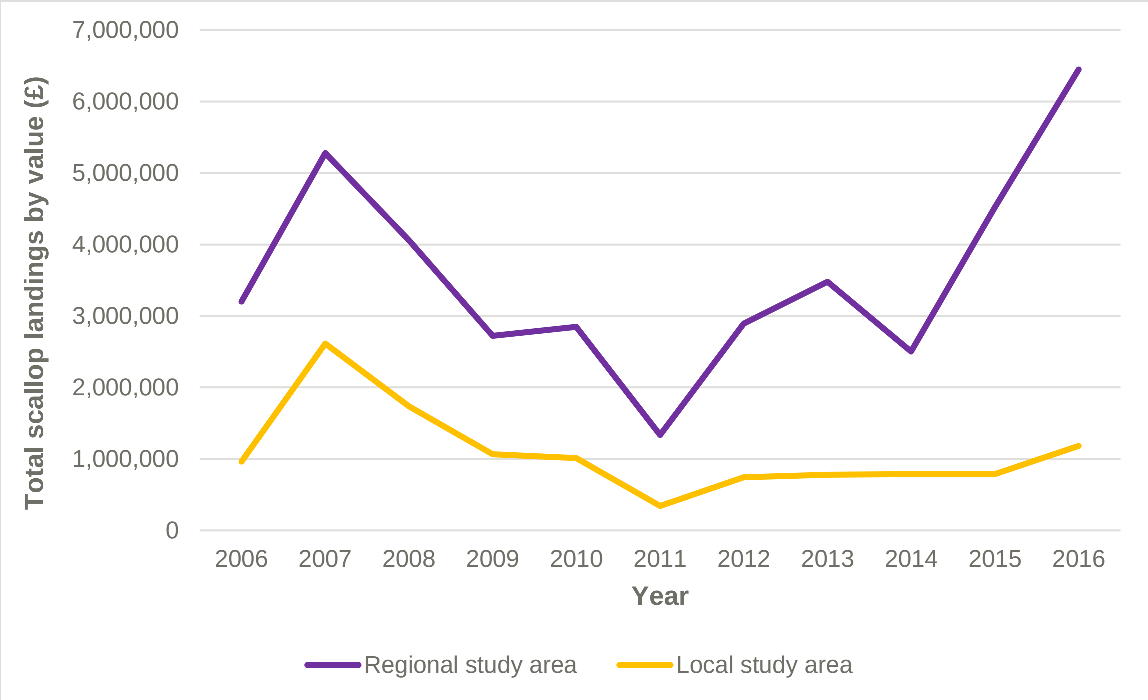


Figure 4.1: Total scallop landings values (£) in the 42E7 and 41E7 and the Forth and Tay region from 2006 to 2016 (MMO)

The average landing figure for over the past 10 years indicate that scallop fishing has moved further offshore in recent years. This evidence is further substantiated by VMS data, which provides an accurate picture of scallop fishing distribution as the majority of scallop dredgers are of over 15 m.

Marine Scotland VMS data for the period 2007-2011 (Kafas *et al.,* 2012) shows that the location of the Development Area was subject to some of the highest intensity scallop dredging in the Forth and Tay region (Figure 4.2). Marine Scotland data from 2009-2013 (Kafas *et al.,* 2013) shows that the area intensively dredged for scallops expanded north east (Figure 4.3). More recent VMS data shows the intensity of scallop dredging in the Development Area becoming less, with areas to the north west of the Development Area being more intensively fished during the period 2011-2015 (Figure 4.4). The most recent VMS data available from ICES shows that in 2016 within the Forth and Tay region, scallop dredging principally targeted north west of the Development Area (ICES rectangle 42E8; Figure 4.5). It should be noted that the VMS for 2016 from ICES includes vessels of between 12-15 m, hence while this increase in intensity may be due to the inclusion of smaller vessels, as most scallop dredgers are over 15 m it is more likely that increase in activity is reflective of increased landings in 2016 particularly in 42E8.

While the landings and VMS data do point to the fact that scallop dredging has moved further offshore in recent years and is now less centred upon the Development Area, it should be noted that fluctuations in scallop dredging activity are subject to annual fluctuations due to the cyclical nature of the fishery, with nomadic vessels targeting different areas in different years. Thus, annual variations in fishing intensity can be somewhat dependant on productivity elsewhere. Hence it is possible that the area of the Development Area may be targeted intensity in future years.

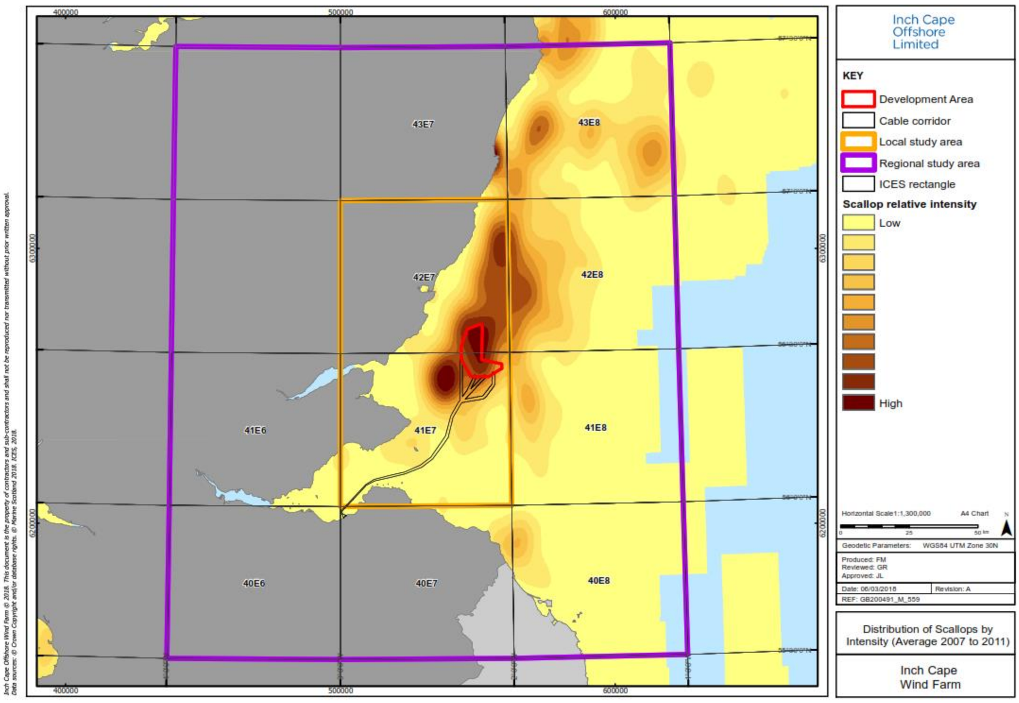


Figure 4.2: Distribution of Scallops by Intensity (Average 2007 -2011) in Regional Study Area (Marine Scotland; Kafas *et al.,* 2011)

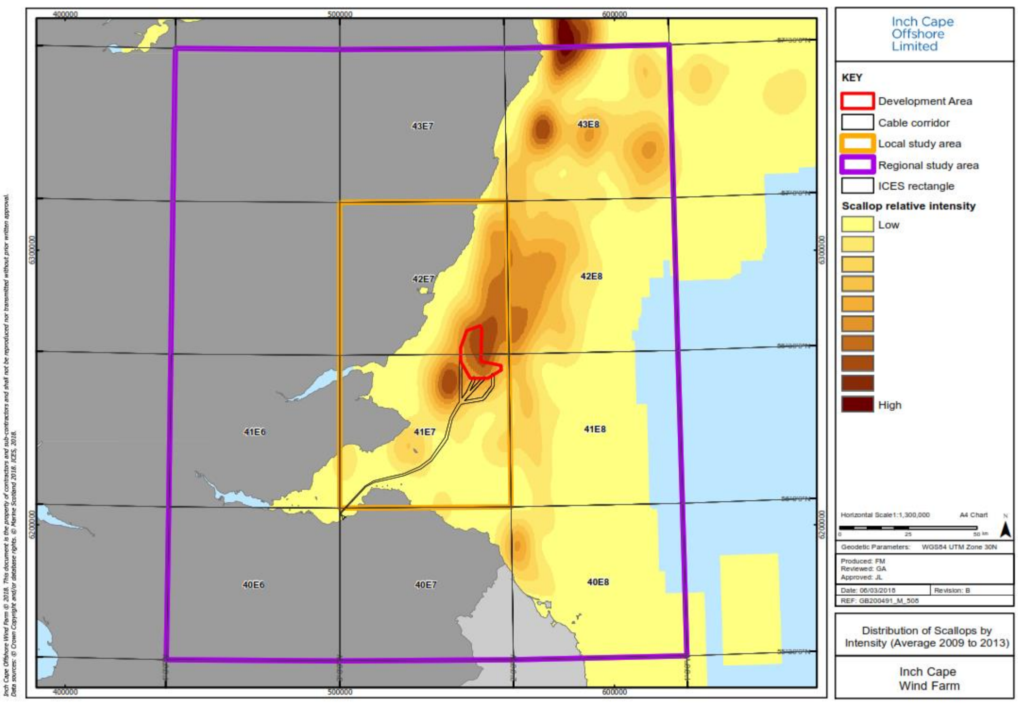


Figure 4.3: Distribution of Scallops by Intensity (Average 2009 -2013) in Regional Study Area (Marine Scotland; Kafas *et al.,* 2013)

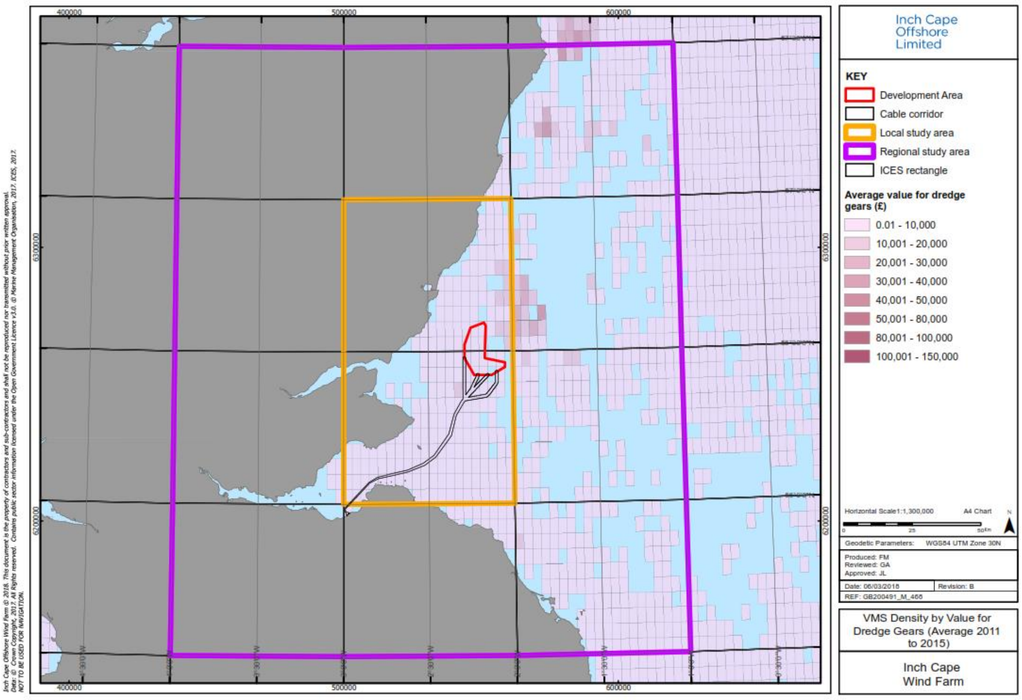


Figure 4.4: VMS Density by Fishing Intensity for Dredge (2011-2015) (Source MMO)

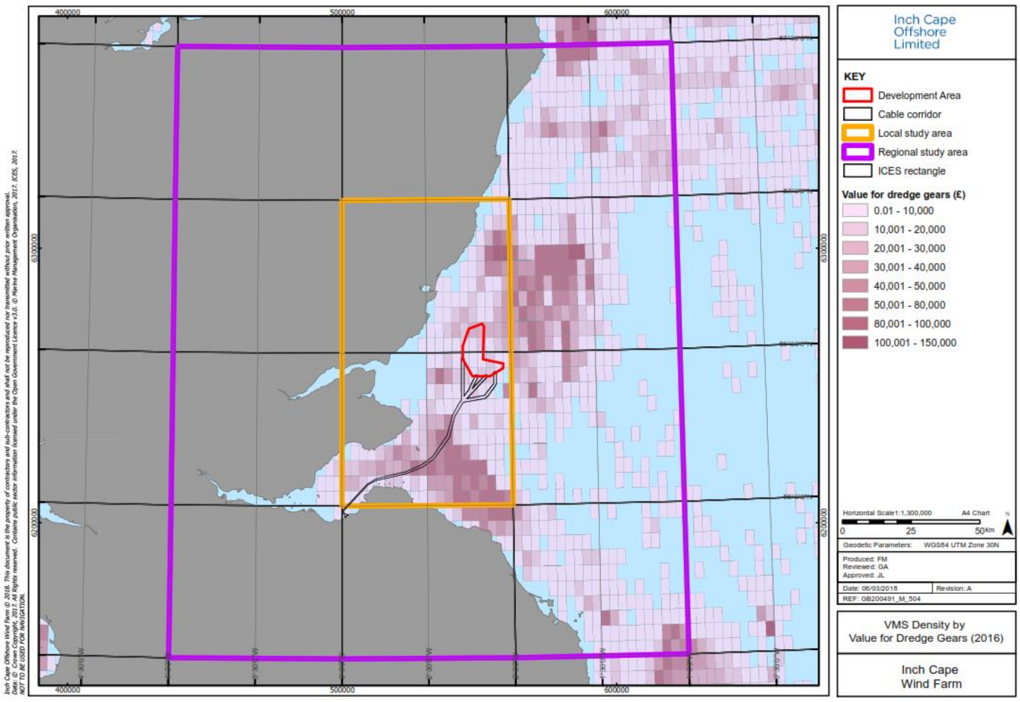


Figure 4.5: VMS Density by Fishing Intensity for Dredge (over 12 m vessels) in 2016 (Source ICES)

4.2. Predicted sediment levels

Sediment modelling for the Revised Development was compared to that from the Original Development for evidence of any significant increase in suspended sediments. The aim of the current study was to provide biologically significant data on predicted levels of SSC and deposition to inform the assessment of impacts on scallops.

The Original Development EIA, the area disturbed as a result of sediment displacement was estimated to be 5.54 km^2 for the installation of 213 WTGs, five Offshore Substation Platforms (OSPs) and 353 km of cable corridor (ICOL, 2013a). The volume of dredge material was estimated to be 28,503 m^3 per GBS, 114,012 m^3 per OSP and trenching requirements of 2 m deep and 1 m across for cable burial (ICOL, 2013b). To mitigate dispersal and reduce the overall area to be affected by burial, spoil would be dumped as close to the seabed as possible (1-5 m above the seabed), however it was modelled at 5 m above the seabed as a worst-case scenario.

Suspended Sediment Concentration (SSC) levels were estimated for each activity:

- GBS dredging works: SSC was predicted to peak at 4000 $mg.l^{-1}$ during GBS dredging works, will be very localised, dropping off within 10-20 minutes, and to 100 $mg.l^{-1}$ or less above background levels within 100 m of the discharge point. Any drilling as part of jacket foundation installation was modelled to produce similar levels of SSC as GBS dredging.
- Cable installation works: SSC was predicted to peak at 300 $mg.l^{-1}$ above background levels, with an average 3-10 $mg.l^{-1}$ (above background) within a few hundred metres of the cable and settling out within a few minutes at most. Very fine sediment or silt could possibly persist longer and travel further (up to 3 km) and will settle within a few hours.
- Jacket scour installation: SSC was predicted to peak at 100 $mg.l^{-1}$ close to the structures, dropping to <10 mg/l above background levels beyond 100 m away from the structures, and <1 $mg.l^{-1}$ beyond 1 km. All Suspended Sediments (SS) were modelled to settle within 1-2 hours, mostly travelling <100 m from the point of release, with finer sediments travelling no more than 3 km.
- Combined SSC plumes were considered to be unlikely as construction activities would need to by simultaneous and in very close proximity.

Deposition depths were estimated for each activity:

- GBS dredging works: deposition footprints for WTGs were predicted to be elliptical, with a thickness of >10 cm reaching up to 150 m away from each WTG, <1 mm within 1.5 km (ICOL, 2013a).
- Cable installation works: deposition footprints were also predicted to be localised with peaks of 3-5 mm, reducing to <1 mm within 1 km either side of the cable trench.
- Jacket scour protection: localised deposition footprints were predicted to have a maximum thickness of 1.1 m, >10 cm at 150 m and <1 mm within 200 m.

The Revised Development includes a maximum number of 72 WTGs which are larger than those consented, representing the greatest change between the Revised and Original Developments. The total area disturbed during construction of these WTGs is estimated to be 4.24 km^2, with 1278 m between each structure. The volume of dredge material is now estimated to be 40,000 m^3 per GBS. While the WTGs proposed for the Revised Development require greater foundation works per turbine, the overall impact of increased suspended sediment levels and sediment deposition depths will be less due to the reduction of total ground disturbance and increased distance between structures.

With regards to other infrastructure within the Development Area, as the number of OSPs has reduced when compared to the Original Development, and as the extent of inter-array cabling has also reduced due to the reduction in the number of WTGs these have not been considered within the modelling. In addition, although the larger WTGs may require more scour protection installation, this is also less overall when compared to the Original Development due to the reduced number of WTGs and therefore also not included in the modelling assessment.

The main differences in the modelling outputs are summarised in Table 4.1.

Table 4.1: Summary of differnce in biologically significant modelling outputs

Activity	Original Development	Revised Development	Difference
SSC Levels			
GBS dredging works	Concentration to drop to 100 mg.l^{-1} within 100 m of discharge point. Maximum peak concentration of 4000 mg.l^{-1} higher than background levels, dropping off within a couple of minutes and overall increase lasting no more than 2 hours.	Concentration to drop to 100 mg.l^{-1} within 100 m of discharge point. SSC expected to drop to background levels (<5 mg.l^{-1}) almost immediately (<1 hour). All SSC expected to return to background levels within 2 days.	Extent of the increased SSC per structure is similar. Overall area affected is less over the Development Area due to reduced number of WTGs.
Inter-array cable installation	Peak at 300 mg.l^{-1} above background levels, lasting a few hours.	Revised model calculated for deposits from GBS dredging, did not distinguish cabling, however methodology has not changed for the Revised Development.	Overall area affected is less due to reduction in cabling requirements.
Scour protection installation	Peak at 100 mg.l^{-1} close to the structures, lasting 1-2 hours, fine sediment travelling <3 km.	Revised model calculated for deposits from GBS dredging, did not include scour protection. Overall value for Revised Development is less. Fine sediment travelling <5 km at low concentration (<0.1 mg.l^{-1}).	Overall area affected is less over the Development Area due to reduced number of WTGs.
Combined SSC plumes	Unlikely, not to exceed 4300 mg.l^{-1}.	Unlikely, though would be a combination of cable installation works with GBS dredging works along NNE-SSW tidal axis. Distance between structures is increased.	Overall area affected is less over the Development Area due to reduced number of WTGs. Combined effects less likely due to increased distances.
Sediment Deposition			
GBS dredging works	10.09 km^2 affected by >5 cm sediment deposition depth (6.7% of the Development Area).	6.08 km^2 affected by >5 cm sediment deposition depth.	Reduction in area affected by sediment deposition.
Inter-array cable installation	Peak depths of 3-5 mm, reducing to < 1mm within 200 m.	No change locally. Overall value for Revised Development is less.	Overall area affected is less over the Development Area due to reduced cabling requirements.
Scour protection installation	Maximum thickness of 1.1 m, reducing to <1 mm within 200 m.	Localised increase in scour, overall value for Revised Development is less.	Overall area affected is less over the Development Area due to reduced scour requirements.

