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Reference: Andrew Topsides and Jacket Decommissioning Programme Public Consultation

Dear Stewart

Drill Cuttings Disturbance during Andrew Jacket Removal

Please find attached the Drill Cuttings dispersion modelling reports for consideration as part of the decommissioning programmes public consultation.

These reports submitted in support of the decommissioning programmes detail the full extent of the drill cuttings that will be required to be displaced as part of the overall decommissioning scopes for Andrew that will be covered by two separate decommissioning programmes.

The extent of the disturbance for the Andrew Topsides and Jacket decommissioning programmes will be limited to the drill cuttings that sit on or around the mudmats on the jacket structure (240m2 each) this equates to a total disturbance of drill cuttings of approximately 10% of the modelled disturbance volume for the removal of the drilling template that will be covered within the separate submission for the Andrew Subsea infrastructure.

Sincerely,

Phil Brunton
HSE&C Lead
08 September 2026

REPORT

Andrew Cuttings Pile Dispersion Modelling

Prepared for: **BPEOC**

Prepared by: **Genesis Energies**

www.genesisenergies.com

Project Title: **Andrew Topsides and Jacket Decommissioning**
Document / Rev No.: 218416C-000-RT-6200-0002/ 2
Client Document No.: DC104-EV-REP-040-00002

Revision No. bp	Revision No. Genesis	Date	Description	Issued by	Checked by	Approved by	Client Approval
A01	A	09/12/2024	Issued for client review	CMc	AR	SO	
-	1B-2B	20/02/2025	Issued for internal review	CMc	DMCS		
A02	B	27/02/2025	Issued for client review	CMc	DMCS/MOS	SO	
C01	0	12/06/2025	Issued for use	CMc	CH	SO	
C02	1	08/04/2026	Re-issued for Use	CMc	AR	SO	
C03	2	14/08/2026	Re-issued for Use	SO	IY	SO	

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ABBREVIATIONS

%	Percent
‰	Parts per thousand
<	Less Than
>	Greater Than
°C	Degrees centigrade
µm	Micrometre
APE	alkylphenol ethoxylates
BAC	Background Assessment Criteria
BAT	Best Available Technique
BEP	Best Environmental Practice
BPEOC	bp Exploration Operating Company Limited
BTEX	Benzene, Toluene, Ethylbenzene and Xylene
CFSR	Climate Forecast System Reanalysis
cm	centimetre
CNS	Central North Sea
CoP	Cessation of Production
DREAM	Dose-related Risk and Effects Assessment Model
EA	Environmental Appraisal
EAC	Environmental Assessment Criteria
ED	European Datum
ERL	Effects Range Low
ERMS	Environmental Risk Management System
FRS	Fisheries Research Service
g/cm^3	Grams per cubic centimetre
HYCOM	Hybrid Coordinate Ocean Model
IOGP	International Association of Oil & Gas Producers
km	Kilometre
K_{OC}	Organic carbon water partition coefficient
K_{OW}	Octanol-water partition coefficient
LAT	Lowest astronomical tide
LC_{50}	Lethal Concentration 50 %
LTOBM	Low toxicity oil-based mud

m	Metre
m^3/hr	Cubic metres per hour
MBES	Multi-beam echo sounder
MEMW	Marine Environmental Modelling Workbench
mg/kg	Milligrams per kilograms
mm	Millimetre
mm/s	Millimetre per second
NCEP	National Centre for Environmental Prediction
NCMPA	Nature Conservation Marine Protected Area
ng/g	Nanograms per grams
NMPi	National Marine Plan interactive
NP	nonylphenol
NPD	Naphthalenes, phenanthrenes and dibenzothiophenes
OBM	Oil-based mud
OP	octylphenol
OPF	Organic Phase Drilling Fluids
OSCAR	Oil Spill Contingency and Response
OSPAR	Convention for the Protection of the Marine Environment of the North-East Atlantic
PAH	Polycyclic aromatic hydrocarbons
PCB	Polychlorinated biphenyls
PEC	Predicted Environmental Concentration
PEC_{sed}	Predicted Environmental Change
PNEC	Predicted No Effect Concentration
$PNEC_{sed}$	Predicted No Effect Change
ppb	Parts per billion
PSD	Particle Size Distribution
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals
ROV	Remotely Operated Vehicle
STS	Subsea Tooling Services
t	Tonnes
THC	Total Hydrocarbon
UCM	Unresolved Complex Mixture

UK	United Kingdom
UKCS	United Kingdom Continental Shelf
UKOOA	United Kingdom Offshore Operators Association
UTM	Universal Transverse Mercator
WBM	Water-Based Mud

1.0 INTRODUCTION

1.1 Background

The Andrew area comprises a number of fields including Andrew, Cyrus, Farragon, Kinnoull and Arundel. All of these fields produce over the Andrew platform which is located *c.* 198 km north-east of the Scottish coastline and *c.* 23 km from the United Kingdom (UK)/Norway median line. The water depth at the field is *c.* 117 m lowest astronomical tide (LAT) and the associated infrastructure span across United Kingdom Continental Shelf (UKCS) Blocks 16/22, 16/23, 16/27 and 16/28 (Figure 1-1). bp Exploration Operating Company Limited (BPEOC) are currently preparing to decommission the Andrew area.

During decommissioning, the recovery of the Andrew jacket, a drilling template located beneath the platform and the pipeline and umbilical ends in closest proximity to the platform will result in a disturbance to the drill cuttings pile located beneath the Andrew platform.

BPEOC have commissioned Genesis to undertake modelling of the disturbance of the Andrew drill cuttings pile to support:

- A Best Available Technique/Best Environmental Practice (BAT/BEP) assessment to assess the optimal approach for decommissioning the cuttings pile;
- The Environmental Appraisals (EA) that will be submitted to support the Decommissioning Programmes[1].

This report presents the results of the modelling carried out as described in Section 1.3.

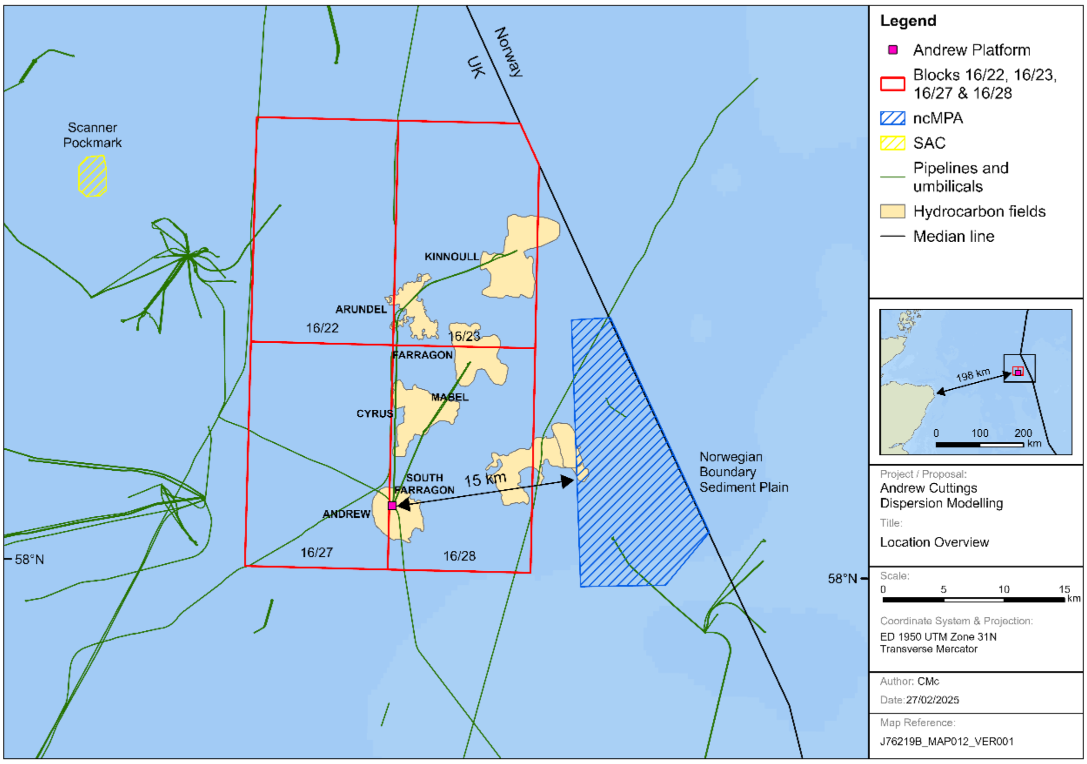


Figure 1-1 Andrew field location

[1] It has been agreed with the Offshore Petroleum Regulator for Environment and Decommissioning (OPRED), that the proposed decommissioning activities will be captured over two Decommissioning Programme (DP) submissions: one capturing the Andrew platform (topsides and jacket) and one capturing the subsea infrastructure for the five fields.

First oil at the Andrew field was in 1996. The Andrew area is currently in operation with a forecast Cessation of Production (CoP) in March 2027.

In total, 17 platform wells were drilled at Andrew from 1994 to 2017, 15 oil producing, one gas producing and one gas injection well. Some of these wells are likely to have been drilled using oil-based mud (OBM) and therefore, in addition to water-based mud (WBM), contaminated cuttings will have been discharged to the seabed prior to 2001. It is also possible that synthetic based muds and low toxicity oil-based muds (LTOBM) may have been discharged. Note that after 2001 OBM could no longer be discharged to the seabed as a result of the prohibition of discharge to the marine environment of drill cuttings contaminated with more than 1% oil by weight of oil-based fluids on dry cuttings (*OSPAR Decision 2000/3 on the Use of Organic Phase Drilling Fluids* [OPF] and *the Discharge of OPF-Contaminated Cuttings*) came into force on 16 January 2001.

Table 1-1 summarises the dimensions of the Andrew cuttings pile as determined by the cuttings survey (Subsea7, 2019) including an estimated cuttings oil content.