The comparison of data from the modelling for the Original Development and the Revised Development did reveal some differences in the instantaneous peaks of SSC, with 4000 $mg.l^{-1}$ being predicted at each point source release of sediment for the Original Development and only 330 $mg.l^{-1}$ for the Revised Development. This difference is, however, unlikely to be a result changes to the design of the Development, but instead to different outputs parameters of the two models. These peaks in SSC for the Original Development were predicted to occur very close to the point source of release and to last only 10 to 20 minutes, and falling to only 100 $mg.l^{-1}$ within 100 m. The modelling for both developments predicted that the majority of all SSC would drop off almost immediately (within 1 hour), and all SSC expected to return to background levels within 2 days. Overall SSC increases per GBS/point source release is broadly the same for both the revised and original development, however due to the reduction in the number of turbines the total area affected by SSC has reduced.

For deposition depth, the depth of sediment deposited for each GBS is greater, hence the total area affected by >5 cm deposition depth (i.e. biological significant levels for scallop survival) has increased per GBS, however due to the reduction in the number of turbines total area affected by burial is reduced.

5. Validation of EIA conclusions

5.1. Impact on scallops

In the Natural Fish and Shellfish chapter of the Original Development ES, scallops were assessed under the receptor group “shellfish”, along with crab, lobster and *Nephrops*. With the receptor group approach, although there may be differences in the species within groups, in terms of exact sensitivities to effects, variations in some stage of their life history, or in their conservation value, these variations fall within a relative range which allows them to be assessed as a group.

In the original EIA, increased suspended sediment levels were predicted to have a negative impact on filter feeders such as scallops through damage to feeding apparatus, and subsequent reduction in growth rates (Bricelj and Shumway, 1991). It was however, considered that recoverability after the cessation of the impact (when magnitude of the effect is below MarLIN benchmark of an arbitrary short term, acute change in background SSCs e.g. a change of 100 $mg.l^{-1}$ for one month) was likely to be high (Marshall and Wilson, 2009). Additional research agrees with this assessment, and has introduced new theories driving recoverability such as food selectivity, particle excretion and behavioural responses (increased clapping rates) as mechanisms to limit damage to feeding apparatus (Macdonald and Ward, 1994; Shumway *et al*., 1997; Last *et al*., 2011). Recoverability after the cessation of the impact is likely to be high.

In the original EIA, scallops buried by less than 5 cm of sediment were considered to be able to lift themselves clear of deposited sediments, and as such, outside of this area no impact of smothering was expected (Marshall and Wilson, 2008). Burial by sediment deeper than 5 cm (benchmark level assessed by MarLIN) was considered to be fatal according to a precautionary standpoint, and a total area of 10.09 km^2 (or 6.7%) of the Development Area would have been impacted to this degree. This area was considered to be negligible in relation to the wider area in which scallops are predicted to exist (scallop grounds are located around the UK on the Scottish east and west coasts, in the Irish Sea and the English Channel (Carter, 2008; Marshall and Wilson, 2008), and as such the magnitude of the smothering effect on scallops was assessed as negligible. Additional research does not indicate a significant change in this assessment and agrees that it is a precautionary standpoint. The area to be affected by smothering as a result of a reduction in WTG has decreased by 40% in the Revised Development (see Section 4.2), and can be considered to be negligible in relation to the wider area in which scallops are predicted to exist.

The effects of suspended sediment on settled larvae and juvenile scallops were not specifically considered in the original EIA. Examination of the literature indicates that settled larvae and juvenile scallops will be negatively affected by increased levels of suspended sediment, affecting growth and survival rates. The extent of this effect on growth potential of settled larvae and juvenile scallops is greater than that of adult scallops, however it does not significantly increase mortality rates (Szostek *et al*., 2013). As concluded for adult scallops, recoverability after cessation of the impact is likely to be high (Marshall and Wilson, 2009; Szostek *et al*., 2013).

The effects of suspended sediment on pelagic eggs and larvae were not specifically considered in the original EIA. The extent of this effect for pelagic eggs and larvae scallops is not specifically known, and is dependent on the characteristics of the suspended particles, its concentration and persistence in the water column (Davis, 1960; Auld and Schubel, 1978; Kang, 2012; Ricardo *et al*., 2016). However, due to the spawning behaviour of adult scallops (Le Pennec *et al*., 2003), natural dispersal of pelagic larvae (Beaumont and Gjedrem, 2007; AFBI, 2017), and the short duration of the impact (see Section 4.2), recoverability can also be considered to be high after the cessation of the impact. In addition the natural mortality of scallop larvae is extremely high (Thorson, 1950).

The findings of this review, in relation to the predicted level of impact are presented below for increased SSC and smothering respectively (Table 5.1). Although the sensitivity of the different life phases of scallops to sediment were not considered individually in the original assessment, the assumptions made for scallops in general were sufficiently conservative to encompass the biologically significant levels of SSC and deposition found in papers reviewed for this discussion paper. It is, therefore, considered that the conclusions of the ES in relation to the impact of predicted sediment (SSC and smothering) disturbance on scallops remain valid.

Table 5.5.1: Table 5.1 Summary of Impacts to scallops from an increase in suspended sediment concentration (SSC)

Impact	Original ES Conclusion	New Relevant Information	Validation
Smothering	Loss of scallops in sediment deposition depths >5 cm over a total estimated area of 10.09 km^2. The sensitivity of this group was defined as low therefore, combined with an effect of a low magnitude, a minor impact is predicted.	Loss of settled larvae and juvenile scallops in sediment deposition depths >5 cm is consistent with the loss of adult scallops. Increase in mortality up to 20% for settled larvae and juvenile scallops in sediment deposition depths <5 cm. Interruption of spawning activity due to loss of mature adults. Pelagic oocytes and larvae present in the water column will not be affected.	Studies indicate high recoverability of scallops also applies to oocyte, larval and juvenile life stages of scallops. In relation to the Revised Development, sediment deposition may increase per WTG foundation installation, but total area affected by sediment deposition depths >5 cm is likely to be reduced. Net impact will be less than original prediction. Conclusion of Original EIA remains valid; (not significant) no further assessment is required.
Increase in suspended sediment concentration (SSC)	Decreased feeding and potential growth rates in scallops during episodes higher than background levels of SSC, with a maximum peak concentration of 4000 $mg.l^{-1}$ higher than background levels dropping off within 10-20 minutes, and overall increase lasting no more than 2 hours. The sensitivity of this group was defined as low therefore, combined with an effect of a low magnitude, a minor impact is predicted.	Decreased feeding and potential growth rates in settled larvae, juvenile and adult scallops during episodes higher than background levels of SSC, dropping off within a couple of minutes and overall increase lasting no more than 2 hours. Possible interruption of spawning activity. Reduction in larval scallop survival during episodes of higher than background SSC (>200 $mg.l^{-1}$), lasting no more than 2 hours. Reduction in oocyte survival during episodes of higher than background SSC (>200 $mg.l^{-1}$), lasting no more than 2 hours.	Studies indicate high recoverability of scallops also applies to oocyte, larval and juvenile life stages of scallops. In relation to the Revised Development, activities causing SSC will be fewer in number, and areas of increased SSC will affect a smaller total area. Net impact will be less than original prediction. Conclusion of Original EIA remains valid (not significant); no further assessment is required.

5.2. Impacts on fishing

The Commercial Fisheries chapter of the Original Development ES recognised that scallop grounds overlapped with the Development Area. While it is beyond the scope of this discussion paper to validate the commercial fisheries baseline of the Original Development ES for scallop fishing, as a new commercial fisheries baseline will be submitted as part of the Revised Development EIA report, it is clear that scallop grounds still overlap the Development Area (as the area remains unchanged and scallop fisheries continue).

The Original Development ES commercial fisheries assessment considered impacts to scallops from indirect disturbance as a result of sediment deposition and temporary increases in SSC, and concluded that this impact would be of Negligible/Minor significance, and therefore not significant for the purposes of this assessment. The validity of which has been discussed above in relation to both the revised levels of sediment predicted and the new papers reviewed. Therefore, the conclusion of this assessment is considered to remain valid. It is worth noting that sediment modelling for the Revised Development demonstrates that that levels of SSC and deposition will also not be sufficiently high to affect scallops outside the Development Area, therefore impacts to scallops or scallop fishing are not predicted beyond the boundary of the Development Area.

6. Conclusion

A literature review was undertaken on the effect of sediment (SSC and deposition) on scallops at different phases of their life cycle. In addition, sediment dispersal modelling was undertaken for the Revised Development and the predicted levels assessed in terms of the biological impact on scallops. This information was then compared to the distribution of fishing which provides evidence of the distribution of scallop. This information was then used to validate the predictions of the original assessment.

Although the sensitivity of the different life phases of scallops to sediment were not considered individually in the Original Development EIA, the assumptions made for scallops in general were sufficiently conservative to encompass the biologically significant levels of SSC and deposition found in papers reviewed for this discussion paper. It is, therefore, considered that the conclusions of the Original Development ES in relation to the impact of predicted sediment (SSC and smothering) disturbance on scallops remain valid and not significant.

7. References

Agri-Food and Biosciences Institute – Fisheries and Aquatic Ecosystems Branch (2017). Scallop Larval Dispersal Background Study. Available at: www.seafish.org/media/Publications/Scallop_reseeding_report_Final.pdf

Auld, A.H. and Schubel, J.R. (1978). Effects of suspended sediment on fish eggs and larvae: A laboratory assessment. Estuarine and Coastal Marine Science, 6(2):1 53-164

Barber, B.J. and Blake, N.J. (2006). Reproductive Physiology: In Shumway, S.E and Parsons, G.J. (2006) Scallops: Biology, Ecology and Aquaculture. Developments in Aquaculture and Fisheries Science. Amsterdam, Elsevier 35

Beaumont, A.R. and Budd, M.D. (1983). Effects of self-fertilisation and other factors on the early development of the scallop *Pecten maximus*. Marine Biology. 76: 285-289

Beaumont, A.R., and Gjedrem, T. (2007). Scallops — *Pecten maximus* and *P. jacobaeus*. Genetic impact of aquaculture activities on native populations. Genimpact final scientific report (EU contract n. RICA-CT-2005–022802). Edited by T. Svåsand, D. Crosetti, E. García-Vázquez, and E. Verspoor. pp. 83–90. Available at: www.imr.no/genimpact/filarkiv/2007/07/scallops.pdf/en

Beecham, J. (2008). Literature review on particle assimilation by molluscs and crustaceans. Science commissioned by the Food Standards Agency. Cefas Contract C2706, Environment Report RL 10/08. Available at: https://www.cefas.co.uk/publications/environment/Literature-review-on-particle-assimilation.pdf

Brand, A.R. (2006). The European scallop fisheries for *Pecten maximus*, *Aequipecten opercularis* and *Mimachlamys varia*. In: Shumway, S.E., Parsons, G.J., Eds., *Scallops: Biology, Ecology and Aquaculture*, Second Ed. Elsevier, Amsterdam, pp. 991-1058.

Bricelj, V.M. and Malouf, R.E., (1984). Influence of algal and suspended sediment concentrations on the feeding physiology of the hard clam *Mercenaria mercenaria*. Marine Biology, 84(2): 155-165. DOI: 10.1007/BF00393000.

Bricelj, V.M. and Shumway, S. (1991). Physiology: energy acquisition and utilization. In: Shumway, S.E., Parsons, G.J., Eds., *Scallops: Biology, Ecology and Aquaculture*, Second Ed. Elsevier, Amsterdam, pp. 305-346

Cappell, R., Robinson, M., Gascoigne, J. and Nimmo, F.A. (2013). Review of the Scottish Scallop Fishery. Poseidon. Report to Marine Scotland, December 2013

Carter, M.C. (2008). *Aequipecten opercularis* Queen scallop. In Tyler-Walters H. and Hiscock K. (Eds.) Marine Life Information Network: Biology and Sensitivity Key Information Reviews, [on-line]. Plymouth: Marine Biological Association of the United Kingdom. Available at: http://www.marlin.ac.uk/species/detail/1997. [Accessed on: 02/10/2017]

Cragg, S.M. (1980). Swimming behaviour of the larvae of *Pecten maximus* (L.) (Bivalvia). Journal of the Marine Biological Association of the United Kingdom' 60: 551-564

Davis, H.C. (1960). Effects of Turbidity-Producing Materials in Sea Water on Eggs and Larvae of the Clam (*Venus* (*Mercenaria*) *Mercenaria*). The Biological Bulletin, 118(1): 48-54

J. Ellis, J., Cummings, v., Hewitt, J., Thrush, S. and Norkko, A. (2000). Determining effects of suspended sediment on condition of a suspension feeding bivalve (*Atrina zelandica*): results of a survey, a laboratory experiment and a field transplant experiment. Journal of Experimental Marine Biology and Ecology, 267: 147-174

Foden, J., Rogers, S.I. and Jones, A.P. (2010). Recovery of UK seabed habitats from benthic fishing and aggregate extraction – towards a cumulative impact assessment. Marine Ecology Progress Series, 411:259-270

Gibson, F. A. (1956). Escallops (*Pecten maximus* L.) in Irish waters. Scientific Proceedings of the Royal Dublin Society. 27: 253-271

Guijarro-Garcia, E., Ragnarsson, S.A., Naevestad, D, Haukur, Haraldsson, H.Þ., Fossa, J.H., Tendal, O.S. and Eiriksson, H. (2007). Bottom trawling and Scallop Dredging in the Arctic, P120-121. Nordic Council Ministers, Copenhagen. TemaNord 2006:529

Hansen, B., Hansen, P.J. and Nielsen, T.G. (1991). Effects of large nongrazable particles on clearance and swimming behaviour of zooplankton. Journal of Experimental Marine Biology and Ecology, 152(2): 257-269

Hayward, P.J. and Ryland, J.S. (2017). Handbook of the Marine Fauna of North-West Europe. Oxford University Press.

Heasman, M.P., O'Connor, W.A., Frazer, A.W.J. (1995). Induction of anaesthesia in the commercial scallop, *Pecten fumatus* Reeve. Aquaculture, 131(3-5):231-238

Hendrick, V.J., Hutchinson Z.L., Last, K.S. (2015_. Sediment Burial Intolerance of Marine Macroinvertebrates. PLoS ONE, 11(2): e0149114.doi:10.1371/journal.pone.0149114

Hinchey, E.K., Schaffner, L.C., Hoar, C.C., Vogt, B.W. and Batte, L.P. (2006). Responses of Estuarine Benthic Invertebrates to Sediment Burial: The Importance of Mobility and Adaptation. Hydrobiologia. 556(1): 85-98

Howarth, L.M., and Stewart, B.D. (2014). The Dredge Fishery for Scallops in the United Kingdom (UK): Effects on Marine Ecosystems and Proposals for Future Management Marine Ecosystem Management Report No. 5. University of York

Howell, T.R.W & Fraser, D.I. (1984). Observations on the dispersal and mortality of the scallop Pecten maximus (L.). ICES Council Meeting Papers, K: 35

ICOL (2013a). Inch Cape Wind Farm, Offshore Environmental Statement Chapter 13: Natural Fish and Shellfish. Available at: http://www.inchcapewind.com/publications/environmental-statement/introduction

ICOL (2013b). Inch Cape Wind Farm, Offshore Environmental Statement Chapter 10: Metocean and Coastal Processes. Available at: http://www.inchcapewind.com/publications/environmental-statement/introduction

Intertek (2013). Inch Cape Offshore Limited (ICOL) Appendix 10A: Metocean and Coastal Processes Assessment Technical Report. Report reference: p1476_RN3026_Rev5_App10A. Available at: http://marine.gov.scot/datafiles/lot/inch_cape/Environmental%20Statement/Volume%202B%20-%20Appendices/

Jenkins, S.R., Lart, W., Vause, B.J. and Brand, A.R. (2003). Seasonal swimming behaviour in the queen scallop (*Aequipecten opercularis*) and its effect on dredge fisheries. J. Exp. Mar. Bio. Ecol. 289, 163-179

Kafas, A., Jones, G., Watret, R., Davies, I. and Scott, B. (2012). Representation of the use of marine space by commercial fisheries in marine spatial planning. ICES CM I:23

Kafas, A., Jones, G., Watret, R., Davies, I. and Scott, B. (2013). 2009 - 2013 amalgamated VMS intensity layers, GIS Data. Marine Scotland, Scottish Government. doi: 10.7489/1706-1

Kafas, A., McLay, A., Chimienti, M., and Gubbins, M. (2014). ScotMap Inshore Fisheries Mapping in Scotland: Recording Fisherman's use of the Sea. Vol 5 [No. 17]. Scottish Marine and Freshwater Science. Available at: http://www.gov.scot/Resource/0046/00466802.pdf

Kang, H.K. (2012). Effects of suspended sediments on reproductive responses of *Paracalanus sp*. (Copepoda: Calanoida) in the laboratory. Journal of Plankton Research, 34(7): 626-635

Kotta, J., Herkül, K., Kotta, I., Orav-Kotta, H., and Aps, R. (2009). Response of benthic invertebrate communities to the large-scale dredging of Muuga Port. Estonian Journal of Ecology. 58(4): 286-296

Lambert, G.I., Jennings, S., Kaiser, M.J., Davies, T.W. and Hiddink, J.G. (2014). Quantifying recovery rates and resilience of seabed habitats impacted by bottom fishing. Journal of Applied Ecology, 51:1 326-1336

Lambert, G. I., Murray, L.G., Hiddink J. G., Hinz H., Salomonsen H, & Kaiser, M.J. (2015). Impact of Scallop Dredging on Benthic Communities and Habitat Features in the Cardigan Bay Special Area of Conservation. Part I – Impact on Infaunal Invertebrates. Fisheries & Conservation Report No. 59, Bangor University. pp.73

Lambert, G.I., Murray, J.G., Hiddink, J.G., Hinz, H., Lincoln, H., Hold, N., Cambiè, G. and Kaiser, M.J. (2017). Defining thresholds of sustainable impact on benthic communities in relation to fishing disturbance. Science Reports. 7, Article number 5440

Land, M.F. (1965). Image Formation by a Concave Reflector in the Eye of the Scallop, *Pecten maximus*. Journal of Physiology, 179: 138-153

Last, K.S., Hendrick, V.J., Beveridge, C.M. and Davies, A.J. (2011). Measuring the effects of suspended particulate matter and smothering on the behaviour, growth and survival of key species found in areas associated with aggregate dredging. Marine Aggregate Levy Sustainability Fund, Project MEPF 08/P76

Le Pennec M., Paugam A., Le Pennec G. (2003). The pelagic life of pectinid *Pecten maximus* – a review. ICES Journal of Marine Science, 60: 211–223

Lewis, R.I and Thorpe, J.P. (1994a). Are queen scallops, *Aequipecten* (*Chlamys*) *opercularis*, self-recruiting? In: N.F. Bourne, B.L. Bunting and L.D. Townsend (Eds.) *Proceedings of the 9th International Pectinid Workshop, Nanaimo, B.C., Canada, April 22-27, 1993*. Volume I. Canadian technical Report of Fisheries and Aquatic Sciences 1994: 214-221

Lewis, R.I and Thorpe, J.P. (1994b). Temporary stability of gene-frequencies within genetically heterogeneous populations of the queen scallop, *Aequipecten* (*Chlamys*) *opercularis*. Marine Biology 121: 117-126

Lo, M.C. (2009). Spatial variation in king scallop Pecten maximus maturation state around Isle of Man. MSc Dissertation, School of Ocean Science, Bangor University. Available at: fisheries-conservation.bangor.ac.uk/iom/documents/MScMarineBiology2009_KingScallopmaturationstatus_Mandy_dissertation.pdf

MacDonald, B.A., Ward, J.E. (1994). Variation in food quality and particle selectivity in the sea scallop *Placopecten magellanicus* (Mollusca: Bivalvia). Marine Ecology Progress Series, 108: 251-264

Marine Scotland (2016). Consultation on New Controls in the Queen Scallop Fishery in ICES Divisions VIa and VIIa. Available at: https://consult.scotland.gov.uk/marine-scotland/queen-scallop-consultation/user_uploads/queen-scallop-consultation---oct-2016.pdf

Marine Scotland (2017a). King Scallop. Available at: http://www.gov.scot/Topics/marine/marine-environment/species/fish/shellfish/scallop

Marine Scotland (2017b). Scallop Conservation Measures. Available from: http://www.gov.scot/Topics/marine/Sea-Fisheries/InshoreFisheries/scallopconservation

MarLIN (2006). BIOTIC - Biological Traits Information Catalogue. Marine Life Information Network. Plymouth: Marine Biological Association of the United Kingdom. Available at: www.marlin.ac.uk/biotic. [Accessed on: 02/10/2017]

Marshall, C. and Wilson, E. (2008). Pecten maximus. Great scallop. Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme [on-line]. Plymouth: Marine Biological Association of the United Kingdom. [cited 05/09/2017]. Available at: www.marlin.ac.uk/speciesfullreview.php?speciesID=4056. [Accessed on 02/10/2017]

Minchin, D. (1992). Biological observations on young scallops, Pecten maximus. Journal of the Marine Biological Association of the United Kingdom. 72(4): 807-819

Moore, J.D. and Trueman, E.R. (1971). Swimming of the scallop, *Chlamys opercularis* (L.). Journal of Experimental Marine Biology and Ecology, 6: 179-185

New England Fishery Management Council (1993). Supplemental Environmental Impact Statement: Sea Scallop Fishery Management Plan

Orpin A.R., Ridd P.V., Thomas S., Anthony K.R.N., Marshall P., Oliver J. (2004). Natural turbidity variability and weather forecasts in risk management of anthropogenic sediment discharge near sensitive environments. Marine Pollution Bulletin, 49: 602−612

Partrac Ltd. (2018). Inch cape offshore wind Farm Dredge Disposal – Plume Dispersion Study. Reference: P1796.05.D01v02

Ricardo, G.F., Jones, R.J., Negri, A.P. and Stocker, R. (2016). That sinking feeling: Suspended sediments can prevent the ascent of coral egg bundles. Scientific Reports 6, Article number: 21567

Seafish (2016). King Scallop in ICES Sub-Division VIa (Scottish waters), Scallop Dredge. Available at: www.seafish.org/rass/do_pdf.php?id=4303&section=all

Seafish (2017). Queen Scallop in ICES Sub-Division VIa (Scottish waters), Scallop Dredge. Available at: www.seafish.org/rass/do_pdf.php?id=6219&section=all

Seafood Scotland (2012). Scottish Scallops. Available at: www.seafoodscotland.org/en/responsible-sourcing/top-species/scallops.html

Shumway, S.E., Cucci, T.L., Lesser, M.P., Bourne, N., Bunting, B. (1997). Particle clearance and selection in three species of juvenile scallops. Aquaculture International, 5(1): 89-99

Speiser, D.I., and Johnsen, S. (2008). Scallops visually respond to the size and speed of virtual particles. Journal of Experimental Biology 2008 211: 2066-2070

Szostek C.L., Davies A.J., Hinz H. (2013). Effects of elevated levels of suspended particulate matter and burial on juvenile king scallops *Pecten maximus*. Marine Ecology Progress Series, 474: 155-165

Thorson, G. (1950). Reproductive and larval ecology of marine bottom invertebrates. Biological Reviews of the Cambridge Philosophical Society, 25(1): 1-45

8. Appendix A - Modelling results

PARTRAC

natural power

Inch Cape Wind Farm

Dredge Disposal – Plume Dispersion Study

March 2018

Partrac Ltd
440 Baltic Chambers
50 Wellington Street
Glasgow
G2 6HJ

+44 (0) 141 202 0644
info@partrac.com
www.partrac.com

DOCUMENT CONTROL

Version History					
Version	Date	Prepared by	Reviewed by	Approved by	Approved as
V01	17/01/2018	J Poleykett	M Wright	M Wright	Draft for comment
V02	25/01/2018	J Poleykett	M Wright	M Wright	Draft for comment
V03	06/03/2018	J Poleykett	M Wright	M Wright	Final

Changes from the Previous Version	
V01	N/A
V02	Changes made following comments received from Laila Higgins.
V03	Revised in line with comments received from Natural Power (28/02/2018)

Recipient	Distribution Method		
	Paper (copies)	Word doc	Online
Stuart McCallum (Natural Power), Laila Higgins		x	
Holders of controlled copies will automatically be provided with subsequent approved versions of this document when they become available.			

CONTENTS

FIGURES

TABLES

1. INTRODUCTION

As part of the application for a Revised Development, being developed by Inch Cape Offshore Limited (ICOL), for the Inch Cape Wind Farm, Partrac has undertaken an assessment of the sediment dispersion potential associated with the disposal of material to be dredged during the installation of Wind Turbine Generator's (WTG's). Dredging of seabed sediments up to 72 locations would be required as part of the ground preparation for the installation of the Revised Development WTG's. Specifically, Partrac was requested to quantitatively evaluate the sediment dispersion potential within the surrounding North Sea associated with the continuous disposal of dredged material from the fall pipe of a Trailer Suction Hopper Dredger (TSHD). To ascertain potential impacts of dredge material dispersal to potential near, and far field receptors, a (numerical) dispersion modelling study has been conducted.

The objectives of this report are to provide a description of the:

- Methodology adopted (section 2);
- Model input parameters (section 2);
- Model set-up and validation (section 2 and appendix 1)
- Impact of disposal operations (section 3);
- Conclusions (section 5)

1.1 Study Context

The wind farm development is to be located approximately 15 to 22 km, to the east of the Angus coastline in Scotland, UK. Figure 1 shows the location of the Development Area.

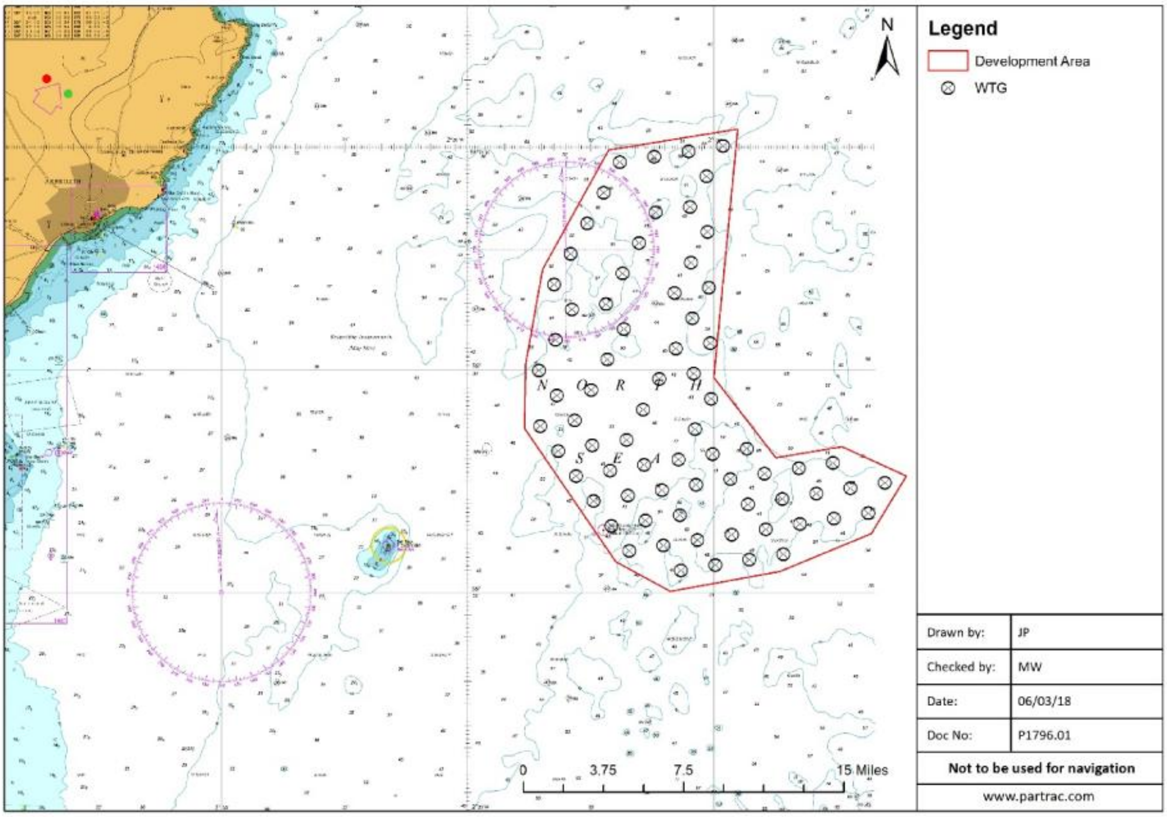


Figure 1. Map showing the location of the Development Area (72 WTG layout).

The original Environmental Statement assessed the construction of 213 fixed structure WTGs, whilst the Revised Development is proposing up to 72 WTGs. Due to the changes in the turbine foundation parameters associated with larger WTGs, and in order to inform responses to the scoping opinion, the extent and magnitude of the potential distribution(s) of dredged sediments arising from their disposal at sea have been reassessed.

1.2 Modelling the Dispersion of Dredged Material

Effects associated with the proposed dredging activities have the potential to affect marine processes within the North Sea. The extent, and manner, of these effects is complex and difficult to predict. Consequently, a numerical model has been developed, calibrated and a scenario run to allow any effects on marine and coastal processes associated with the dredging of seabed material at the proposed foundations to be identified and, where possible, quantified.

At the wind farm fairly uniform flows are observed across the Development Area (Partrac Ltd, 2011). Tidal flows are strongly rectilinear in form with a principal tidal axis oriented NNE/SSW (Figure 2). Flood currents are generally stronger than ebb currents and flow south-westward (minorly southward), whereas ebb currents flow NNE (i.e. they are aligned with the general shoreline orientation). The flow velocity magnitude is generally low (< 1 ms^{-1}, see Figure 2). The spatial variation in flow across the development area is broadly anticipated to be minor (Inch Cape Offshore Limited, 2013), though some variation (however slight) will likely exist due to bathymetric change, with the flow velocity magnitude reducing as water depth reduces. Figure

2 presents flow data, in the form of current roses, collected at two locations (see Figure 4) near the Development Area, during a six-month metocean monitoring campaign (Partrac Ltd, 2011). The data presented, (captured using two seabed mounted, Acoustic Doppler Current Profiler (ADCP) was captured between March and June 2010. These data were also used for model validation (see Section 2.4).

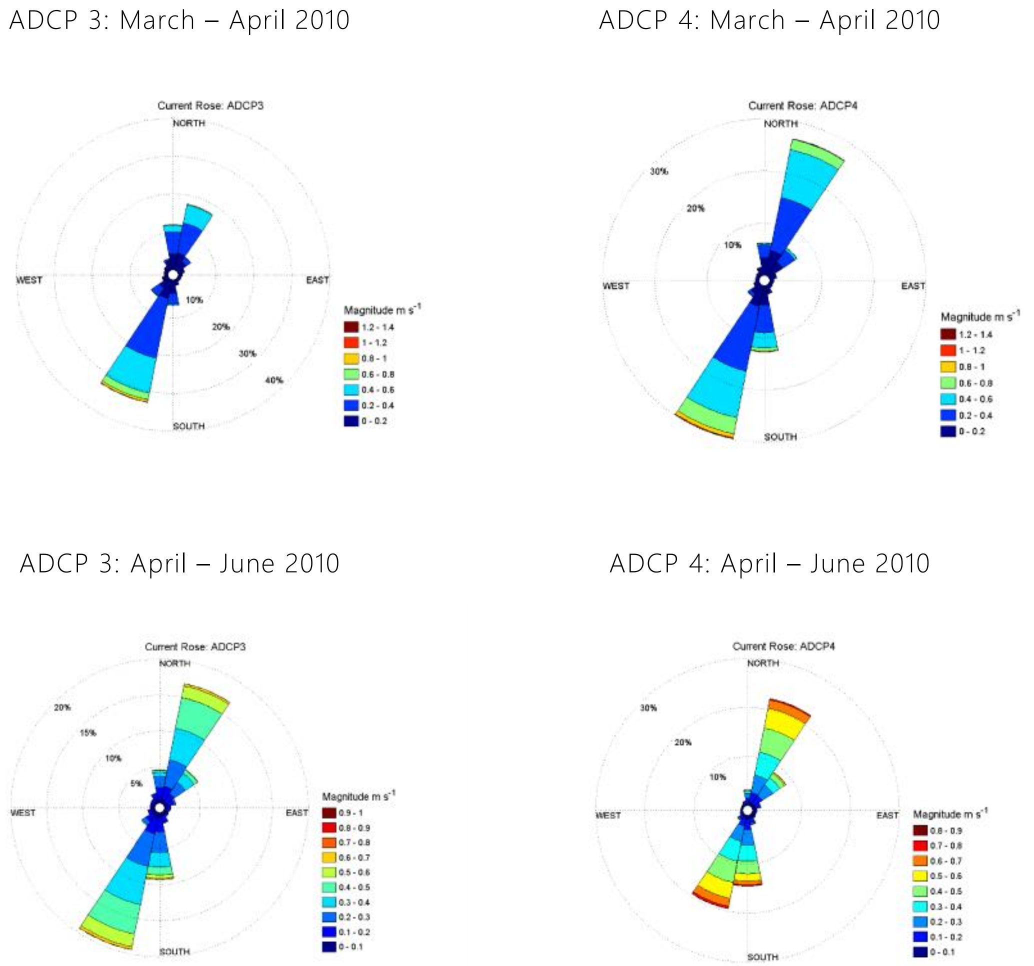


Figure 2. Current roses showing the direction, and magnitude, of tidal flows at two locations around the Development Area. Data Source: Partrac Ltd (2011).

2. METHODOLOGY

2.1 Modelling Approach

Suspended sediment plumes are one of the process effects of dredging operations which may impact the environment. Dredge material disposed of at sea generates a suspended sediment plume which is subsequently open to transport, driven by the local hydrodynamic regime. Modelling this phenomenon allows the processes driving sediment dispersion to be simulated, (advection, diffusion, settling) enabling an assessment of the localised and wider impacts of dredge disposal operations to be investigated. The model was developed and run to simulate the behaviour of sediment plumes in the region where dispersion processes are dominated by ambient environmental forcing and passive settling due to gravity. The results were used to evaluate the fate of the sediment plume and any accumulation of sediment on the seabed.

Prior to the commencement of the model run, NPC advised that the *'worst case'* estimate of dredging requirements, including all worst-case tolerances, is 40,000 m^3 of material to be excavated from each WTG foundation location (72 in total). The total dredge volume provided was utilised as input data to the dispersion model.

To set up the dispersion simulations, the operational cycle (i.e. the length of time it will take the TSHD to excavate, and dispose of, 40,000 m^3 of sediment from each WTG location) was estimated as 48 hours. During the model run dredging operations were continuous[1]. During the operational cycle, excavated sediments were also disposed of continuously from the fall pipe positioned 5m above the sea bed[2]. The disposed sediments were then subject to advection and dispersion by the ambient flows. The downward momentum occurring due to disposal via the fall-pipe was not modelled. Use of an appropriate model coefficient to estimate this would inherently lead to a greater sediment thickness on the bed in the close vicinity of the disposal site. Assessment of the scenario where a larger depositional footprint will occur is conservative, and can be considered the worst-case scenario, since the thickness of deposited sediments close

1 In reality, it is likely to take several days to complete the preparation of each base, which may be undertaken in several phases, and there will be periods between the completion of one base, and the commencement of excavating the next (Inch Cape Offshore Limited, 2013). Further, the material will likely be discharged in controlled phases, rather than as a continuous discharge. Thus, this assessment is not sensitive to the precise duration of excavation or the rate of discharge.

2 The height of the fall-pipe is anticipated to vary during dredging operations from between one metre and five metres above the seabed. The greater the release height, the greater the size of the resulting depositional footprint. Thus, to consider the worst-case scenario, the fall pipe was positioned at 5m above the seabed in the model scenario.

to each foundation site is estimated to be large under any feasible scenario (Inch Cape Offshore Limited, 2013).

To assess the potential impacts arising from dredge disposal operations from all 72 WTG foundation sites, the model was setup to simulate 9 TSHD, excavating the foundation sites of 8 WTG sites, simultaneously, across a 16-day period (referred to as the operational cycle). We consider this approach to be more robust than directly extrapolating the findings from a reduced model run (as was conducted in Inch Cape Offshore Limited [2013]) as the spatial variation in bathymetry and flow velocity magnitude is captured.

Within the model, disposal begun on the 30th March and continued for the following 16 days, through to the 15th April. The model simulation was continued until the Suspended Sediment Concentration (SSC) returned to likely background levels (defined as < 5 mg l^{-1}) to consider the potential for continued dispersion of sediment.

The model outputs were interrogated to establish the maximum SSC's (mg l^{-1}) and maximum deposited sediment thickness (mm) arising from the disposal operations. These metrics are considered key output parameters required for the assessment of potential environmental impacts. In addition, to provide further information which may be of use to the assessment, a representative example of a *worst case* (within the context of dredge disposal operations across the development area) foundation site (nominally WTG 8[3]) was interrogated in further detail. From this, the sediment thickness predicted at locations to the north and south (broadly along the tidal axis) is predicted and the evolution of the sediment plume via time sliced snapshots are presented.

2.2 Model Scenario

The model employed is a cumulative impact model encompassing all disposal operations at the site. The scenario modelled was as follows:

Tidal Phase: The first release within the model commenced on 30th March at 19:10 coincident with the spring tidal phase. The operational cycle (16 days), occurred over the spring- neap tidal cycle. As the tailings were released continuously throughout this period, tailings were released variously across the spring – neap cycle and on the flooding and ebbing tide.

3 WTG 8 was determined as a representative example of the worst-case scenario due to the location (offshore location), and release timing (close to peak spring tidal cycle) which resulted in disposal operations occurring in an area, and at the time, of the greatest flow velocity magnitude.

Release Location: The excavated material was released from the proposed location of each WTG (provided by NPC). Each TSHD employed [9] excavated 8 WTG foundation sites, working from West to East across the site. The TSHD operational cycle modelled is detailed in Table 1.