Table 1-1 Andrew cuttings pile characteristics

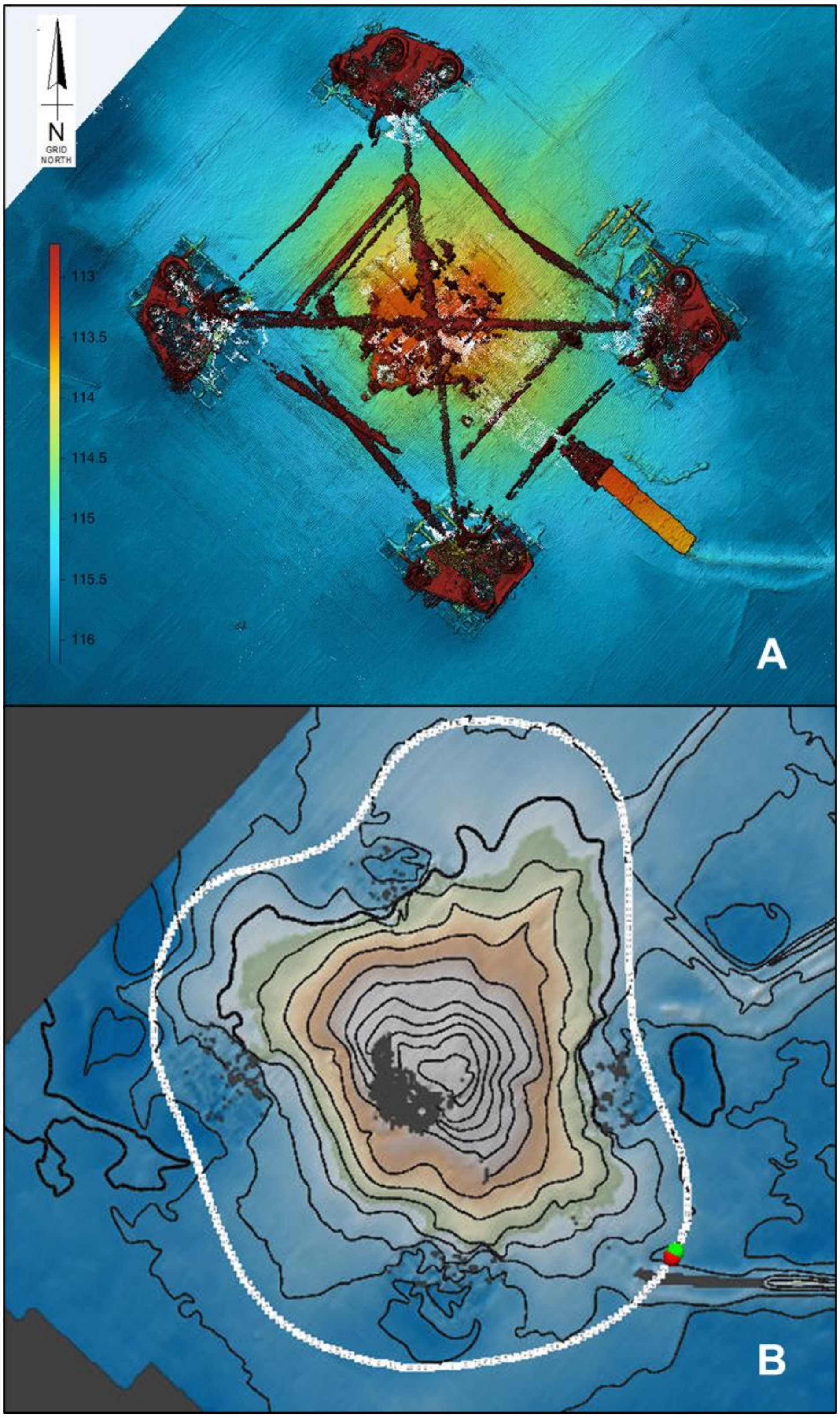
Name	Estimated Area (m^2)	Estimated height (m)	Estimated volume (m^3)	Estimated THC content (t)[1]
Andrew	5,280.89	2.34	3,212.93	14.71

Note:

[1] Estimated total hydrocarbon (THC) content is calculated based on the maximum THC concentration reported in the Andrew cuttings samples and estimated wet bulk density of the cuttings pile, in line with modelling inputs (see Section 3.7).

A bathymetric multi-beam echo sounder (MBES) survey and visual inspection of the Andrew cuttings pile was conducted and the Volume Calculation Utility in NaviModel reported the overall area of 5,280.89 m^2 and the calculated volume of 3,212.93 m^3 (Subsea7, 2019). The Andrew cuttings pile is considered to be a “small cuttings pile” (<5,000 m^3) according to the Norwegian Oil and Gas Association Guidance (Norsk Olje & Gass, 2016). This report captures the results of the modelling carried out to determine the impact of disturbing the Andrew cuttings pile when recovering the Andrew jacket and template.

Figure 1-2 shows the likely extent of the cuttings pile around the Andrew jacket and template based on the MBES survey (Subsea7, 2019).



Source: Subsea7, 2019.

Figure 1-2 A) Drill cuttings mound MBES Image, B) Drill cuttings pile boundary

1.2 OSPAR Threshold for Cuttings Piles

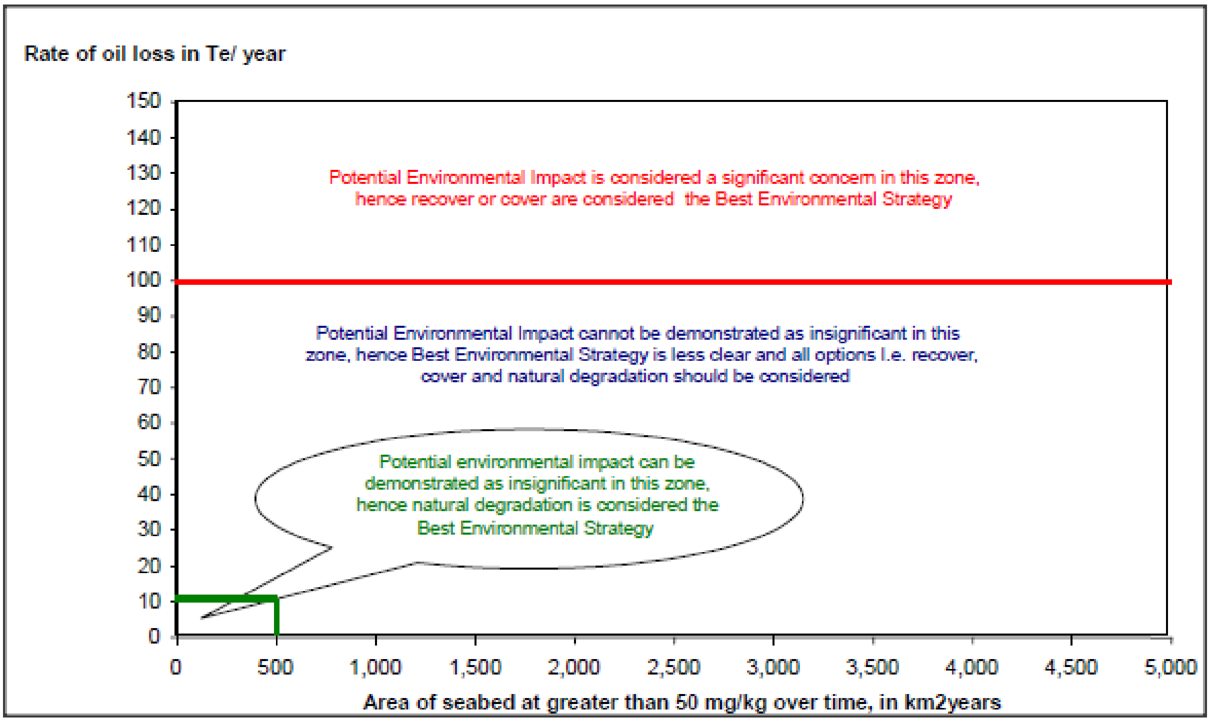
In 2006, the Oslo Paris Convention (OSPAR) agreed Recommendation 2006/5 (OSPAR, 2009a) on a Management Regime for Offshore Cuttings Piles. Stage 1 required the assessment of drill cuttings piles against two criteria. The criteria relate to the rate of oil loss from the cuttings pile and the persistence of the cuttings piles. Thresholds for each were set as follows:

- The rate of oil loss from the cuttings pile to the water column should be less than 10 t/year; and
- The persistence of the area of contaminated seabed should be less than 500 km^{2}years. This is based on the area of the seabed where contamination of oil in surface sediments is above 50 mg/kg and the rate at which this area reduces.

Where both the rate and persistence are below the set thresholds and no other discharges have contaminated the cuttings pile, no further action is considered necessary and the cuttings pile may be left in situ to degrade naturally (Figure 1-3).

The survey results have been used to assess the Andrew cuttings pile against the OSPAR thresholds. The Andrew cuttings pile falls below the OSPAR thresholds with a rate of oil loss to the water column of 0.24 t/year and a 50 mg/kg sediment hydrocarbon footprint of 0.26 km^2 (Fugro, 2019). Therefore, if left undisturbed no further action would be required to manage this pile.

However, as the Andrew jacket and drilling template will be removed as part of decommissioning, this will result in disturbance of the cuttings piles which will result in increased leaching of contamination from the pile, therefore further assessment has been carried out to determine the likely environmental risk and help inform the Environmental Appraisal (EA).



Source: UKOOA, 2005

Figure 1-3 OSPAR identified management strategies relating to historic drill cuttings piles.

1.3 Scope of Work

bp are currently assessing the Best Available Technique/Best Environmental Practice (BAT/BEP) for managing the Andrew cuttings pile. Any management option considered must take account of the inevitable disturbance to the cuttings pile associated with the recovery of the jacket, drilling template and the pipeline and umbilical ends covered with cuttings.