Definition of Worst Case: The worst case is defined here as release of 40,000 m^3 from a fall pipe continuously discharging material from 5m above the bed at each of WTG location.

Meteorological forcing: A historic meteorological dataset was used to simulate 'typical' meteorological forcing experienced during the springtime.

Table 1. The dredging cycle simulated within the model scenario.

Release	Time after first release (days)	Dredge Volume (m^3)	Discharge duration (h)	Discharge rate (kg s^{-1})	Height above seabed of discharge (m)
1	0	40,000	48	314.81	5
2	2	40,000	48	314.81	5
3	4	40,000	48	314.81	5
4	6	40,000	48	314.81	5
5	8	40,000	48	314.81	5
6	10	40,000	48	314.81	5
7	12	40,000	48	314.81	5
8	14	40,000	48	314.81	5

** The dredging cycle was repeated for all 72 WTG locations by simulating 9 dredgers working simultaneously across the site.*

2.3 Input Parameters

Where appropriate, to provide continuity, model input parameters were garnered from the environmental statement (Inch Cape Offshore Limited, 2013). The dredge mass (kg) was derived by multiplying the dredge volume by the bulk density. The sediment mass was then proportioned into 6 size classes being: very coarse sand, coarse sand, medium sand, fine sand, very fine sand and silt. The median grain size values (derived from sediment samples taken throughout the Development Area [Inch Cape Offshore Limited, 2013]), enabled the sedimentological characteristics of each sediment size fraction to be calculated and model input parameters to be defined (Table 2). Transformations of deposition rates into equivalent sedimentation thickness was facilitated using a dry bulk density value of 1360 kg m^{-3}; assuming a 15% water content. The re-suspension of deposited sediment was not considered in the assessment.

Table 2. Model input parameters, and default input parameters used within the model, for each dredge site. The sedimentological characteristics of disposed sediments were derived from the environmental statement (Inch Cape Offshore Limited, 2013).

Metric	Value
Bulk wet density (kg m^{-3})	1600
Dry Bulk density (kg m^{-3}) assumed 15% water content	1360
Total dry mass of dredged material (kg)	54400000
Average proportioned mass – very coarse sand (kg)	103904
Average proportioned mass - coarse sand (kg)	6573696
Average proportioned mass – medium sand (kg)	28346752
Average proportioned mass – fine sand (kg)	17769216
Average proportioned mass – very fine sand (kg)	579904
Average proportioned mass – silt (kg)	1026528
Very coarse sand mean grain size (mm)	1.5
Coarse sand mean grain size (mm)	0.75
Medium sand mean grain size (mm)	0.38
Fine sand mean grain size (mm)	0.19
Very fine sand mean grain size (mm)	0.09
Silt mean grain size (mm)	0.03
Very coarse sand settling velocity (ms^{-1})	0.203
Coarse sand settling velocity (ms^{-1})	0.1031
Medium sand settling velocity (ms^{-1})	0.0471
Fine sand settling velocity (ms^{-1})	0.0179
Very fine sand settling velocity (ms^{-1})	0.0054
Silt settling velocity (ms^{-1})	0.0007
Specific gravity (kg m^{-3})	2650
Porosity (%)	60
Bulk dry density at seabed for sedimentation thickness calculations (kg m^{-3})	1360

2.4 Hydrodynamics

A numerical hydrodynamic model was configured to establish the magnitude and extent of changes to the physical marine environment. Details relating to the configuration, calibration and validation of this model are provided below. The model enabled investigation of the dispersion of disposed material in the worst-case scenario. MIKE21 software was used to set-up and operate a European scale two-dimensional (depth-averaged) flexible mesh model, to properly capture the relevant physical processes. A dedicated regional model was then developed using the MIKE21 hydrodynamic modelling package. This is a comprehensive modelling system for two- and three-dimensional water modelling developed by DHI. Such modelling systems have been developed for complex applications within oceanographic, coastal and estuarine environments. The MIKE21-HD (Hydro-Dynamic) and MIKE21-PT (Particle-Tracking) modules were applied to investigate tidal and sediment plume processes at a regional and local scale, respectively.

2.4.1 Model Domain

A European, basin scale "flexible mesh" model was developed (Figure 3). By employing a flexible mesh with triangular tessellations, it was possible to refine the resolution of the grid in the area covering the proposed development. Such localised refinement provides an enhanced representation of the bathymetry and therefore allows spatial variability in currents to be more accurately represented. The resolution of the model varied from approximately 10 km in the open Atlantic Ocean to 5 km in the approaches around the UK, 3 km in the North Sea and down to a maximum resolution of approximately 75 m (Figure 4). The model consisted of a total of 480,000 triangular tessellations, the majority of which were around the Development Area.

.

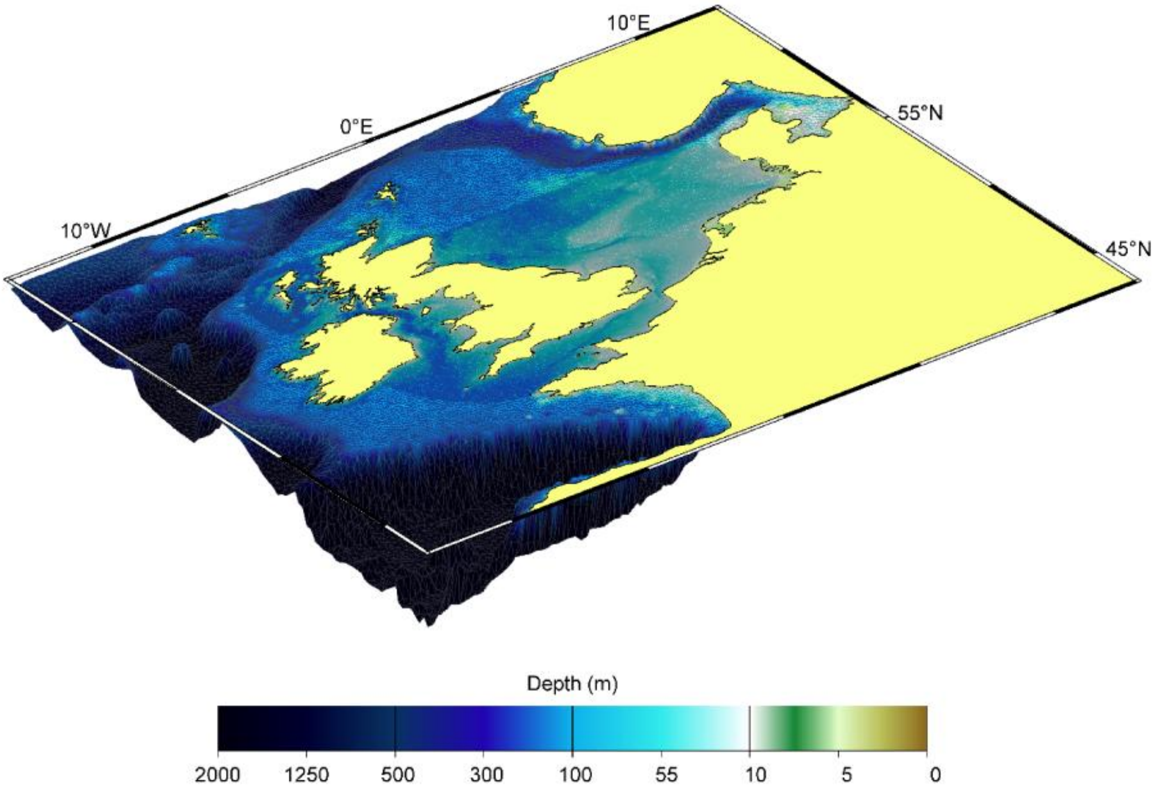


Figure 3. Development of regional MIKE21 flexible model mesh.

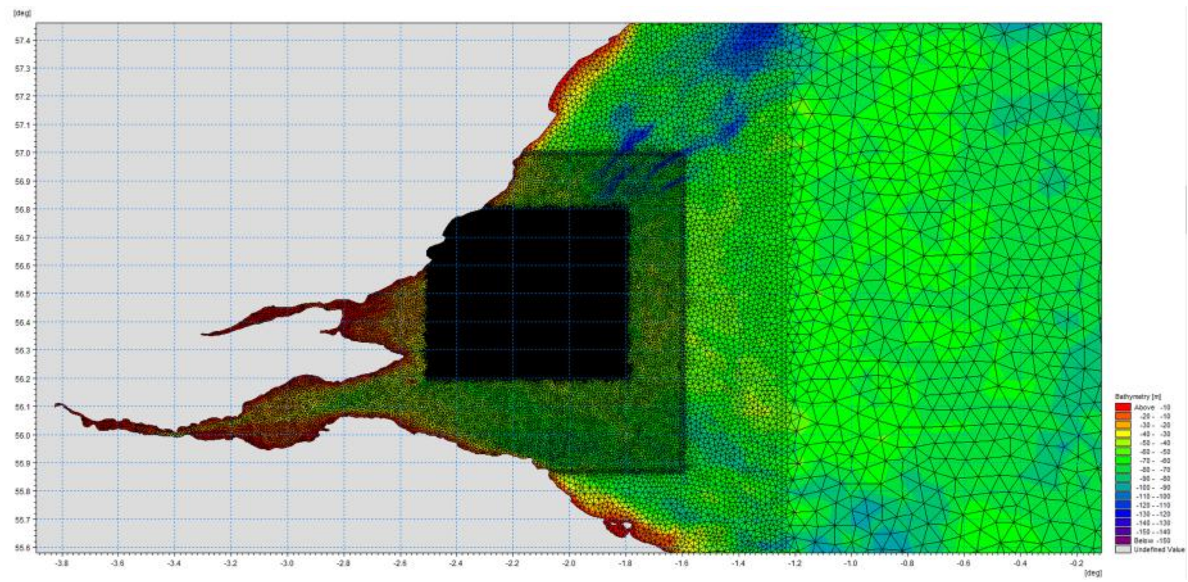


Figure 4. Development of local MIKE21 flexible model mesh showing increased resolution around the Development Area.

2.4.2 Bathymetry

The primary source of bathymetry used in the hydrodynamic model was Oceanwise raster charts. These data deliver some of the best available information on water depth around the UK. At a resolution of 1 arc second in the Development Area (or approximately 30m, depending on latitude) and 6 arc seconds in the wider model domain, physical features such as trenches, ridges, sand banks and sand waves are well represented. These data were augmented with data from GEBCO, ETOPO, EMODnet. The coastline was discretised using the Global Self-consistent, Hierarchical, and High-resolution Geography (GSHHG) Database. The GSHHG is a high-resolution geography data set, amalgamated from two databases in the public domain: World Vector Shorelines (WVS) and CIA World Data Bank II (WDBII).

2.4.3 Boundary Conditions

As the hydrodynamic model was based on a simulation of the European shelf, boundaries were applied in the North Atlantic beyond the continental shelf break to allow the deep water tidal wave to propagate into the model domain and generate any associated higher harmonics. Tidal boundary conditions to the hydrodynamic model originated from the 1/12-degree TPXO 7.2 Atlantic Ocean tidal model.

2.4.4 Regional (2D) Model Calibration and Validation

The numerical model was calibrated against measured current data gathered during a 6 month - long metocean survey campaign which commenced in December 2010 (Partrac Ltd, 2011). Model outputs were compared with the measured current data from the two ADCP deployed in the region of interest. Figure 5 shows the locations of the two ADCP used for model validation, reported as 'ADCP 3' and 'ADCP 4'.

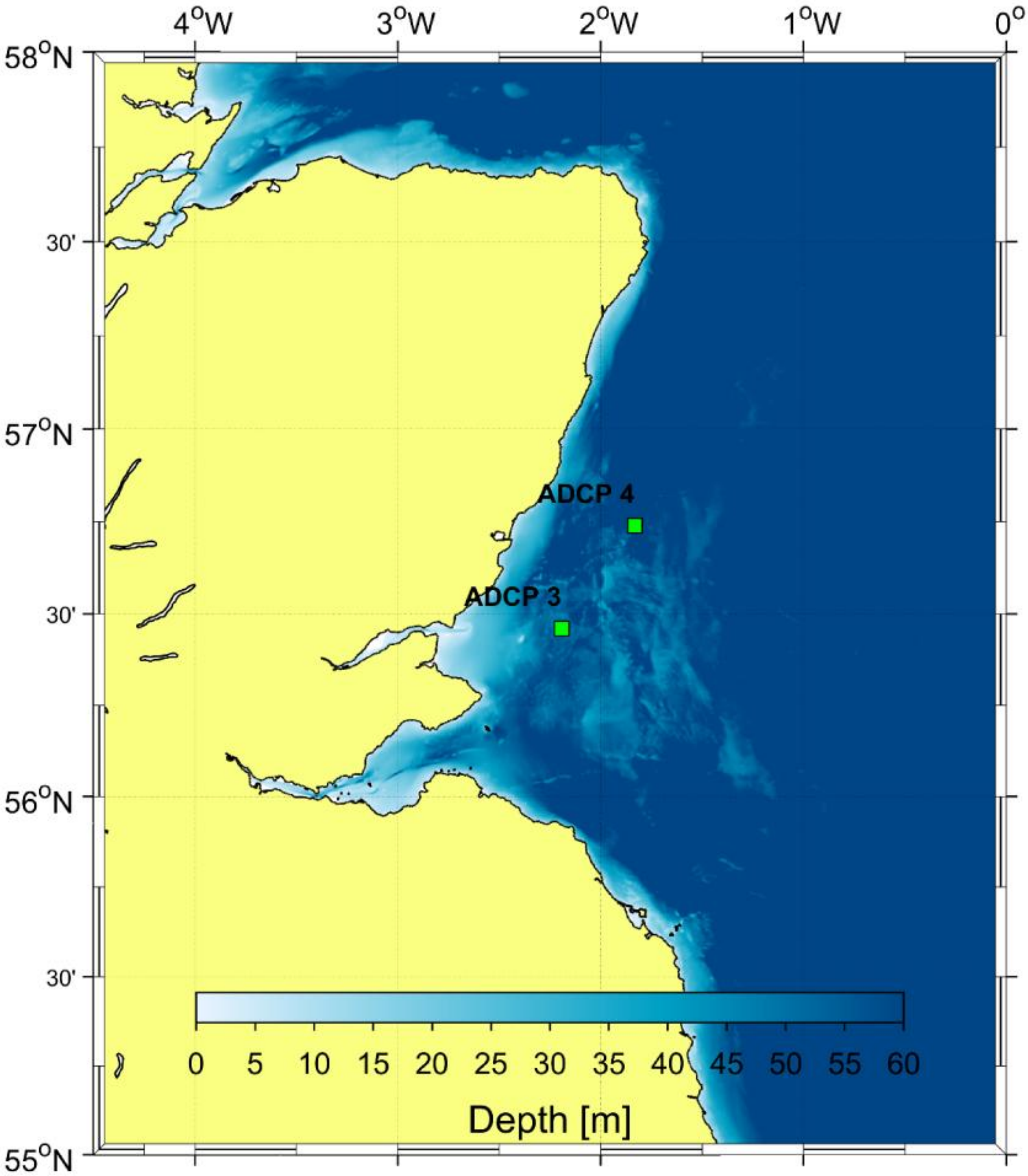


Figure 5. Measurement locations used for model validation presented in this report.

For each dataset in turn, the model output at the corresponding location was compared to the tidal component of depth averaged current velocities.

The information provided in Appendix 1 displays that the current speed and direction showed a strong fit with real data (Partrac Ltd, 2011). The observed high correlation (determination) coefficients (R^2 values of 0.93), regression slopes marginally in excess of unity and low scatter indexes suggest excellent model fit with real data and thus the model can be considered a strong reflection of reality.

2.5 Model Outputs

Figure 6 and Figure 67 display the maximum SSC and the maximum sediment thickness (in mm) of deposited sediment observed at any time throughout disposal operations, and in the days following, respectively.

In addition, Figure 8 - Figure 11 and appendix 2 display the following outputs based upon the release of dredge material from WTG 8.

1) The SSC observed at locations 100, 250, 500 and 1000 m north and south (i.e. broadly in the direction of the tidal axis) of the simulated release point throughout dredge disposal operations.
2) The thickness of sediment deposited at locations 100, 250, 500 and 1000 m north and south (i.e. in the direction of the tidal axis) of the simulated release point throughout dredge disposal operations.
3) Time sliced snapshots of the location and SSC of the sediment plume that arises from the disposals of excavated material from WTG 8, and the associated SSC through time until the concentrations are imperceptible in relation to background SSC.

3. RESULTS

3.1 Modelled Predictions

The following figures show the outputs for the modelled scenario. Figure 6 and Figure 7 show the maximum SSC encountered at any time during the model run scenario, and the maximum sediment thickness following dredge disposal operations, respectively.

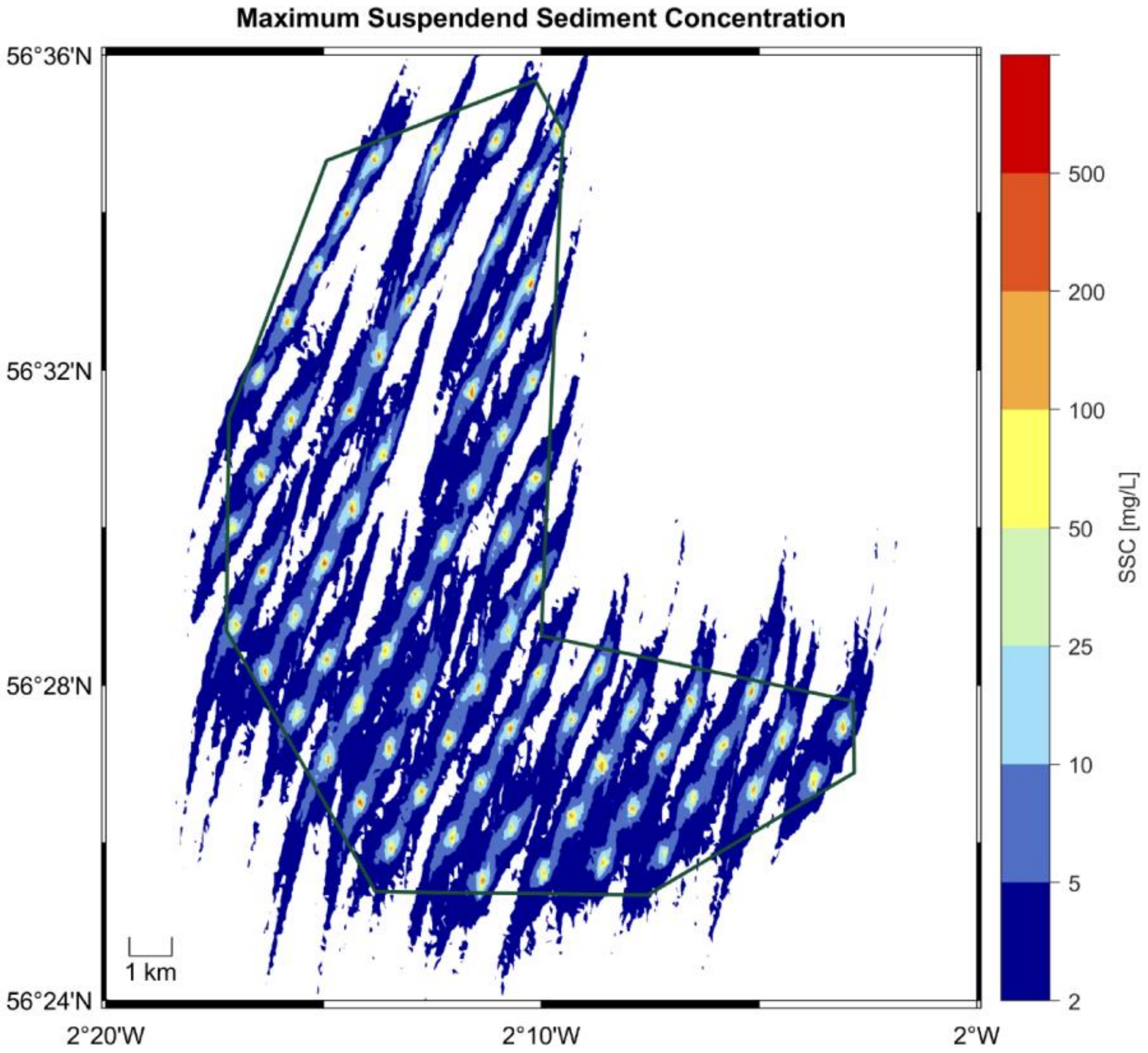


Figure 6. Predicted maximum SSC observed at any time throughout disposal operations and in the days following.