This study examines the effects relating to the disturbance of the drill cuttings pile for two key scenarios:

- Scenario 1: The anticipated worst-case scenario of spreading 100% of the cuttings pile (3,212.93 m^3) to support the assessment of the option of spreading the whole pile to promote the natural breakdown of hydrocarbons; and
- Scenario 2: Relocation of 40% of the cuttings pile (1,285.17 m^3) to recover the jacket, drilling template and pipeline and umbilical ends covered with cuttings. A disturbance of 40% to the cuttings pile was estimated based on internal cutting of the jacket piles. These modelling results will be used to support the assessment of the option to leave the cuttings pile in situ after the decommissioning activities are completed.

No allowance has been made for disturbance to the natural underlying sediment beneath the Andrew cuttings pile in the model.

Drill cuttings modelling was used to predict the fate of cuttings following disturbance associated with decommissioning of the Andrew jacket and drilling template.

The model was used to analyse:

- Depositional thickness on the seabed;
- Environmental risk to the seabed resulting from burial thickness, particle size change, toxicity and pore water oxygen depletion; and
- Environmental risk in the water column resulting from toxicity and particle stresses.

The outcomes of the assessment will be used to support the Andrew decommissioning EA.

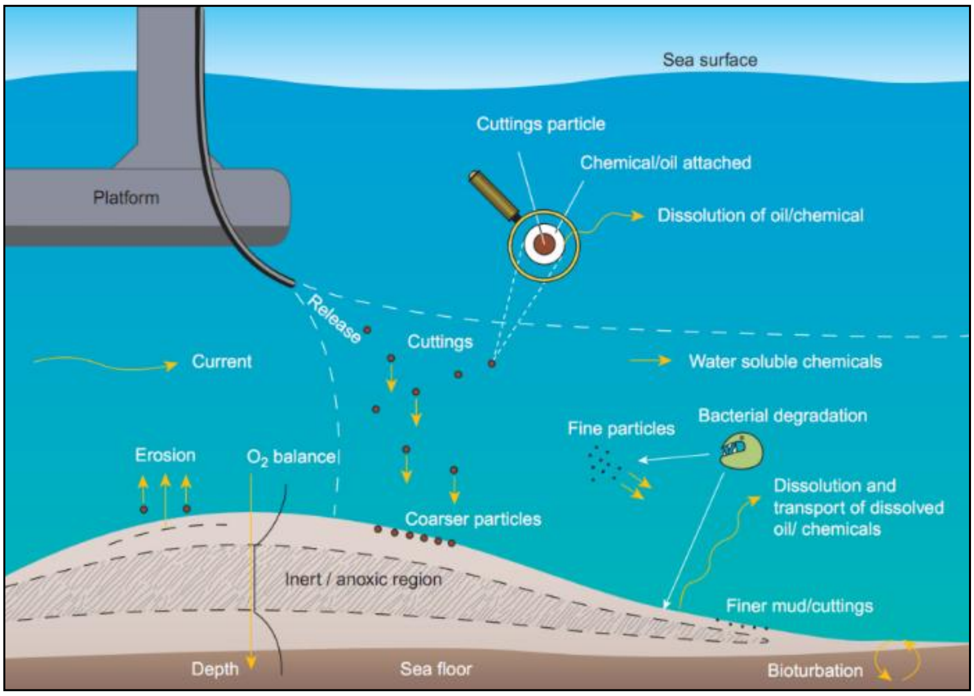
The details of the modelling inputs and outputs are presented in this report.

2.0 OVERVIEW OF THE MODELLING METHODOLOGY

2.1 DREAM/ParTrack

Disturbance of the cuttings on the seabed was modelled using Dose-related Risk and Effects Assessment Model (DREAM) published by Sintef, as part of the Marine Environmental Modelling Workbench (MEMW) suite of models, version 15.0.0. This incorporates the ParTrack sub-model for modelling dispersion and settlement of solids. The model predicts the fate of materials discharged to the marine environment, specifically their dispersion and changes to their physicochemical composition.

The model has been developed to calculate the dispersion and deposition on the seabed of drilling mud and cuttings as well as the dispersion of chemicals in free water masses. The model consists of a plume model and a far-field model. The calculations are based on the "particle" approach, combined with a near field plume model and the application of external current fields for the horizontal advection of the particles. The plume model takes into account effects from water stratification on the near-field mixing, ambient currents and geometrical configuration of the outlet. Once plume advection ceases, particles fall out of the plume and deposit on the seabed. Vertical velocity (rise/fall) of the particles depends on their size and density as well as on the agglomeration of solids in the presence of oil-related components. The far-field model includes the downstream transport and spreading of particles and dissolved matter, once the plume mode is terminated. The processes involved are illustrated in Figure 2-1.



Source: Rye *et al.* (2006)

Note: In the case of cuttings redistribution, the release is not from a platform, as shown, but from a separate dredger, which in this study is approximately 50 m from the outer edge of the Andrew template.

Figure 2-1 Processes involved in the DREAM model

Model predictions have been validated through field measurements at the Troll-A field in the Norwegian Sea, where reasonably good correspondence was obtained between measured and simulated deposition of the cuttings on the sea floor (Rye, 2010; Jødestøl and Furuholt, 2010).

2.2 Risk Assessment Method

The risk assessment method was initially developed for assessing impacts due to the discharge of toxic stressors (i.e. chemicals) to the marine environment or particle stressors (e.g. barite and bentonite) and was primarily intended for the assessment of produced water and other chemical discharges.

The methodology is based on a comparison of modelled concentrations of chemicals in the water column (termed the Predicted Environmental Concentration, (PEC)) and the highest theoretical concentration of the same chemicals at which harmful effects are not expected to occur in marine organisms (termed the Predicted No Effect Concentration, (PNEC)). In cases where the ratio PEC:PNEC exceeds 1, a risk to at least 5% of the most sensitive species occurs. This methodology is used by the DREAM/ParTrack model to calculate the risk to the water column due to toxicity from chemicals in drill cuttings discharges.

The protocol for assessing risks from drill cuttings discharges was further developed by the Environmental Risk Management System joint industry project to include the assessment of risk to seabed sediment and was founded on well-established scientific studies such as those in Smit *et al.* (2006), Trannum (2004), Kjeilen-Eilertsen *et al.* (2004) and Neff (2005). The assessment methodology for sediments is similar to that for the water column and is based on a combined risk approach using the PEC_{sed}:$PNEC_{sed}$ ratio. However, for sediments PEC_{sed} represents the Predicted Environmental Change (as opposed to predicted environmental concentration used for water column), and $PNEC_{sed}$ is the Predicted No Effect Change (as opposed to Predicted No Effect Concentration used for water column). Where PEC_{sed}: $PNEC_{sed}$ exceeds 1, a risk to at least 5% of the most sensitive species occurs. Where there is a risk to less than 5% of the most sensitive species, this is considered a tolerable risk level.

Trannum (2004), Kjeilen-Eilertsen *et al.* (2004) and Neff (2005) established that in the absence of any other stressors sediment risk would exceed 5% when:

- Chemical concentrations in pore water exceeded the PNEC;
- Burial thickness exceeded 6.5 mm;
- Median grain size change exceeded 52.7 µm; and
- Oxygen content was depleted by more than 20%.

The effects of burial include mortality of organisms, reduced growth of some species, reduced larval settlement and changed fauna composition. Effects can be short-term and mainly on an individual level, or they can be more long-term and affecting whole populations (Kjeilen-Eilertsen *et al.,* 2004). In general, the effect of burial mainly depends on the mobility of organisms in the sediment matrix and on the settling rate of particles. Sedentary organisms, which have no or very limited ability to move, such as attached barnacles or mussels, are very sensitive (Smit *et al.,* 2006).

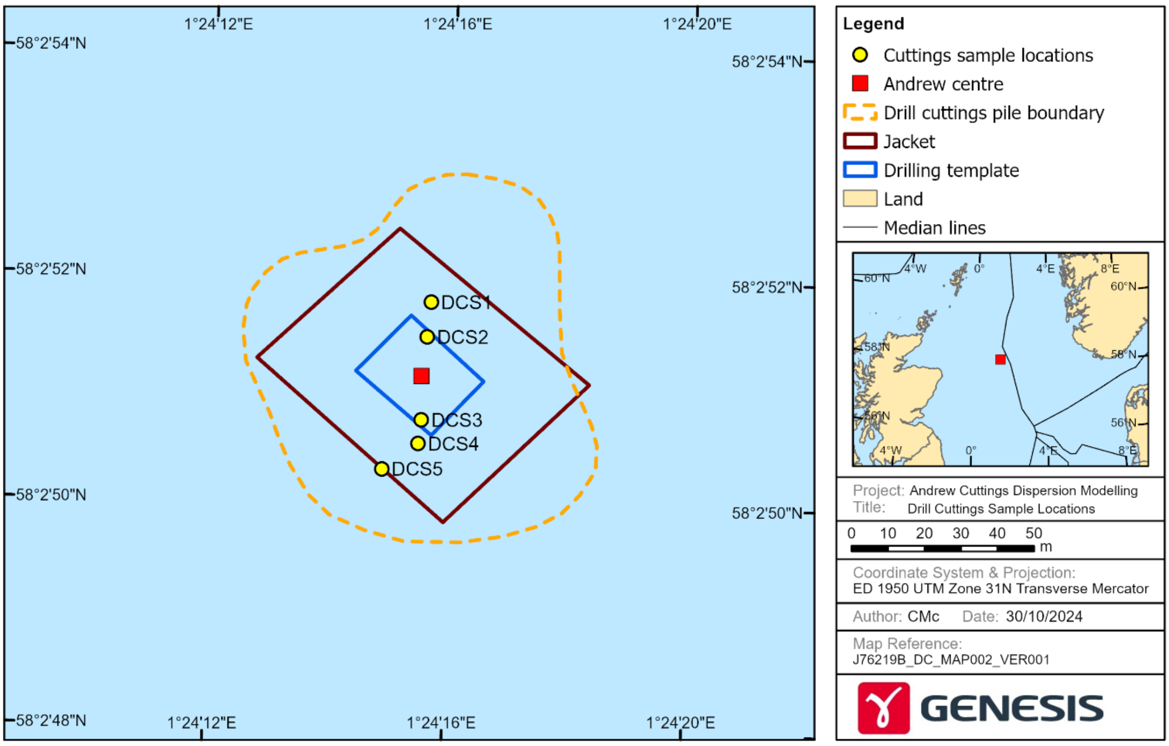
Following the settlement of drilling particles, benthic communities have been observed to be dominated by opportunistic species which generally are small, with short life spans and high population growth rates. There is considerable variability in species responses to specific sediment characteristics. The factors ultimately controlling infauna distributions may not be sediment grain size *per se* or factors linked to grain size such as organic content, but rather interactions between hydrodynamics, sediments and infauna and how these affect sediment distribution, larval supply, particle flux and pore water chemistry (Smit *et al.,* 2006). DREAM uses the change in median grain size to represent the overall changes in sediment characteristics.