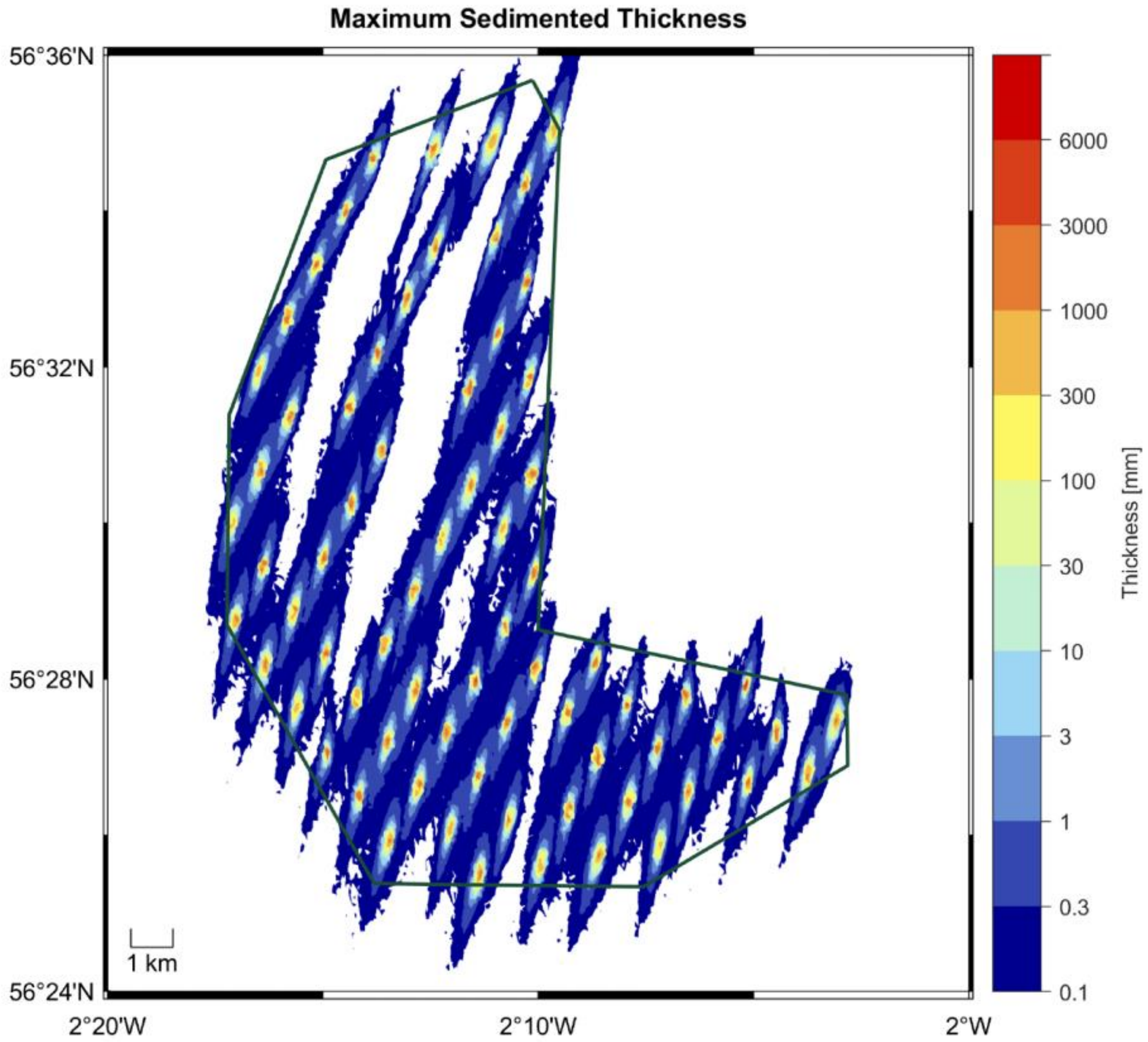
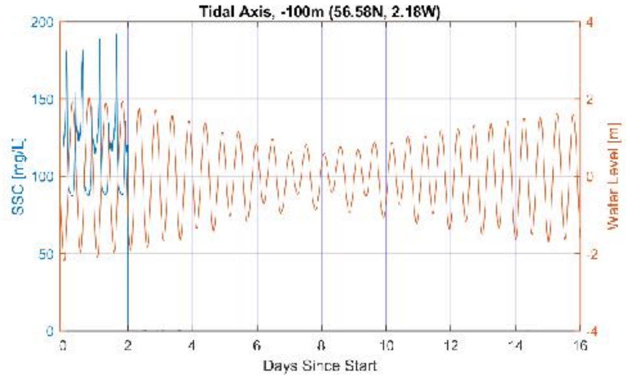


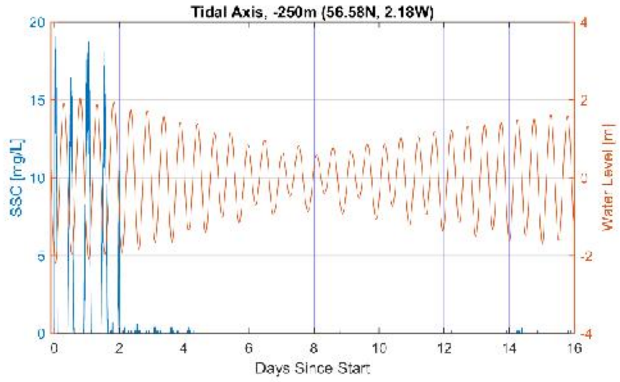
Figure 7. Predicted maximum sediment thickness on the seabed following dredge disposal operations.

Figure 8 and Figure 9 show the SSC observed and Figure 10 and Figure 11 show the thickness of sediment deposited at locations 100, 250, 500 and 1000 m north and south (i.e. in the approximate direction of the tidal axis) following the simulated release from WTG 8.

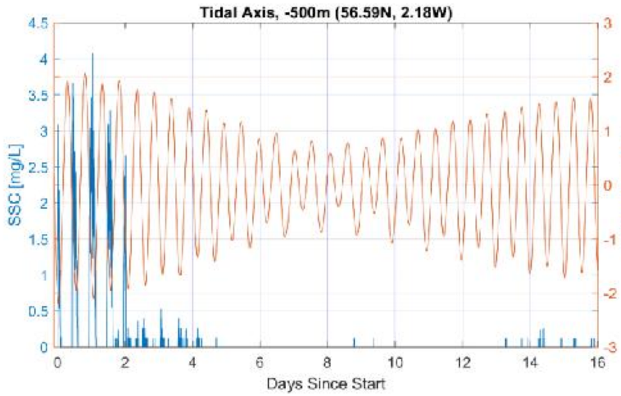
-100m



-250m



-500m



-1000m

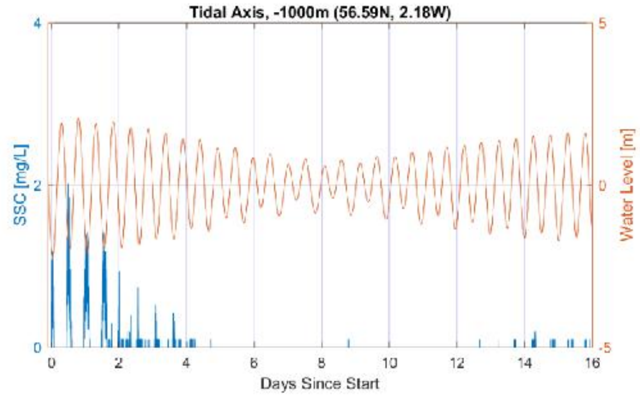
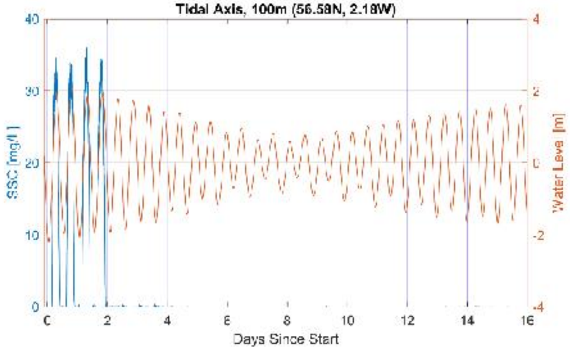
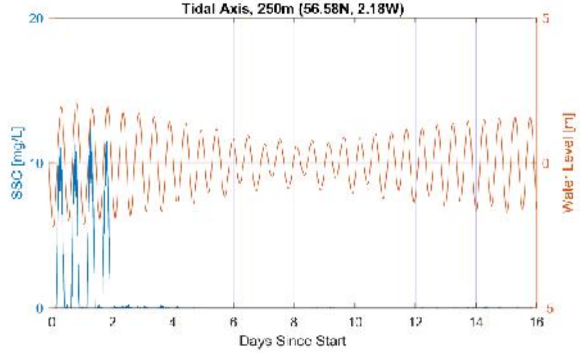


Figure 8. Predicted SSC (mg l^{-1}) at locations 100, 250, 500 and 1000 m to the south along the tidal axis from the release point (WTG 8) following the commencement of disposal operations.

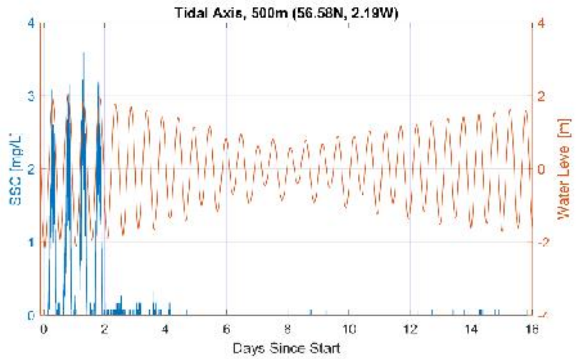
+100m



+250m



+500m



+1000m

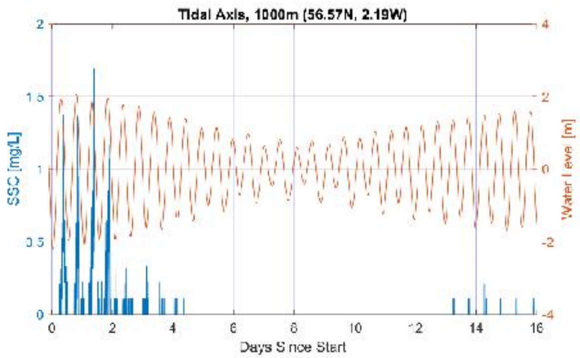


Figure 9. Predicted SSC (mg l^{-l}) at locations 100, 250, 500 and 1000 m to the north (along the tidal axis) from the release point (WTG 8) following the commencement of disposal operation.

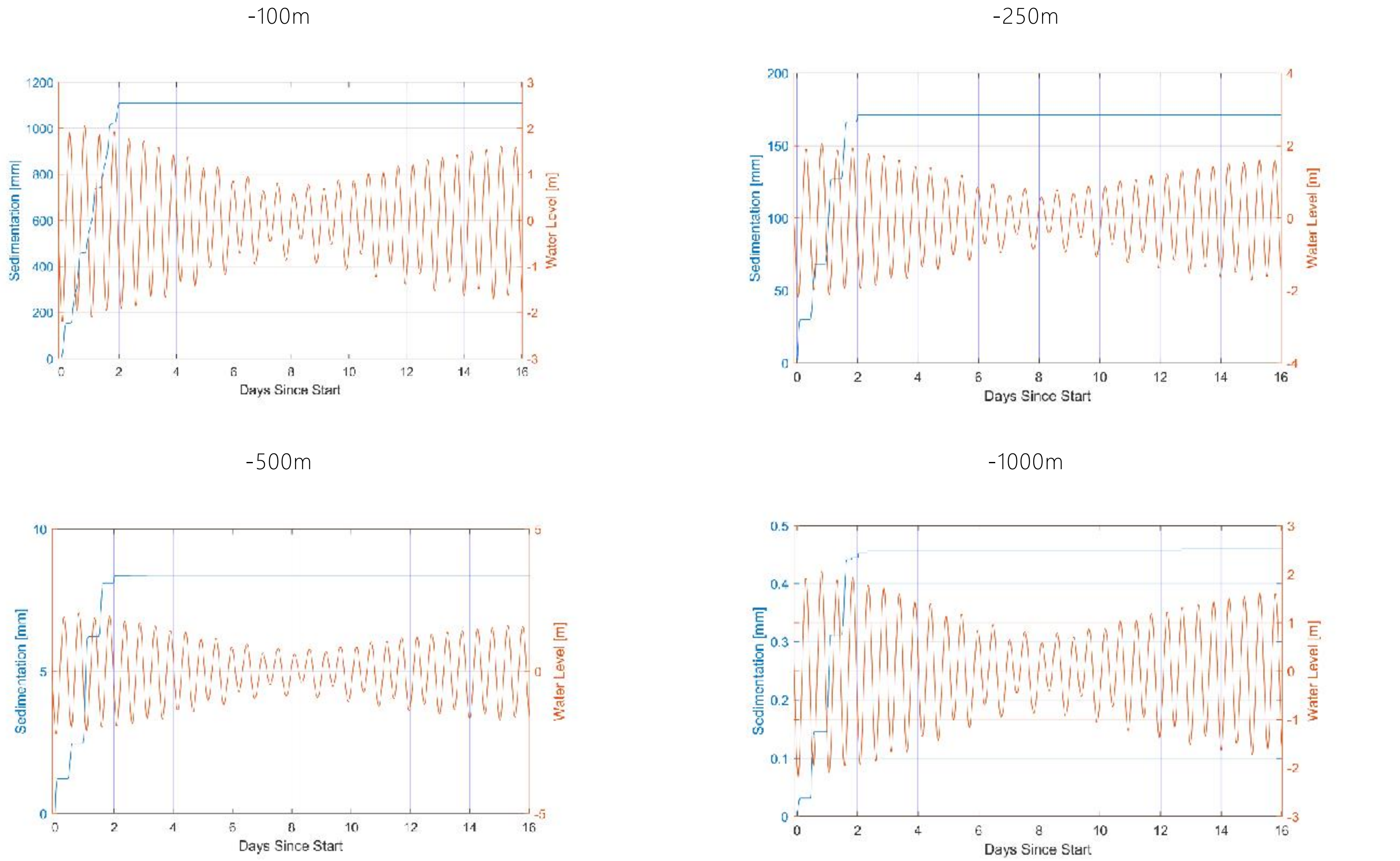


Figure 10. Predicted cumulative sedimentation thickness (mm) at 100, 250, 500 and 1000 m to the south (along the tidal axis) from the release point (WTG 8) following the commencement of the disposal operations.

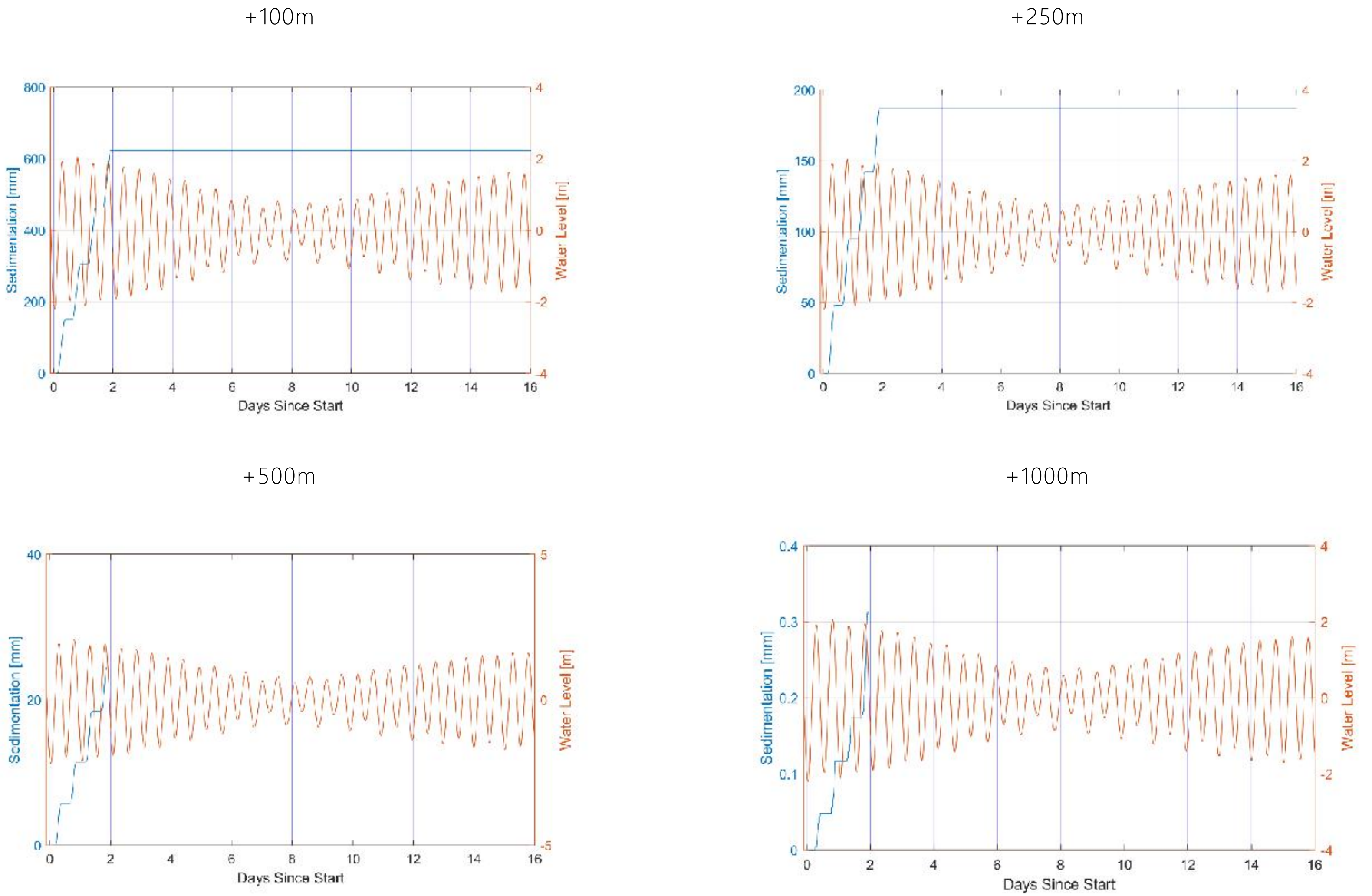


Figure 11. Predicted cumulative sedimentation thickness (mm) at 100, 250, 500 and 1000 m to the north (along the tidal axis) from the release point (WTG 8) following the commencement of the disposal operations.

Table 3 details the relationship between the tidal phase and the deposited sediment thickness and spatial extent of the deposit on the bed.

Table 3. The tidal phase, sedimentation thickness and spatial extent of the deposit during the model run.

Sedimentation thickness (mm)	Spatial extent (~ km²)
➢ 0.1	123.25
➢ 0.3	49.80
➢ 1	20.82
➢ 3	13.33
➢ 10	9.55
➢ 50	6.08
➢ 30	7.19
➢ 100	4.69.
➢ 300	2.70
➢ 1000	0.77
➢ 3000	0.02

3.2 Disposal Plume Dispersion and Deposited Sediment Thickness

Significant points to note from the outputs of the modelling with regard to plume dispersion and deposited sediment thickness are:

- That the plume disperses southwards on the flood tide and northwards on the ebb tide (Figure 6 and Appendix 2).
- The maximum predicted SSC observed at the site during disposal operations is 330 mg l^{-1}, and the maximum observed sediment thickness is 5.9 m.
- Due to the position of the fall pipe in the water column (5 m above the sea bed), and the (relatively) coarse nature of the excavated material, deposition of dredge material generally occurs rapidly in the locality of the release.
- Due to the reduced flow velocity magnitude at neap tides in comparison to spring tides, the predicted SSC locally, are slightly reduced when dredge disposal occurs on the spring tidal cycle. Comparatively, when disposal occurs during neap tides, SSC are slightly increased locally to the release site, the plumes follow a similar path and direction, but of reduced extent in comparison to that observed during releases on the Spring tide.
- SSC return to background levels (< 5 mg l^{-1}) ~2 days following the final release of the modelled scenario (i.e. almost immediately [< 1 hr.] following the completion of dredging operations).
- Figure 8 and Figure 9 show the maximum SSC observed to the north and south (along the tidal axis) following dredge and disposal operations at WTG 8 captured at 100, 250,

500 and 1000 m. During disposal operations the SSC to the south peaked at 200, 19, 4 and 2 (mg l^{-l}) at 100, 250, 500 and 1000 m, respectively. Comparatively, SSC to the north peaked at 35, 12, 4 and 2 (mg l^{-l}) at 100, 250, 500 and 1000 m. This is due to the flood currents (which flow south-westward [minorly southward]) being stronger than ebb currents (which flow north eastward).

Figure 10 and Figure 11 reveal the thickness of deposited sediment at the same locations north and south of WTG 8 during disposal operations. The deposited sediment thickness observed to the south following release at WTG 8 captured at 100, 250, 500 and 1000 m peaked at 1100, 170, 8 and 0.5 (mm) at 100, 250, 500 and 1000 m, respectively. Comparatively, the deposited sediment thickness observed to the north peaked at 620, 185, 25 and 0.3 (mm), at 100, 250, 500 and 1000 m, respectively. Again, this is due to the flood currents (which flow south-westward [minorly southward]) being stronger than ebb currents (which flow north eastward).

4. DISCUSSION

To evaluate the sediment dispersion potential, within the surrounding North Sea, of sediments disposed of at the Development Area, Partrac employed a numerical modelling approach. The model simulated the release of excavated sediments from 72 WTG foundation sites to quantitatively evaluate the sediment dispersion potential, associated with a proposed, continual, sub-surface disposal of excavated sediments from a fall pipe from a TSHD.

For the modelled scenario, the spatial distribution of SSC and the maximum sedimented thickness were predicted during ebb and flood tidal conditions, across the spring- neap tidal cycle. The model simulation outlined the dispersion of the dredge plume and the extent and magnitude of the depositional thickness of the material on the sea bed. The plume dispersion potential is driven by the hydrodynamic and tidal forcing at the site. The extent of the dispersion and subsequent deposition is dependent upon flow velocity magnitude which are increased on Spring tidal cycles and decreased on Neap tidal cycles. Due, to the size of the site, and the bathymetric profile, spatially varying flow velocity magnitudes also impact upon the dispersal and deposition patterns of disposed sediment. The 'worst case' scenario model outputs indicate that the suspended sediment plumes generated from dispersal will encroach beyond the site boundary, though only in low concentrations (< 10 mg l^{-1}). The associated deposited sediment thickness, beyond the site boundary is also predicted to be low, not exceeding a thickness of 30 mm, and generally being < 1-3 mm, thick. Resuspension of deposited sediment has not been investigated during this assessment.

5. CONCLUSIONS

The following key conclusions have been drawn from the outputs of the modelled scenario:

- The numerical model showed strong correlation with the measured hydrodynamic data from the site, indicating excellent model performance.
- Following completion of disposal operations, SSC is predicted to return to 'approximate background levels' (~5 mg l^{-l}) almost immediately.
- The localised (to the point of release) maximum SSC was increased during disposal of dredge spoil at Neap tides, and at inshore (relative to site extent/boundary) sites.
- The spatial extent of disposed sediment deposition was increased during the Spring tidal cycles in comparison to that observed during the Neap tidal cycles. This was enhanced at offshore (relative to site extent/boundary) sites.
- In general, the dispersal of disposed sediments is low due to the generally low flow velocity magnitude experienced at the Development Area and the proposed dredge disposal technique of releasing sediments from a fall pipe, 5m above the seabed.

The results of this study suggest that during the modelled "worst case" scenario there is the potential for suspended sediment plumes created during dredge disposal operations to increase SSC and deposited sediment thickness within, and beyond, the extent of the Development Area. SSC is predicted to be greatest due to increased flow velocity magnitude and greater tidal excursion (the distance a parcel of water travels during a tidal phase) during Spring tides. In addition, during this time the spatial extent of deposition is greatest, but the thickness of sediment deposited is lower. Comparatively, during the Neap tidal phase SSC is predicted to be lower and the spatial extent of deposition is lower, yet the deposited sediment thickness is greater. Consequently, it is reasonable to conclude that increased SSC and the spatial extent of sediments being deposited on the seabed is greatest during the Spring tidal phase, yet the impact during the Neap tidal phase may be less widespread, but the deposited sediment thicknesses in these areas may be more pronounced.

6. REFERENCES

Inch Cape Offshore Limited (2013). Environmental Statement. Chapter 10 Metocean and Coastal Processes, Appendix 10A Metocean and Coastal Processes Assessment. Report reference: P1476_RN3026_REV5_APP10A.

Partrac Ltd (2011). P1127 - MRP Forth and Tay. ADCP data captured from 'ADCP 3' and 'ADCP 4'. Date last accessed: 16/01/2018.

APPENDIX 1 – HYDRODYNAMIC MODEL VALIDATION

Details of the method used to fit the harmonic constituents to measured data are as follows:

Part 1: Fit Harmonic Constituents to Measured Data

Step 1a: Select Data for Fitting

All data was used to fit harmonic constituents, with the following exceptions:

i) Data bins with less than 50 % valid data, i.e. the topmost bins which are more often out of the water than in it, are omitted.

ii) Some sections appear inconsistent to the majority of the data and thus were not included.

Step 1b: Depth Average Selected Data

Measured current speed and direction data were resolved into eastward and northward components (hereafter U and V) and depth averaged.

Step 1c: Fit Harmonic Constituents to Depth Averaged Components

Harmonic constituents were fitted to the depth averaged data using the UTide software package with the following options:

- Two dimensional fit (U and V simultaneously)
- No linear trend included
- Nodal/satellite corrections with exact times
- Constituents selected using the automated decision tree of Foreman and minimum conventional Rayleigh criterion (R_{min}) of 1. Note that alternate values of R_{min} were considered but did not give notable improvements in the quality of the fit.

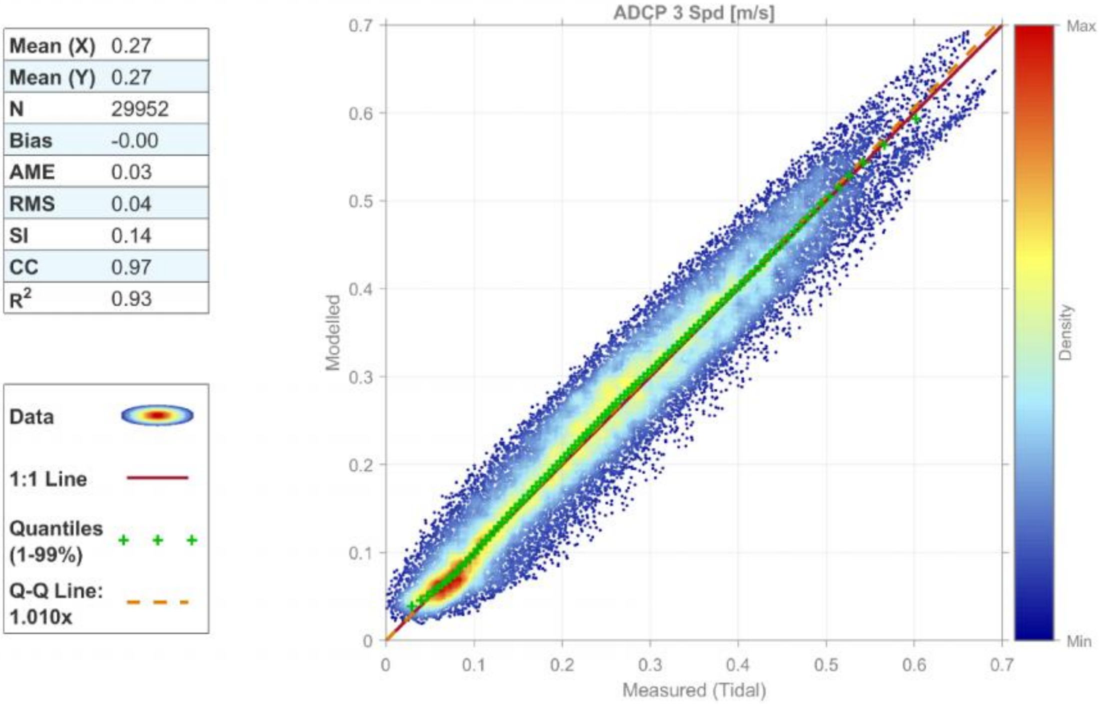
Step 1d: Review Fit

The raw data was subsequently compared to a reconstituted dataset comprising only the tidal components to ensure a good fit.

Part 2: Evaluate Harmonic Constituents at Timestamps of Model Outputs

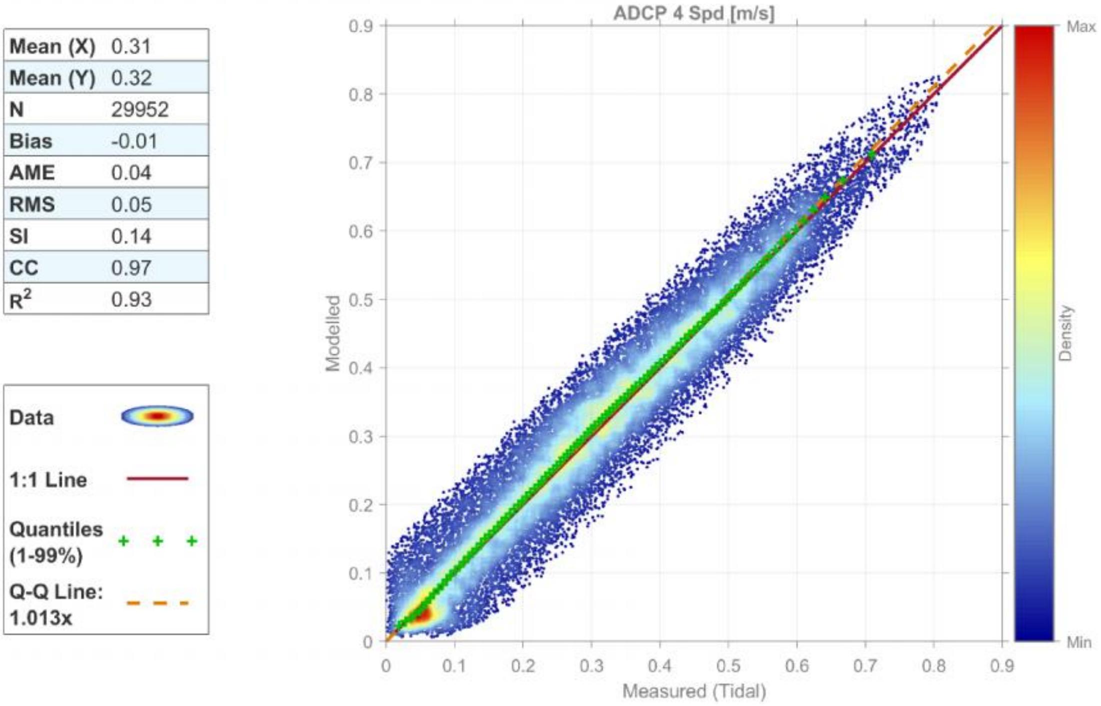
The fitted harmonic constituents were then evaluated at timestamps corresponding to the *model* outputs, giving a direct comparison point for each model timestamp. These values were subsequently compared to the model outputs to create the validation plots included in this report. Simultaneous scatter plot comparisons of modelled and measured depth-averaged tidal current speeds with overlaid Quantile-Quantiles and time-series comparisons are presented below.

Mean (X)	0.27
Mean (Y)	0.27
N	29952
Bias	-0.00
AME	0.03
RMS	0.04
SI	0.14
CC	0.97
R^2	0.93

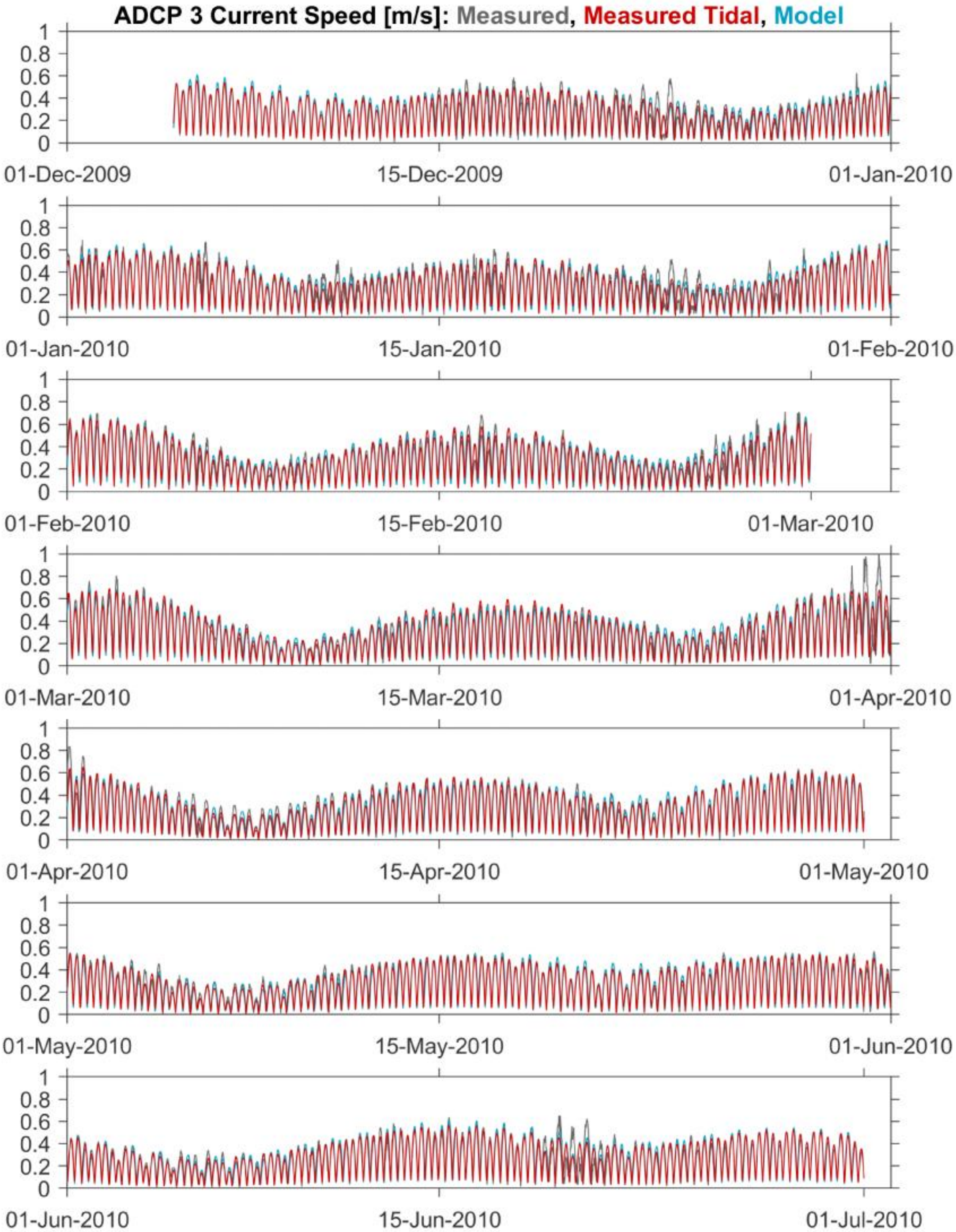


Comparison of modelled and measured tidal currents (ADCP 3).