3.0 MODEL INPUT DATA

Geophysical survey data from the pre-decommissioning survey was used to estimate the dimensions of the Andrew cuttings pile (Subsea7, 2019):

- Volume: 3,212.93 m^3
- Area: 5,280.89 m^2
- Maximum height (above mean seabed): 2.34 m

The characteristics of the cuttings pile represented in the model are based on the sampling data reported in the bp Andrew Decommissioning Consultancy Desk Study (Fugro, 2019). This is explained in detail in the following sections. A summary of sample locations, bathymetry and cuttings pile location at the Andrew template are shown in Figure 1-2 and Figure 3-1.



Note: Cuttings pile boundary is approximate based on survey data.

Figure 3-1 Sampling locations around the Andrew jacket and drilling template.

3.1 Model Scenarios

This study examines the effects relating to the disturbance of the drill cuttings pile for two key scenarios:

- Scenario 1: The anticipated worst-case scenario of spreading 100% of the cuttings pile (3,212.93 m^3) to support the assessment of the option of spreading the whole pile to promote the natural breakdown of hydrocarbons; and
- Scenario 2: Relocation of 40% of the cuttings pile (1,285.17 m^3) to recover the jacket and drilling template where the jacket legs are planned to be cut internally with negligible disturbance to the cuttings pile. The disturbance to 40% of the pile arises from the cuttings falling off each mud mat during the jacket lifting operation followed by suction dredging the cuttings at the two pipeline tie in points and the drilling template to facilitate the removal of the drilling template.[2]

Maximum values for the concentrations of chemicals from the sample analysis (Fugro, 2019) were used to determine a worst-case chemical composition of the cuttings pile (see Section 3.7).

3.2 Metocean Data

3.2.1 Currents and Winds

The study draws on three-dimensional water column current data (daily resolution) obtained from the Hybrid Coordinate Ocean Model (HYCOM). May 2010 data was used for the model as it is representative of calmer conditions, based on known weather patterns in the North Sea. This is likely to result in less dispersion and therefore more likely to lead to higher concentrations of contaminants and greater thicknesses of redeposited cuttings.

At this stage it is not known when operations to relocate the cuttings will take place, but they are most likely to be undertaken during the Spring/Summer months when the weather is calmer.

The study draws on two-dimensional wind data obtained from the National Centre for Environmental Prediction (NCEP) Climate Forecast System Reanalysis (CFSR). In line with the current data, May 2010 was used.

The wind data is used to generate wave height predictions within the model that feed into surface dispersion and resurfacing calculations.

3.2.2 Temperature and Salinity

Water column temperature and salinity profile information is used in the modelling. Local salinity and temperature data for surface and bottom waters was obtained from Scottish Government's National Marine Plan Interactive (NMPi) maps (Berx and Hughes, 2009). In line with the current and wind data May 2010 averages for the area were used.

The average sea temperature in May varies from 6.44°C at the seabed to 8.2°C at the sea surface. Salinity variation in the water column is minimal and an average value of 35.0‰ was used at the surface and the seabed.

[2] There may be differences in the template removal approach; however, this is not expected to significantly change the results of the modelling in Scenario 2.

3.3 Bathymetry

Bathymetry data used in the DREAM model is based on the Sea Topo 8.2 database (Jakobsson *et al.,* 2008).

3.4 Seabed Sediments

DREAM requires an average grain size of surrounding sediments to evaluate the change in grain size distribution as a result of the drill cutting discharge.

A total of 10 samples were taken as part of the environmental monitoring survey around the Andrew template. Sediments across the Andrew survey area have a mean particle size of 63 µm (0.063 mm) (Fugro, 2019) and are predominantly very fine sand (Wentworth, 1922).

3.5 Particle Size Distribution

The model has a default particle size distribution (PSD) for drill cuttings that was obtained from a review of data from drilling in Norwegian waters during the development of the DREAM/ParTrack model (Saga, 1994). However, since PSD data is available for the Andrew cuttings pile from recent sampling, it is considered preferable to use this data. PSDs for barite and bentonite in the model are based on industry standard distributions. A single PSD for the cuttings was created based on the average PSD of the five cuttings samples. Table 3-1 summarises the Andrew cuttings PSDs used in the model taken from the survey data (Fugro, 2019).

Table 3-1 Cuttings PSD (Andrew cuttings pile)

Approximate% In Each Size Class[1]	Size Interval (µm)	Fraction (%)	Cumulative Fraction (%)
Fines (silt/clay) Up to 62.5 µm ~45%	1-3.91	9.19	9.19
	3.91 - < 15.63	15.77	24.96
	15.63 - < 31.25	9.26	34.22
	31.25 - < 63	10.93	45.15
Sand 62.5 µm to 2000 µm ~40%	63 - < 125	13.96	59.10
	125 - < 250	10.95	70.05
	250 - < 500	6.05	76.10
	500 - < 1,000	4.54	80.64
	1,000 - < 2,000	3.73	84.38
Gravel 2000 to 6000 µm ~15% Cobbles >6000 µm (% included in gravel)	2,000 - < 4,000	3.38	87.76
	4,000 - < 8,000	3.03	90.79
	8,000 – 16,000	9.20	100

Notes:

[1] Wentworth Scale (Wentworth, 1922) – note that size intervals used do not exactly match the divisions on the Wentworth scale therefore percentage within each size class is approximate.

3.6 Volume of Cuttings

The total volume of the Andrew cuttings pile was estimated to be 3,212.93 m^3 and the area of the seabed covered by the cuttings pile was estimated to be 5,280.89 m^2 (Subsea7, 2019). The volume and area estimates were calculated by Subsea7 based on MBES data using the Volume Calculation Utility in NaviModel.

In Scenario 1, disturbance to 100% of the cuttings pile has been modelled to represent a worst-case scenario.

For Scenario 2, it is expected that a maximum of 1,979.16 m^3 (40% of the total cuttings pile) would be disturbed during the lifting of the jacket and the dredging to access the pipeline tie in points and to remove the template. However, if the jacket legs cannot be cut internally more of the cuttings will need to be redistributed. Figure 3-2 shows the area of disturbance for each model scenario.

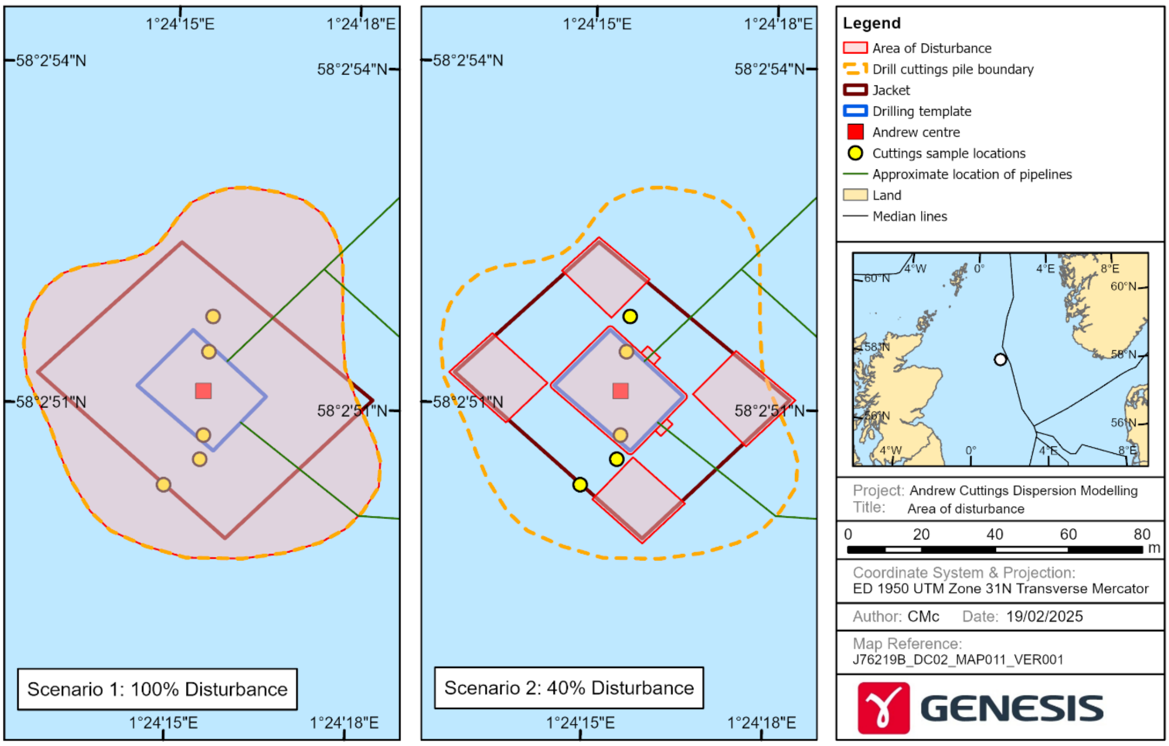


Figure 3-2 Extent of cuttings pile and modelled area of disturbance

At the time of modelling, it is not expected that significant volumes of underlying sediment will be disturbed therefore no underlying sediment has been included in the model for both scenarios.

3.7 Pile Composition

Cuttings piles are made up of a solid fraction, which in turn is made up of three fractions (cuttings/rock, barite and bentonite), and water. At the time of modelling there was limited moisture content information available for the Andrew cuttings pile with three of the five samples reporting a "high moisture content" in the Sample Microscopy Smear Slide Description (Subsea7, 2019). A conservative moisture content of 30% has been estimated based on a review of drill cutting accumulations in the Northern and Central North Sea where generally piles have 20-60% water content (Breuer *et al.*, 2024) and previous Genesis cuttings dispersion modelling experience in the North Sea with moisture contents ranging from 30-40%.

There was limited information available to determine the wet bulk density of the Andrew cuttings pile therefore, a conservative wet bulk density of 2.2 g/cm^3 was assumed. Similar assumptions have been made to estimate the wet bulk density that were made for the moisture content based on a review of drill cutting accumulations in the Northern and Central North Sea where piles generally have a bulk density of 1.6-2.3 g/cm^3 (Breuer *et al.,* 2024) and previous Genesis cuttings dispersion modelling experience in the North Sea with cuttings pile wet bulk densities ranging from 2.1-2.2 g/cm^3.

Using a lower moisture content along with a higher wet bulk density can be deemed a worst-case assumption in terms of sediment risk with a greater solid fraction of materials discharged along with greater masses of chemicals likely resulting in increased seabed deposition and chemical toxicity.

The estimated moisture content and wet bulk density are used to calculate the dry mass of the cuttings pile which in turn is used to calculate the mass of chemicals present based on the maximum concentrations (µg/g of dry sediment) of chemicals measured in the survey samples

The proportion of barite in the cuttings pile was calculated based on the concentration of barium measured during the survey, converted to the equivalent mass of barium sulphate (barite). Based on the maximum barium concentration in the Andrew cuttings pile, it was estimated that approximately 4.43% of the cuttings pile is made up of barite. This is lower than typical industry values for barite/bentonite content in drill cuttings piles (IOGP, 2003), which are typically: 75% cuttings, 20% barite and 5% bentonite, but are not unexpected given the proportions quoted by the International Association of Oil & Gas Producers (IOGP) are more relevant to WBM.

As no information was available for bentonite, the typical industry percentage (5%) quoted above was adopted.

Based on the above assumptions the Andrew cuttings pile composition used for the modelling is shown in Table 3-2.

Table 3-2 Andrew cuttings pile composition

	Solids				Water	Overall
Fraction (%)	70				30	100
	Cuttings	Barite	Bentonite	Chemicals		
% of Solids	90.05	4.43	5	0.52		
Mass – dry solids (t)	4,948					
Scenario 1: 100% Disturbance						
Mass – component parts (t)	4,455.62	219.36	247.40	25.53	2,120.53	7,068.45
Mass per discharge point[1] (t)	556.95	27.42	30.92	3.19	265.07	883.56
Scenario 2: 40% Disturbance						
Mass – component parts (t)	1,782.25	87.74	98.96	10.21	848.21	2,827.38
Mass per discharge point[1] (t)	222.78	10.97	12.37	1.28	106.03	353.42

Notes:

[1] Eight discharge points were assumed during redistribution (Section 3.8)

Typically, cuttings piles are made up of three layers (UKOOA, 2002 and Hayes & Galley, 2013):

- Top layer: an oxygenated surface layer;
- Middle layer: an oil contaminated core; and
- Bottom layer: a less contaminated base layer.

Given no deep cores were available, there was insufficient data to identify whether these layers are present in the Andrew cuttings piles, therefore, a single chemical composition was allocated to the full depth of the cuttings pile.

3.7.1 Chemical Components

Historically, a variety of different drilling muds have been used to drill the Andrew wells and these will have weathered over time. Initially, oil-based drilling fluids were used, then synthetic based muds.

Typically, the oil components used in OBM can be categorised into groups with similar properties (IOGP, 2003 and IOGP, 2016) including:

- Aliphatic oil, originally the principal component of the base oil;
- Benzene and alkylated benzene (Benzene, Toluene, Ethylbenzene and Xylene i.e. BTEX)
- Naphthalenes (including C1-C3 alkyl homologues), phenanthrenes and dibenzothiophenes (NPD); and
- Other polycyclic aromatic hydrocarbons (PAH) (i.e. excluding NPDs).

The survey data was used to establish concentrations of chemicals within the cuttings pile based on the samples taken from the cuttings pile. The chemicals make up approximately 0.5% by weight of the overall total for the cuttings pile and can be either attached to the cuttings and/or the barite and/or present as free chemicals.

As chemical analysis only exists for five surface samples of the cuttings pile (Fugro, 2019), the maximum concentration of each chemical from the available samples has been used to calculate the mass of each chemical discharged in the model. This is considered a worst-case representation of the chemical composition from the available sample data. In reality, the concentration of chemicals throughout the cuttings pile will vary significantly with sediment at the edge of the pile and in the bottom layer of the pile expected to have lower levels of chemical contamination. Therefore, the chemical contamination of the cuttings pile is likely being overestimated however without core samples of the pile, the levels of contamination within the pile are unknown.

Figure 3-3 shows the concentrations of THCs in the samples taken from the cuttings pile. THC concentrations range from 546 mg/kg to 4,450 mg/kg with an average of 2,473 mg/kg. All Andrew samples have a large proportion of Unresolved Complex Mixture (UCM), indicating degradation of the hydrocarbons over time (see Section 3.7.2).

The survey report gives an estimated area of 0.26 km^2 for which THC concentrations are greater than 50 mg/kg (Fugro, 2019). This was based on environmental survey data from 2000 taken at greater distances from the Andrew platform (Aquatera, 2007).

The area where THC concentrations are greater than 50 mg/kg indicate likely areas of impact to the benthos and is not directly equivalent to the area where there is a risk to more than 5%

sensitive species, as calculated by the model (see Section 4). The likely area of impact should be significantly smaller than the modelled area of risk as the latter incorporates a range of conservative assumptions.

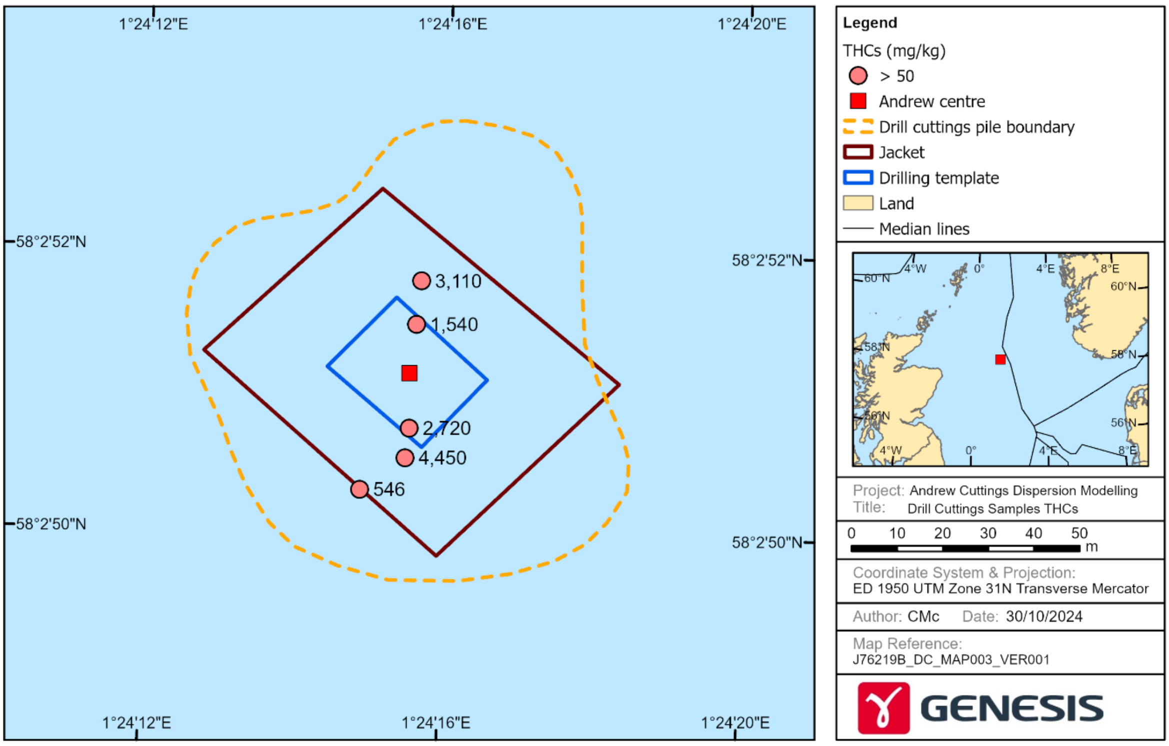


Figure 3-3 Distribution of THCs around Andrew cuttings pile.

Total PAHs in the cuttings samples ranged from 0.81 mg/kg to 3.46 mg/kg with an average concentration of 2.33 mg/kg however, it should be noted that no concentrations for naphthalenes have been included due to "matrix interference" (Fugro, 2019).

Polychlorinated biphenyls (PCBs) were also analysed. PCB concentrations were all below the Environmental Assessment Criteria (EAC) (OSPAR, 2009b). The EAC is defined in relation to chronic toxicity indicating that there are no long-term impacts from PCBs at the Andrew template. Furthermore, PCBs are known endocrine disrupters and were only used on North Sea installations prior to the mid-1980s (OSPAR, 2019) therefore it is expected that concentrations at Andrew are below the EAC. Similar levels of PCBs are seen at North Sea installations post the mid-1980s.

Total alkylphenol ethoxylates (APEs) concentration ranged from 118 ng/g to 3,110 ng/g (pre-normalisation) and showed moderate to high variation. Following normalisation to 1 % TOC, the PNEC was exceeded for octylphenol (OP) at all stations and for nonylphenol (NP) at two stations. Three stations exceeded the Class V (extensive toxic effects) threshold for NP (Fugro, 2019). The maximum concentrations from the cuttings samples for OP and NP are 26.3 ng/g and 1,940 ng/g respectively.