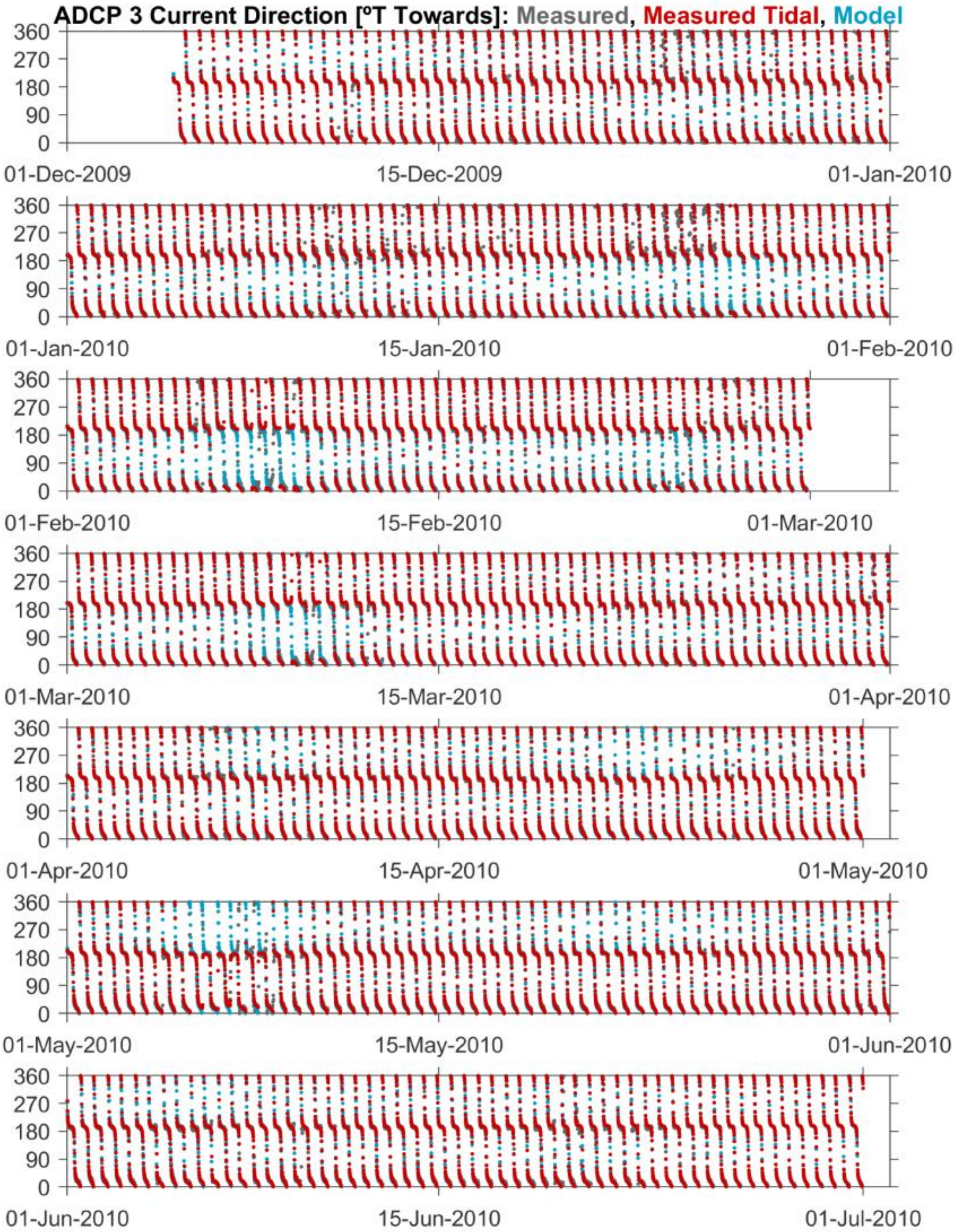
Mean (X)	0.31
Mean (Y)	0.32
N	29952
Bias	-0.01
AME	0.04
RMS	0.05
SI	0.14
CC	0.97
R^2	0.93



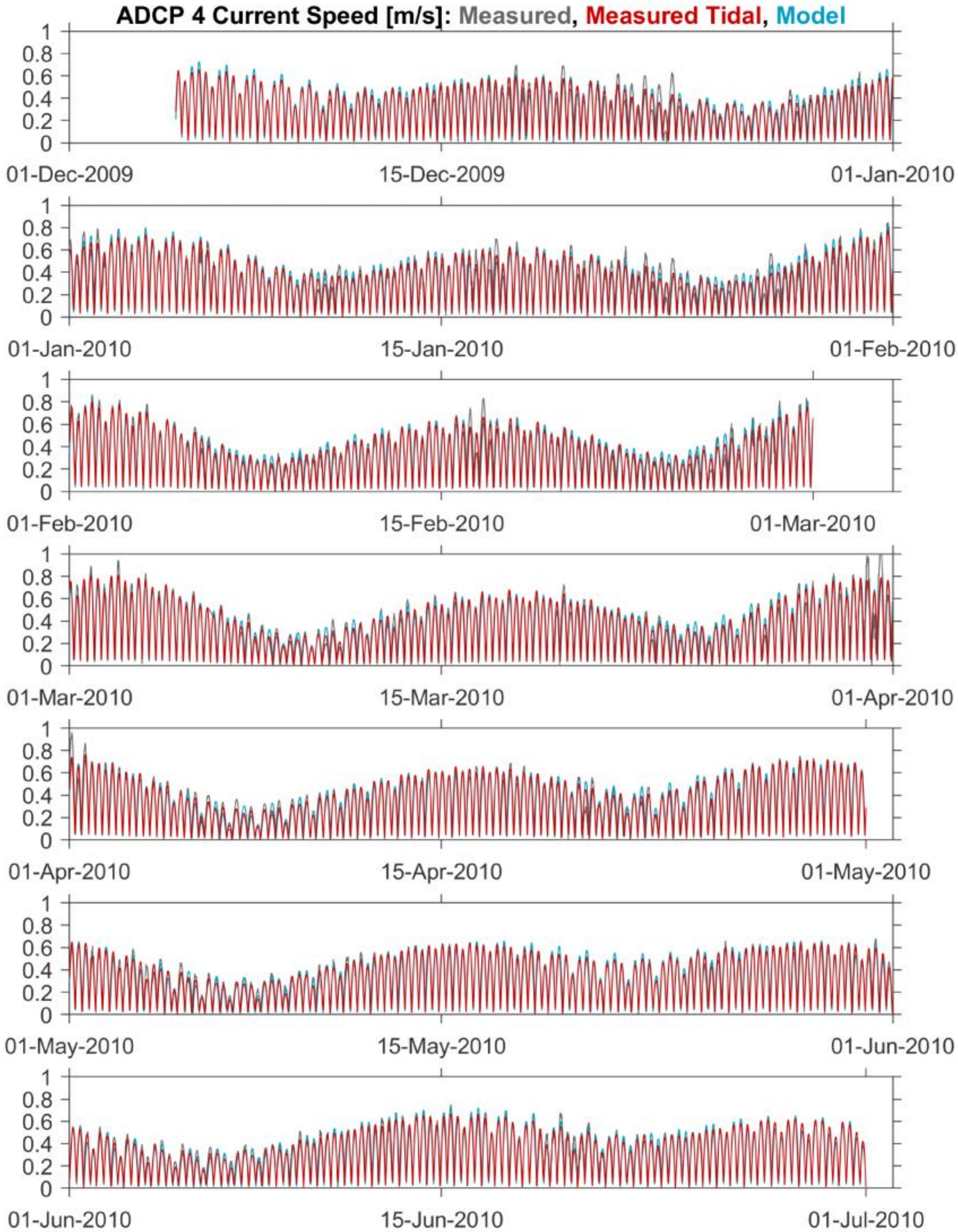
Comparison of modelled and measured tidal currents (ADCP 4)



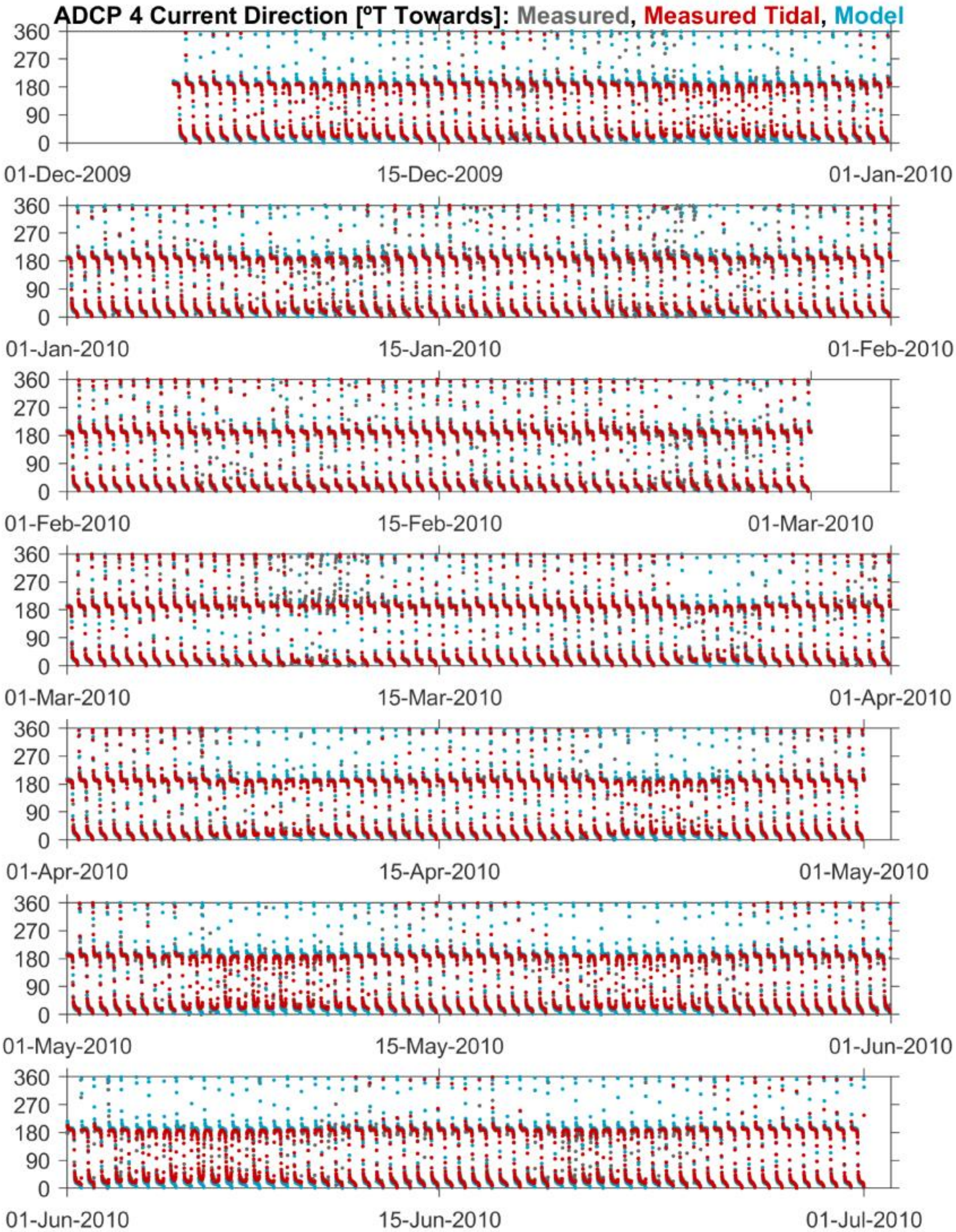
Time-Series comparison of modelled and measured current speed (ADCP 3).



Time-Series comparison of modelled and measured current direction (ADCP 3).



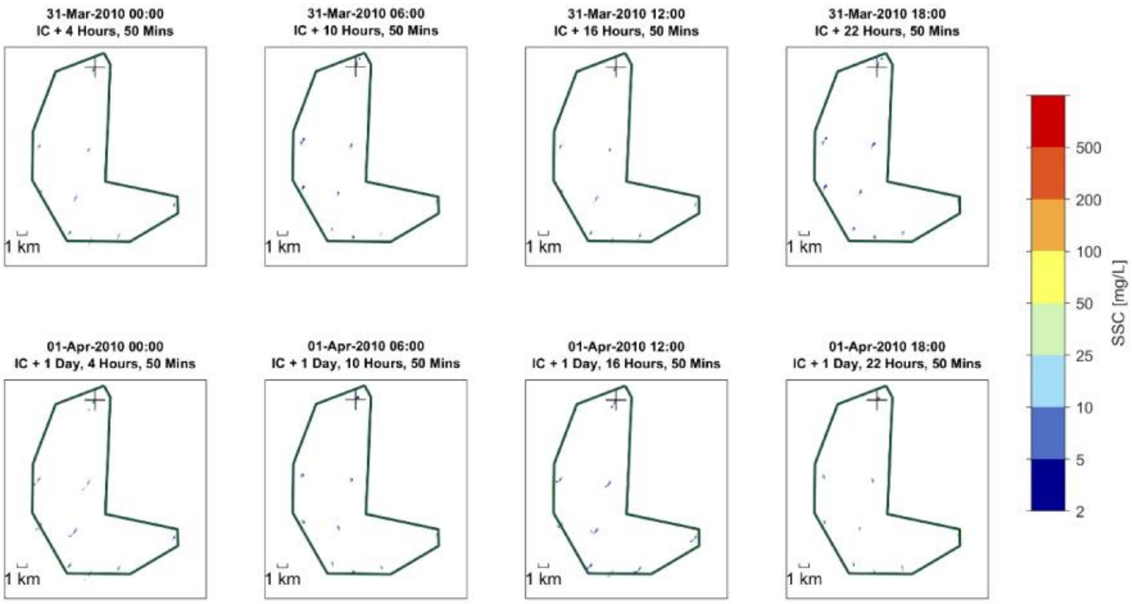
Time-Series comparison of modelled and measured current speed (ADCP 4).

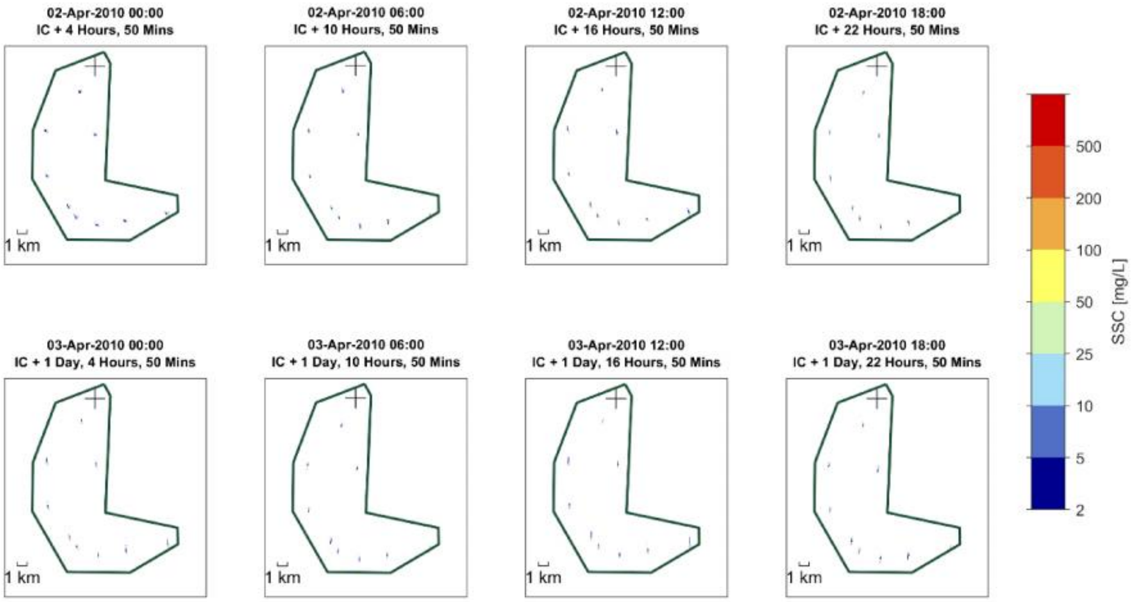


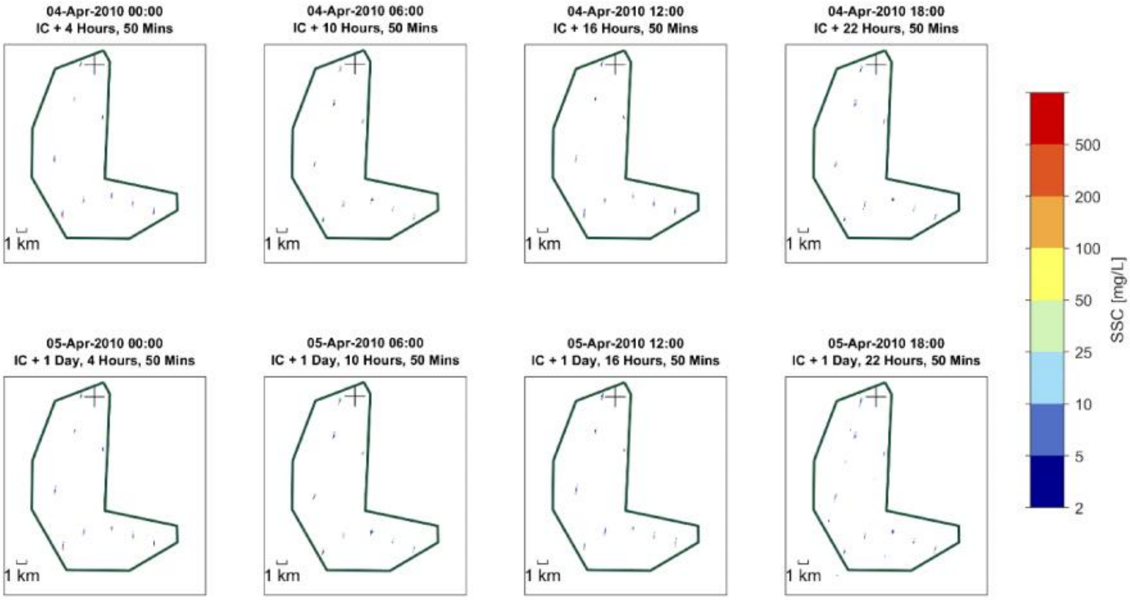
Time-Series comparison of modelled and measured current direction (ADCP 4).

APPENDIX 2 – TIME SLICED SNAPSHOTS

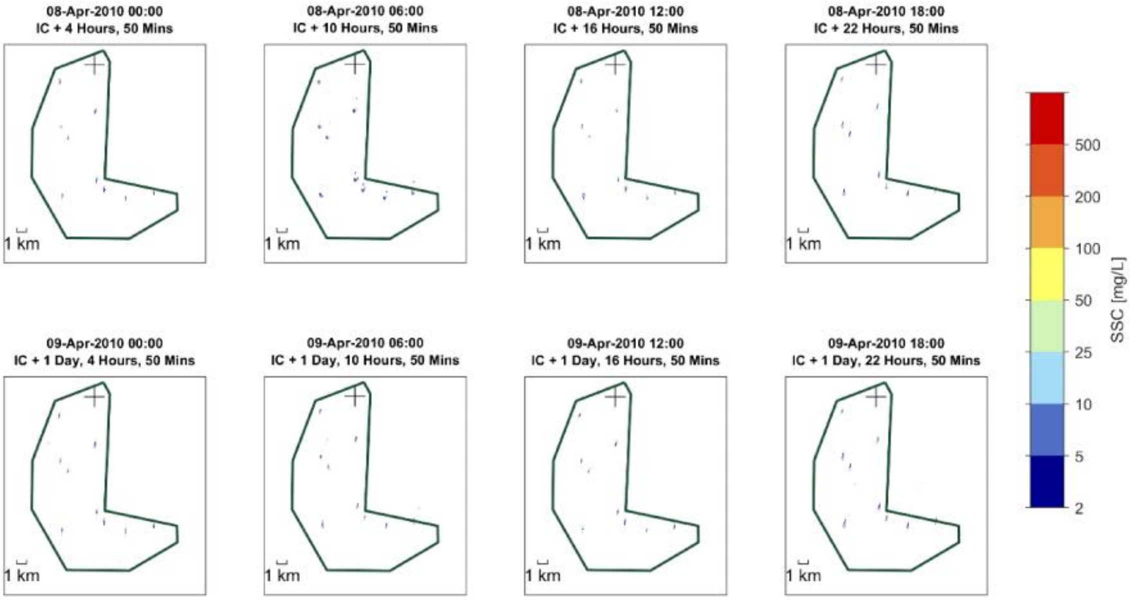
The following plots show time sliced snapshots of the location, size, and associated SSC through time of the sediment plume(s) arising from the disposal of dredged material from WTG 8, and of subsequent disposals which occurred during the time stamp of the data presented.