Organotins were analysed but concentrations were insignificant and therefore they have not been included in the model.

The following metals were measured in the samples: aluminium, arsenic, barium, cadmium, chromium, copper, iron, mercury, lithium, nickel, lead, titanium, and zinc. Overall, with the exception of barium (see below), metals form a relatively small proportion by weight of the chemicals present. Aluminium, iron, lithium and titanium have no readily available data on environmental toxicity against which to assess risk, and therefore were not entered in the model. To avoid entering too many components likely to have no or insignificant environmental impacts into the model, and so focus on the components most likely to contribute to the modelled environmental risk, only the metals for which the maximum concentration exceeded the Background Assessment Criteria (BAC) were entered. Therefore, cadmium, copper, mercury, lead and zinc were included in the model. All other heavy metals were not included as they are present in concentrations below the BAC.

Barium is the largest metal contaminant in the cuttings pile. However, it is not bio-available and has a low toxic potential (not included in OSPAR 2014-05 PNECs background document (OSPAR, 2014). The impact of the barium stems from the physical impact of the particles themselves and this is accounted for by the inclusion of barite (barium sulphate) in the model. Barium was therefore not entered as a separate chemical.

The behaviour of OBM contaminated cuttings in the water column is potentially complex and is discussed at some length in the Sintef Environmental Risk Management System (ERMS) project reports (e.g. Rye *et al*., 2006). In summary, the model applies algorithms to the overall discharge to agglomerate the particles according to the level of oleophilic compounds present (i.e. those with a high organic carbon water partition coefficient - K_{oc}). Assumptions also need to be made as to whether different chemical components (including oil-related components) will be associated with cuttings, or other solids e.g. barite, or whether they may be 'free' in the liquid to disperse. OBM is designed as a cohesive mixture that resists separation into components, but it is unclear whether this behaviour would remain in an aged cuttings pile, or whether in fact new associations would form between chemicals and solids over time. Judgement has been applied as follows in order to prepare a chemical profile that can be modelled:

- Components typically related to the base oil (alkanes, PAHs and NPDs) are treated in equal thirds as being attached to the cuttings, the barite and as a free component. This represents the original cohesive design of the mud mixture and its propensity to remain in contact with cuttings and solids, but also allowing for a component that is dispersed when resuspended during relocation operations; and,
- Metals are attached to barite, which relates to levels of metals known to be present in historic sources of barite.

All components can subsequently dissolve and partition into the water and sediments according to the model chemistry.

While this is an approximation, the sum of contaminants released in the model in total are equal to those indicated by the cuttings' samples. The separation made above is to match their dispersion behaviour more closely to expectations, given their origins and general physical and chemical properties, as they will be affected differently by the presence of solids and residual mud chemicals.

The main compositional input parameters are summarised in Table 3-3 and Table 3-4. Overall, the total mass of oil in the cuttings pile mostly comprises of UCMs.

Table 3-3 Total mass of chemicals – Scenario 1: 100% Disturbance.

Chemical	Dispersed oil	PAHs (minus NPD)	NPDs	UCMs	APEs (OP & NP)
	Chemicals attached to rock fraction, barite fraction and as free chemicals (split equally).				
Mass (t)	1.62	0.0106	0.0065	13.06	0.0096
Chemical	**Cadmium**	**Copper**	**Mercury**	**Lead**	**Zinc**
	Heavy metals attached to barite only.				
Mass (t)	0.0082	1.1430	0.0018	0.3548	1.9990

Table 3-4 Total mass of chemicals – Scenario 2: 40% Disturbance.

Chemical	Dispersed oil	PAHs (minus NPD)	NPDs	UCMs	APEs (OP & NP)
	Chemicals attached to rock fraction, barite fraction and as free chemicals (split equally).				
Mass (t)	0.649	0.0042	0.0026	5.225	0.0038
Chemical	**Cadmium**	**Copper**	**Mercury**	**Lead**	**Zinc**
	Heavy metals attached to barite only.				
Mass (t)	0.0033	0.4572	0.0007	0.1419	0.7996

The chemical groups listed in Table 3-3 and Table 3-4 have been aligned with representative substances within the DREAM model substance database which contains physical, chemical and biological properties for a variety of substances including oils. PNEC values have been drawn from the OSPAR list of PNECs in produced water (OSPAR, 2014) along with values from the OSPAR EAC and Effects Range Low (ERL) values. There is no consistent source of applicable PNECs that can be applied to this scenario hence a number of sources have been used.

EACs are defined by OSPAR and represent the contaminant concentration in the environment below which no chronic effects are expected to occur in marine species, including the most sensitive species. Therefore, concentrations below the EAC are considered to present no significant risk to the environment.

3.7.2 Unresolved Complex Mixtures

UCM is a term that encompasses mixed breakdown products of oil in the marine environment, especially over long periods of time in sediments. This material has a wide range of molecular masses and appears as a 'hump' in gas chromatogram results, in contrast to the distinct spikes that correspond to specific common reservoir hydrocarbon species.

UCM composition in oil-contaminated sediments is discussed in a number of papers and a typical summary of characteristics is given in (Brownawell *et al.*, 2007) which references other studies, and also reviewed in (Neff, 2002). The components of the UCM include alkanes, branched alkanes, cycloalkanes, mono aromatics, multi-ring aromatics, hetero atomic aromatics, steranes and cyclic triterpenoids. When crude oil or refined fuels enter the marine environment, the following occurs: evaporation removes the most volatile compounds; dissolution removes the more polar and water-soluble compounds; and biodegradation generally attacks the linear alkanes, branched alkanes, and then the cycloalkanes and aromatic compounds. These weathering processes produce the UCM which persists in sediments and has often been used as a marker for petroleum contaminated sediments. UCM concentrations in the sediment can be present at much higher levels than other traditional organic contaminants such as PAHs. Research has shown that components of the UCM may be the source of toxicity caused by weathered oils when the toxic effects are based upon a mass of known toxic components in oil (e.g. PAHs and phenols) (Neff & Ostazeski, 2000). Studies performed have also shown that the monoaromatic components of the UCM amongst other components produce a toxic response in *Mytilus edulis* in aqueous exposures at concentrations found in polluted environments (Rowland *et al*., 2011). The UCM is lipophilic and therefore can accumulate in the fatty tissues of benthic organisms like *M. edulis* which are continuously exposed to it in the environment.

Given their complex nature, there is a variety of data on environmental response levels for UCM material, and it is difficult to be certain of the relevance of UCM literature data in terms of its source – the oils present in the Andrew cuttings pile are derived from drilling base oils which will differ from oils in for example harbour sediments on which other studies are based. The PNEC is derived from a 50% Lethal Concentration (LC_{50}) of 50 parts per billion (ppb) for insoluble aliphatics with a carbon number higher than 10, which the UCM is assumed to consist of along with an assessment factor of 10, i.e. a PNEC of 5 ppb is adopted. Further information on the PNEC derivation is given in Section 4.5.

3.8 Redistribution of the Cuttings to the Adjacent Seabed

Modelling of the pile disturbance was undertaken assuming relocation of cuttings would take place using a suction dredger.

Data from technical data sheets provided by Subsea Tooling Services (STS) for the MKII T6 Predator Dredger were used to determine a representative pumping regime. A typical set up is shown in Figure 3-4 and further illustrated in Figure 3-5.

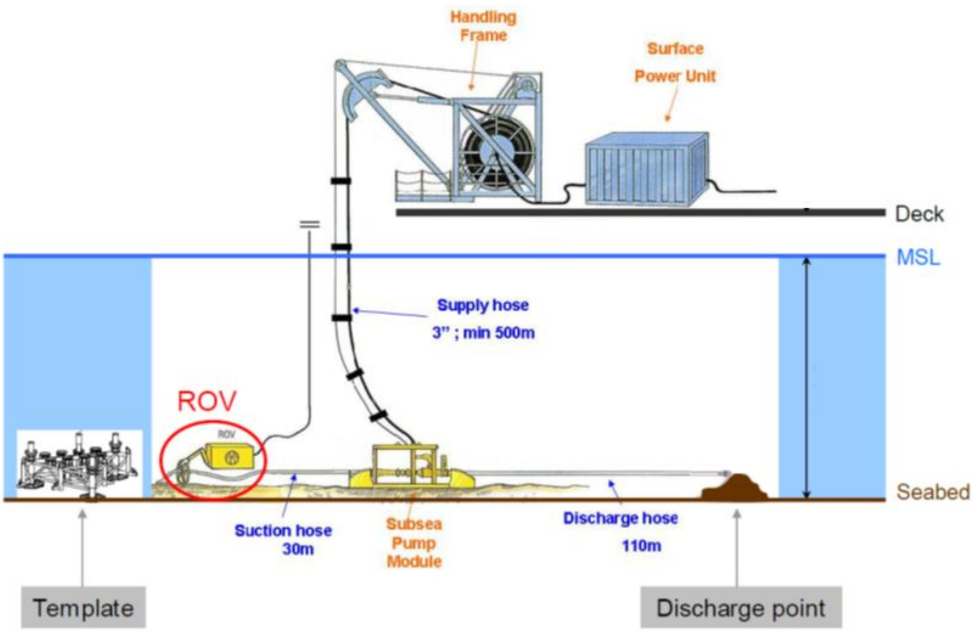


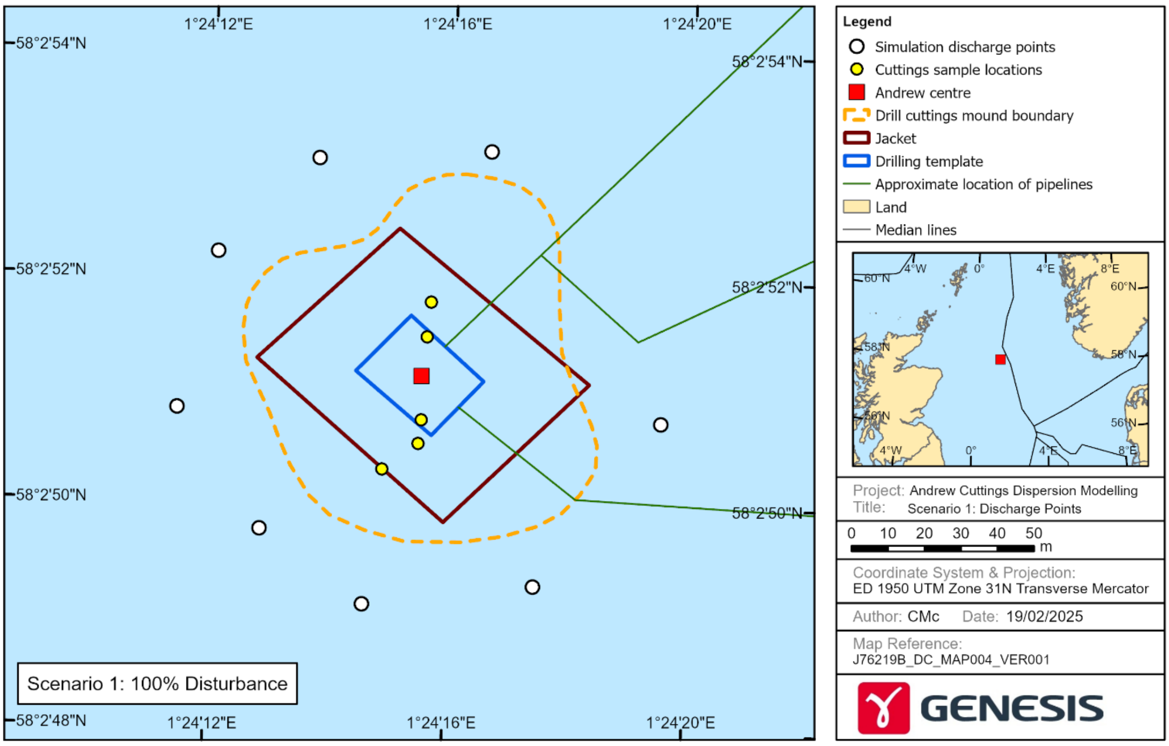
Figure 3-4 Schematic representation of redistribution of a cuttings pile using a dredger (dimensions of hoses are examples only)

(DNV, 2017b)

Figure 3-5 Photos of hose discharge and accumulation of cuttings at discharge point

3.8.1 Discharge Locations

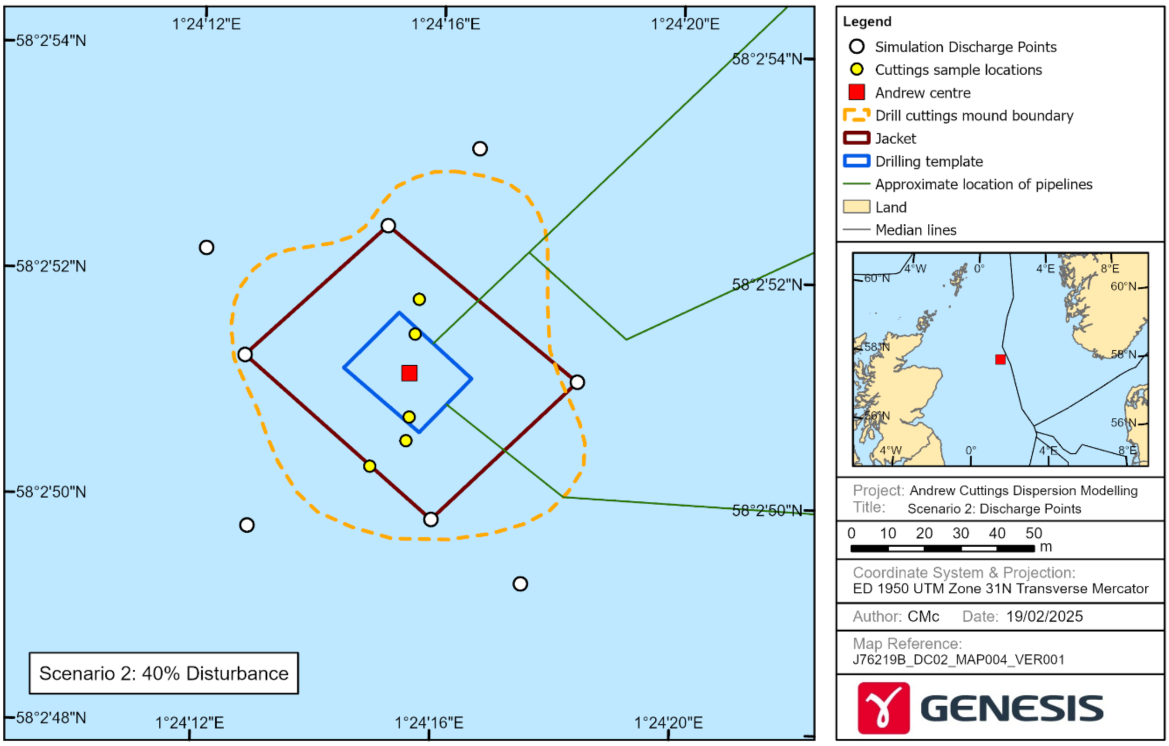
For Scenario 1 (100% disturbance), a single pumping regime was modelled to represent the whole pile being pumped to 8 separate locations, approximately 50 m from the Andrew template and avoiding subsurface infrastructure that may be removed after spreading the cuttings (see Figure 3-6).



Note: Pipeline locations are an approximate only.

Figure 3-6 Location of discharges in relation to the Andrew template – Scenario 1

For Scenario 2 (40% disturbance), the cuttings falling from the mud mats during the lifting of the jacket have been modelled as a discharge at each corner of the jacket. The cuttings from dredging to access the pipeline tie in points and to remove the template are modelled as being pumped to four separate locations, approximately 50 m from the Andrew template and avoiding subsurface infrastructure that may be removed after cuttings redistribution.



Note: Pipeline locations are an approximate only.

Figure 3-7 Location of discharges in relation to the Andrew template – Scenario 2

All discharges were assumed to be approximately 2 m above the seabed. This ensures that in practice during suction dredging the hoses do not become blocked with cuttings piling up in front of them. The same depth has been adopted for the cuttings falling from the mud mats (Scenario 2, points 1-4) as an appropriate approximation as to when the cuttings will fall during the lifting of the jacket. Discharge locations and orientations are detailed in Table 3-5.

Table 3-5 Discharge locations

Discharge point reference		Coordinates (WGS84)		Outlet orientation	Outlet angle (° from north)
Scenario 1	Scenario 2	Longitude	Latitude		
-	1	01° 24.1566' E	58° 02.8358' N	Vertical down	-
-	2	01° 24.2103' E	58° 02.8133' N	Vertical down	-
-	3	01° 24.1704' E	58° 02.7926' N	Vertical down	-
-	4	01° 24.1176' E	58° 02.8163' N	Vertical down	-
1	-	01° 24.1336' E	58° 02.8467' N	Horizontal	331
2	5	01° 24.1814' E	58° 02.8482' N	Horizontal	16
3	-	01° 24.2302' E	58° 02.8084' N	Horizontal	105
4	6	01° 24.1955' E	58° 02.7840' N	Horizontal	155
5	-	01° 24.1480' E	58° 02.7810' N	Horizontal	196
6	7	01° 24.1189' E	58° 02.7918' N	Horizontal	226
7	-	01° 24.0953' E	58° 02.8095' N	Horizontal	260
8	8	01° 24.1059' E	58° 02.8327' N	Horizontal	298

3.8.2 Discharge Timeline

A pumping rate of 50 m^3/hr for the cuttings was chosen based on the expected pumping rates of the STS Predator Dredger.

For Scenario 1 (100% disturbance), based on the volume of redistributed material and the pumping rate, the duration of each discharge was calculated to take approximately 0.74 days. A 0.26-day gap was included between discharges so that there would be 24 hours between the start of each discharge, resulting in the completion of spreading operations within 8 days. The model was run for a further 5 days following the end of dredging operations to allow for dispersion, giving a total model run time of 13 days.

For Scenario 2 (40% disturbance), the four discharges from lifting the jacket were modelled based on the volume of material on the mud mats and the “falling” rate (for modelling purposes assumed to be equivalent of the pumping rate), the duration of each discharge was calculated to take approximately 0.29 days. These four discharges were modelled simultaneously followed by the four discharge points from dredging operations (to access the pipeline tie-in points and the drilling template), resulting in the completion of relocation operations within 3 days. The model was run for a further 5 days following the end of dredging operations to allow for dispersion, giving a total model run time of 8 days.

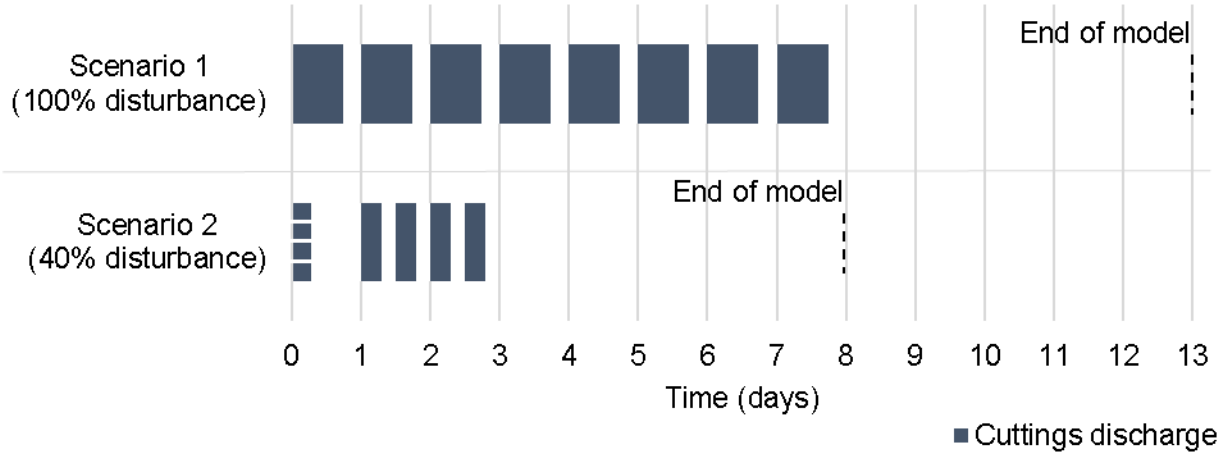


Figure 3-8 Modelled discharge timeline.