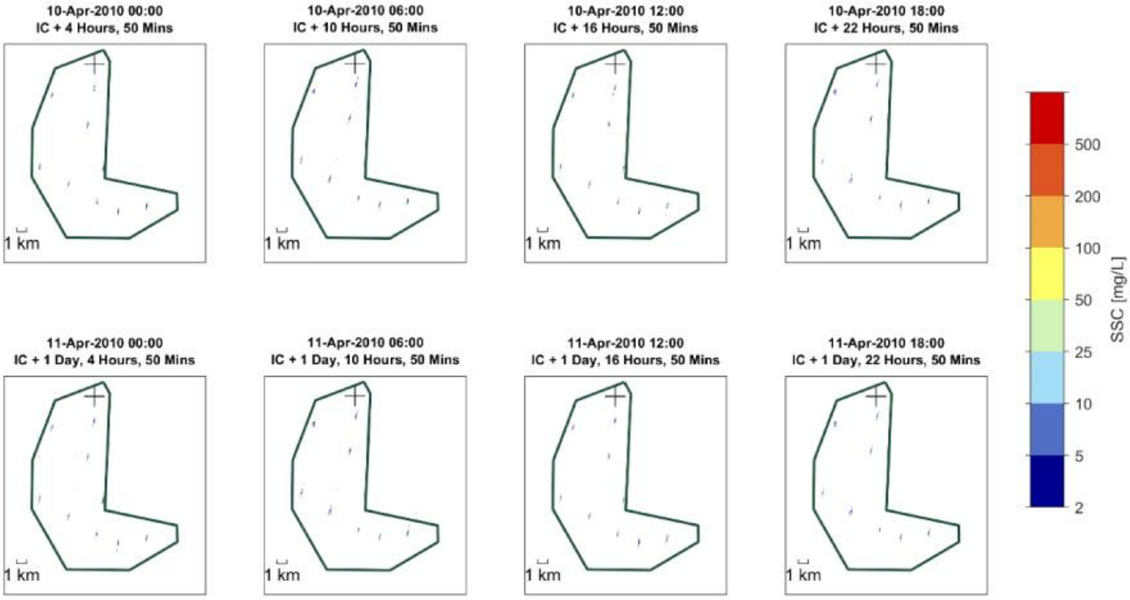


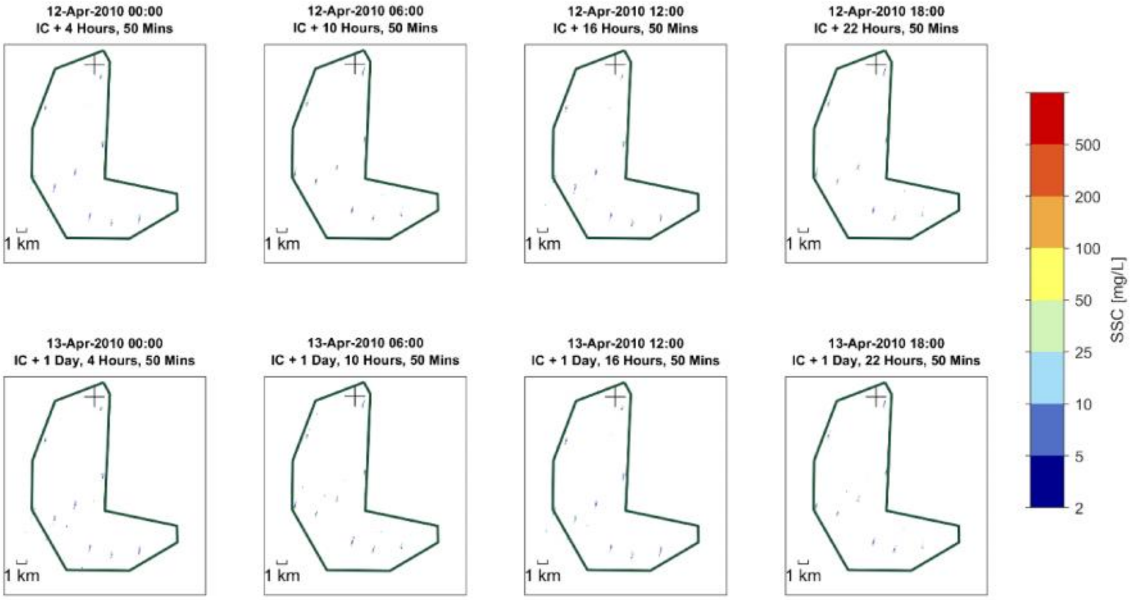


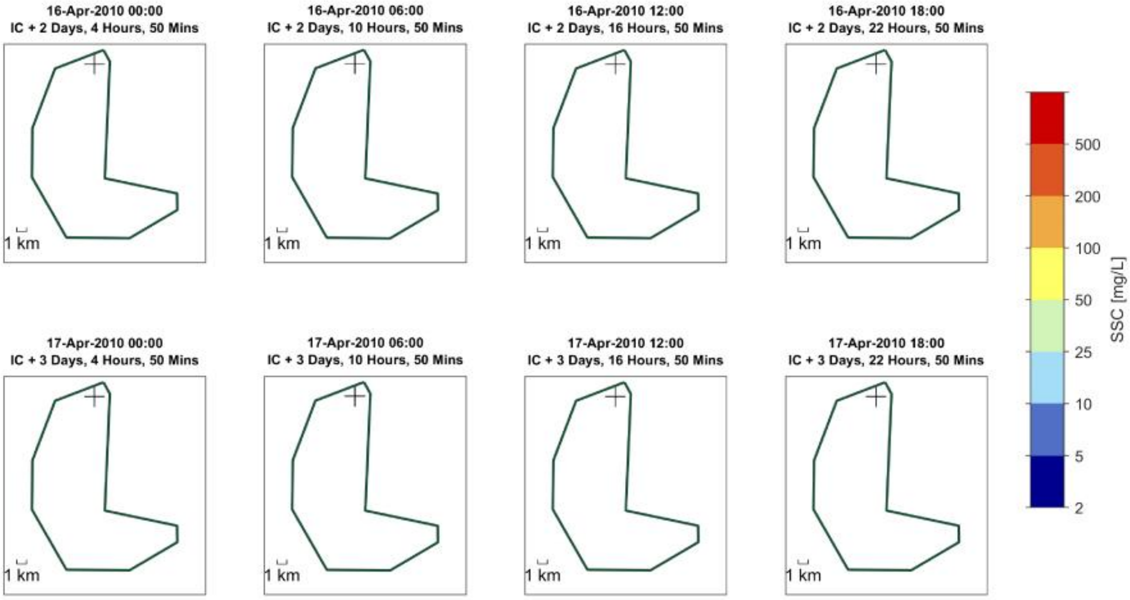

04-Apr-2010 00:00
IC + 4 Hours, 50 Mins
04-Apr-2010 06:00
IC + 10 Hours, 50 Mins
04-Apr-2010 12:00
IC + 16 Hours, 50 Mins
04-Apr-2010 18:00
IC + 22 Hours, 50 Mins
05-Apr-2010 00:00
IC + 1 Day, 4 Hours, 50 Mins
05-Apr-2010 06:00
IC + 1 Day, 10 Hours, 50 Mins
05-Apr-2010 12:00
IC + 1 Day, 16 Hours, 50 Mins
05-Apr-2010 18:00
IC + 1 Day, 22 Hours, 50 Mins
1 km
SSC [mg/L]
500
200
100
50
25
10
5
2

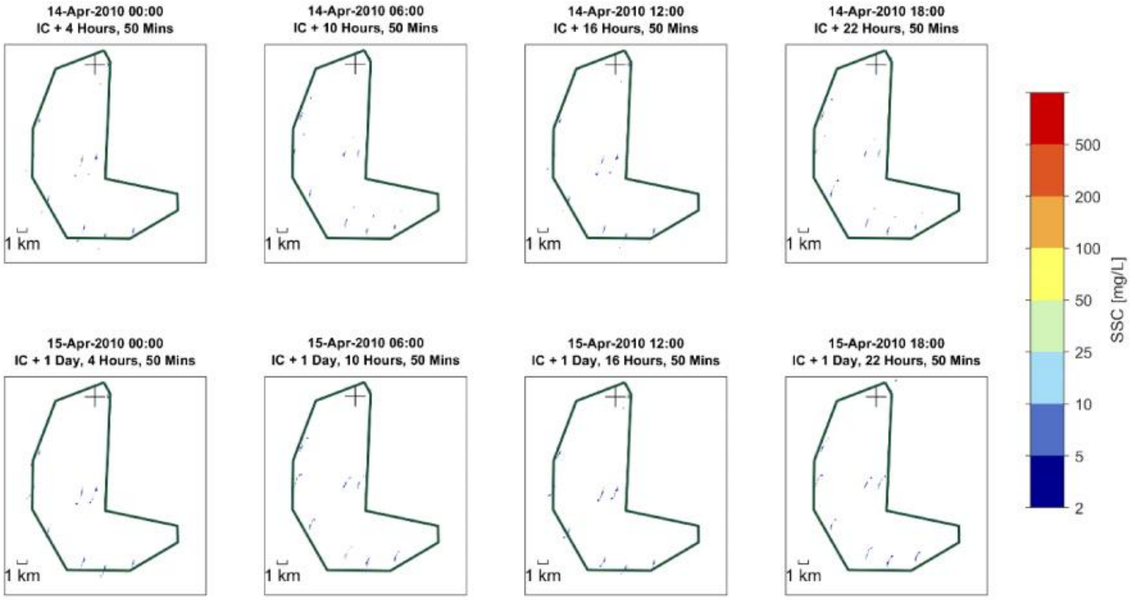

06-Apr-2010 00:00
IC + 4 Hours, 50 Mins
06-Apr-2010 06:00
IC + 10 Hours, 50 Mins
06-Apr-2010 12:00
IC + 16 Hours, 50 Mins
06-Apr-2010 18:00
IC + 22 Hours, 50 Mins
07-Apr-2010 00:00
IC + 1 Day, 4 Hours, 50 Mins
07-Apr-2010 06:00
IC + 1 Day, 10 Hours, 50 Mins
07-Apr-2010 12:00
IC + 1 Day, 16 Hours, 50 Mins
07-Apr-2010 18:00
IC + 1 Day, 22 Hours, 50 Mins
1 km
SSC [mg/L]
500
200
100
50
25
10
5
2

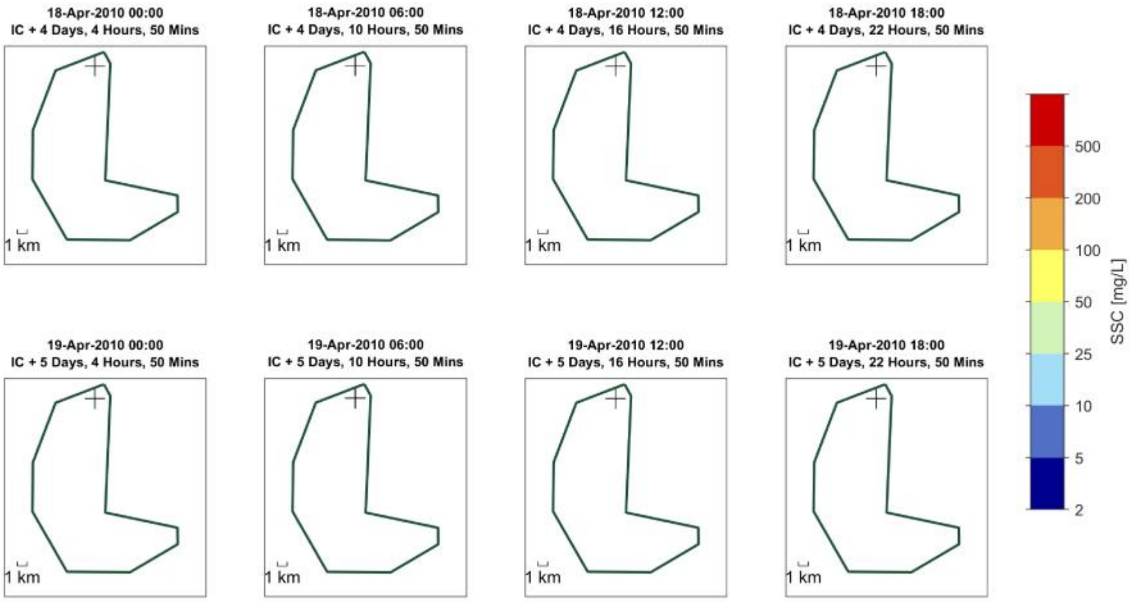

08-Apr-2010 00:00
IC + 4 Hours, 50 Mins
08-Apr-2010 06:00
IC + 10 Hours, 50 Mins
08-Apr-2010 12:00
IC + 16 Hours, 50 Mins
08-Apr-2010 18:00
IC + 22 Hours, 50 Mins
09-Apr-2010 00:00
IC + 1 Day, 4 Hours, 50 Mins
09-Apr-2010 06:00
IC + 1 Day, 10 Hours, 50 Mins
09-Apr-2010 12:00
IC + 1 Day, 16 Hours, 50 Mins
09-Apr-2010 18:00
IC + 1 Day, 22 Hours, 50 Mins
1 km
500
200
100
50
25
10
5
2
SSC [mg/L]


10-Apr-2010 00:00
IC + 4 Hours, 50 Mins
10-Apr-2010 06:00
IC + 10 Hours, 50 Mins
10-Apr-2010 12:00
IC + 16 Hours, 50 Mins
10-Apr-2010 18:00
IC + 22 Hours, 50 Mins
11-Apr-2010 00:00
IC + 1 Day, 4 Hours, 50 Mins
11-Apr-2010 06:00
IC + 1 Day, 10 Hours, 50 Mins
11-Apr-2010 12:00
IC + 1 Day, 16 Hours, 50 Mins
11-Apr-2010 18:00
IC + 1 Day, 22 Hours, 50 Mins
1 km
500
200
100
50
25
10
5
2
SSC [mg/L]


12-Apr-2010 00:00
IC + 4 Hours, 50 Mins
12-Apr-2010 06:00
IC + 10 Hours, 50 Mins
12-Apr-2010 12:00
IC + 16 Hours, 50 Mins
12-Apr-2010 18:00
IC + 22 Hours, 50 Mins
13-Apr-2010 00:00
IC + 1 Day, 4 Hours, 50 Mins
13-Apr-2010 06:00
IC + 1 Day, 10 Hours, 50 Mins
13-Apr-2010 12:00
IC + 1 Day, 16 Hours, 50 Mins
13-Apr-2010 18:00
IC + 1 Day, 22 Hours, 50 Mins
1 km
500
200
100
50
25
10
5
2
SSC [mg/L]


16-Apr-2010 00:00
IC + 2 Days, 4 Hours, 50 Mins
16-Apr-2010 06:00
IC + 2 Days, 10 Hours, 50 Mins
16-Apr-2010 12:00
IC + 2 Days, 16 Hours, 50 Mins
16-Apr-2010 18:00
IC + 2 Days, 22 Hours, 50 Mins
17-Apr-2010 00:00
IC + 3 Days, 4 Hours, 50 Mins
17-Apr-2010 06:00
IC + 3 Days, 10 Hours, 50 Mins
17-Apr-2010 12:00
IC + 3 Days, 16 Hours, 50 Mins
17-Apr-2010 18:00
IC + 3 Days, 22 Hours, 50 Mins
1 km
500
200
100
50
25
10
5
2
SSC [mg/L]


14-Apr-2010 00:00
IC + 4 Hours, 50 Mins
14-Apr-2010 06:00
IC + 10 Hours, 50 Mins
14-Apr-2010 12:00
IC + 16 Hours, 50 Mins
14-Apr-2010 18:00
IC + 22 Hours, 50 Mins
15-Apr-2010 00:00
IC + 1 Day, 4 Hours, 50 Mins
15-Apr-2010 06:00
IC + 1 Day, 10 Hours, 50 Mins
15-Apr-2010 12:00
IC + 1 Day, 16 Hours, 50 Mins
15-Apr-2010 18:00
IC + 1 Day, 22 Hours, 50 Mins
1 km
500
200
100
50
25
10
5
2
SSC [mg/L]


18-Apr-2010 00:00
IC + 4 Days, 4 Hours, 50 Mins
18-Apr-2010 06:00
IC + 4 Days, 10 Hours, 50 Mins
18-Apr-2010 12:00
IC + 4 Days, 16 Hours, 50 Mins
18-Apr-2010 18:00
IC + 4 Days, 22 Hours, 50 Mins
19-Apr-2010 00:00
IC + 5 Days, 4 Hours, 50 Mins
19-Apr-2010 06:00
IC + 5 Days, 10 Hours, 50 Mins
19-Apr-2010 12:00
IC + 5 Days, 16 Hours, 50 Mins
19-Apr-2010 18:00
IC + 5 Days, 22 Hours, 50 Mins
1 km
500
200
100
50
25
10
5
2
SSC [mg/L]


20-Apr-2010 00:00
IC + 6 Days, 4 Hours, 50 Mins
1 km
500
200
100
50
25
10
5
2
SSC [mg/L]

What we do

Natural Power is a leading independent renewable energy consultancy and products provider. The company offers proactive and integrated consultancy, management and due diligence services, backed by an innovative product range, across the onshore wind, offshore wind, wave, tidal, renewable heat, solar pv and hydro sectors, whilst maintaining a strong outlook on other new and emerging renewable energy sectors.

Established in the mid 1990s, Natural Power has been at the heart of many groundbreaking projects, products and portfolios for more than two decades, assisting project developers, investors, manufacturers, research houses and other consulting companies. With its iconic Scottish headquarters, The Green House, Natural Power has expanded internationally and now employs more than 330 renewable energy experts.

Creating a better environment

Our global expertise

Natural Power delivers services and operates assets globally for our clients, with eleven offices across Europe and North America and agencies active in South America and AsiaPac.

UK & IRELAND

Registered Office, Scotland
The Green House, Forrest Estate
Dalry, Castle Douglas, DG7 3XS
SCOTLAND, UK

Stirling, Scotland
Ochil House
Springkerse Business Park
Stirling, FK7 7XE
SCOTLAND, UK

Inverness, Scotland
Suite 3, Spey House, Dochfour
Business Centre, Dochgarroch
Inverness, IV3 8GY
SCOTLAND, UK

Dublin, Ireland
First Floor, Suite 6, The Mall,
Beacon Court, Sandyford,
Dublin 18
IRELAND

Aberystwyth, Wales
Harbour House, Y Lanfa
Aberystwyth, Ceredigion
SY23 1AS
WALES, UK

London, England
Token House Business Centre
11/12 Tokenhouse Yard
City of London, EC2R 7AS
ENGLAND, UK

Newcastle, England
Unit 5, Horsley Business Centre
Horsley
Northumberland, NE15 0NY
ENGLAND, UK

EUROPE

Paris, France
4 Place de l'Opéra
75002 Paris
FRANCE

Nantes, France
1 boulevard Salvador Allende,
44100 Nantes
FRANCE

Ankara, Turkey [Agent]
re-consult
Bagi's Plaza
- Muhsin Yazıcıoğlu Cad. 43/14
TR / 06520 Balgat-Ankar
TURKEY

THE AMERICAS

New York, USA
63 Franklin St
Saratoga Springs, NY 12866
USA

Seattle , USA
2701 First Avenue, Suite 440
Seattle, WA 98121
USA

Valparaiso, Chile [Agent]
Latwind Energías Renovables
Lautaro Rosas 366, Cerro Alegre
Valparaiso, CHILE

naturalpower.com
sayhello@naturalpower.com

we are ISO 9001:2008 certified (NPC - UK & Ireland) (NPS - UK)

we are ISO 14001:2004 certified (NPC - UK & Ireland) (NPS - UK)

UVDB Verify empowered by Achilles Verified

IEMA Transforming the world to sustainability - EIA -