3.9 Model Configuration

A range of grid sizes and model timesteps have been used in order to optimise specific outputs, whilst not resulting in unmanageable model run times.

Different grid sizes were used to evaluate particle dispersion:

- Larger, coarser grid to evaluate risk of impacts to the water column; and
- Smaller, finer grids to evaluate impacts on the seabed.

This reflects the likely extent of particle dispersion. Water column dispersion of dissolved and suspended particles occurs over a wide area, whereas deposition of drill cuttings is a more localised event.

Different timesteps and overall model durations were used to allow short-term and long-term impacts to be investigated. A description of each configuration used is summarised in Table 3-6.

Table 3-6 Model configuration

Aspect	Domain Size	Cell Size	Time Step	Model Duration	Sediment risk model?
Scenario 1 (100% disturbance)					
Water column	30 km × 30 km	100 m × 100 m	30 mins	13 days	Not included
Seabed (risk)	10 km × 10 km	40 m × 40 m	2 hours	13 days plus 10 years[1]	Included
Seabed (thickness)	4 km × 4 km	10 m × 10 m	30 mins	13 days	Not included
Scenario 2 (40% disturbance)					
Water column	30 km × 30 km	100 m × 100 m	30 mins	8 days	Not included
Seabed (risk)	5 km × 6 km	20 m × 20 m	1 hours	8 days plus 10 years[1]	Included
Seabed (thickness)	4 km × 4 km	10 m × 10 m	30 mins	8 days	Not included

[1] Main DREAM model runs for 13 days for Scenario 1 and 8 days for Scenario 2 using timestep shown, followed by the sediment model which was run for 10 years using a 24-hour timestep.

4.0 MODEL UNCERTAINTIES

There are a number of uncertainties in an exercise of this type and conclusions should be drawn at a high level. The main uncertainties are discussed in the following sections, together with additional model runs undertaken to test the sensitivity of the model.

4.1 Relocation Technique

At this stage it is not known exactly what equipment will be used to undertake the cuttings relocation at Andrew. The modelling presented assumes that suction dredging would be used. The DREAM modelling software is based around a discharge of a given flow rate through a circular opening which has a specific diameter and orientation. This undergoes near-field dispersion using an algorithm known as PLUME3D, a good analogue for discharges through a pipe or hose and is similar to the outlet of a Remotely Operated Vehicle (ROV) used for dredging operations. Therefore, uncertainties around these aspects should be low.

Assumptions regarding the pumping rate have been made based on technical data sheets for typical dredging equipment that could be used on the project. A pumping rate of 50 m^3/hr for the cuttings was chosen based on the expected pumping rate of the STS Predator Dredger for sand. A small allowance has been made in the model for interruptions to pumping, to clear obstructions or to move between discharges (0.21-0.26 days), but in practice the relocation operations would likely take longer than modelled. Previous modelling and sensitivity runs at Murchison showed that the model was not particularly sensitive to the pumping rate (Hayes & Galley, 2013). It is therefore considered that these parameters are sufficiently well defined for the purposes of the modelling study.

Further assumptions have been made regarding the disturbance of the cuttings present on the mud mats. It has been assumed that cuttings are deposited vertically downwards, at each corner of the jacket 2 m above the seabed. The pumping rate of the dredger (50 m^3/hr) has been adopted as the rate of deposition of cuttings falling from the mud mats during the lifting of the jacket.

It is not expected that the pattern of deposition around the discharge points will vary significantly if a slightly different configuration of discharge points is used (for example additional discharge points, nearby locations, or slightly different orientation).

Given the volume of material around the Andrew template and the type of material, it is expected that the majority of the cuttings will be relocated using suction dredging, though limited use of jetting for specific areas is possible. Jetting uses pressurised water which would be applied to the drill cuttings, in order to re-suspend them into the water column and move them from their original position. Jetting is considered to be more efficient and have higher manoeuvrability than dredging but less control over the sediment settling area.

Modelling of jetting in DREAM is difficult as it requires a number of approximations to be made. Based on experiences of jetting and dredging, the long-term impacts on the seabed are likely to be broadly similar. Jetting may result in more disturbance to the water column (assuming the oil is more likely to dissociate from the solids due to the increased energy from the jetting), but this will be short-term only (DNV, 2017a). Short-term impacts on the seabed could extend over a slightly larger area for jetting relative to dredging, however long-term impacts on the seabed are likely to be similar or slightly reduced if the thickness of the redeposited cuttings is lower than for dredging.

4.2 Particle Size Distribution

The PSD for the cuttings was based on five samples taken from the Andrew template cuttings pile and the data is considered robust.

Grain size is not a dominant seabed stressor in the risk calculations, and practically, cuttings are from relatively well-defined sources (barite, bentonite and rock from a small range of geologies and specific drill bits) so a large variation would not be expected. Therefore, although refining the PSD may potentially affect the results, it is unlikely to affect the overall conclusions.

4.3 Metocean Data

Metocean data used was for the year 2010, starting in May. Use of a different start date or a different set of current data would result in small changes to the precise pattern of cuttings deposition, but the predicted extent of risk is likely to be of a similar magnitude.

4.4 Sediment Grain Size

Grain size change is an important parameter, and it should be noted that the thresholds for this parameter within the risk assessment are based on the analysis of environmental monitoring data from the Dutch section of the North Sea, the Norwegian Sea and the Barents Sea covering 300 species (Smit *et al*., 2006). There may be regional differences in prevailing fauna that would give different thresholds for the discharge location. However, the basis of the threshold is considered to represent the best available data and covers a wide range of benthic fauna.

The threshold for burial thickness is based on the probability that a specific species will escape a given depth of burial with both exotic (e.g. drill cuttings) and native sediments. The threshold was derived from the burial sensitivity of 33 species (Smit *et al*., 2006 and Kjeilen Eilersten *et al*., 2004).

4.5 Oil composition and Content

The survey report presents detailed results of the cuttings pile sampling and composition of the cuttings pile in the model is based on these results.

The biggest uncertainty lies around the fact that a very large proportion of the hydrocarbon fraction is classed as UCM i.e. unidentified hydrocarbons. The DREAM database contains physical and chemical properties for UCM, including a PNEC of 5 ppb which is conservative. It is, however, uncertain as to how representative of the actual material these properties are.

The Sintef chronic PNEC of 5 ppb is based on an acute LC_{50} of 50 ppb in the water column for relatively insoluble aliphatic oils with a carbon number higher than 10. Based on the biodegradation and K_{ow} value, Sintef has applied an assessment factor of 10 to derive a PNEC of 5 ppb. This value is reflected in other data in circulation such as Wolfe (1976) and Environment Canada (2009) that point to a chronic PNEC of 5 ppb in pore water being relevant for aliphatic hydrocarbons, so this is considered a reasonable basis in the absence of specific toxicity data for the material at this site. There are also other sources, such as OSPAR Agreement 2014/05, which reference a higher PNEC of 70.5 ppb, although the scientific panel responsible reported that only one reliable source was found for an aliphatic PNEC. Further, OSPAR Agreement 2014/05 is for the assessment of produced water where exposures are arguably relatively short-term, versus chronic exposure in sediment pore-water, and chronic

PNECs are often assumed to be an order of magnitude smaller than acute PNECs in the absence of other data.

The toxicity of the UCM component in the oil is potentially conservative as there is little applicable data for this component whose properties can vary from site to site. This leads to predictions of prolonged persistence in the seabed sediments. Additional toxicity testing could reduce this uncertainty and could lead to predictions of smaller areas of seabed at risk, and faster recovery times.

There are a range of PNECs available in the literature for contaminants in both water and sediments. OSPAR Agreement 2014/05 resulted from a lengthy process of expert consultation and drew on work undertaken within the auspices of the Water Framework Directive and the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) Regulation. Further iteration or sensitivity analysis of these PNECs would refine the outputs, but this is unlikely to change the finding relating to UCMs as the key risk factors in sediments.

4.6 Oil Sheen

DREAM does not model the formation of oily sheens on the sea surface. This process is modelled using OSCAR (Oil Spill Contingency And Response), another model under the MEMW suite. Therefore, the absence of a sheen as a result from this discharge cannot be verified with modelling in DREAM alone. However, given the high value of the partition coefficient for the oil on cuttings, most of the oil is retained on cuttings particles and any oil sheen that might form is expected to be short-lived and non-persistent.

4.7 Allocation of Contaminants to Solids

Over the life of the field, different contaminants have been released in different ways into the sediment, mainly in association with the drill cuttings and OBM. On discharge, contaminants may remain associated with the solids, and tend to settle out quickly, or may be freely available to disperse in the water column. There is relatively little published data on the relocation of oily drill cuttings and the behaviour of specific contaminants, therefore, assumptions have been made regarding the proportions of contaminants associated with the different fractions (rock/barite/water).

Overall, the total sum of contaminants released in the model is equal to the total measured in the cuttings samples so there is no ‘loss’ of contaminant. The majority of predicted risk is associated with UCMs, related to the base oil which was originally designed to be a cohesive mixture associated with the fine drilling solids and able to transport cuttings in circulation.

Should some components be more closely associated with the solids, they will deposit more closely to the release point, and conversely if some components were more freely dispersible then they would travel further.

4.8 Overall Uncertainty of the Modelling Process

The underlying model has a well-documented basis in the way the particle mechanics are handled, the physical, chemical and biodegradation and bioturbation processes involved, the significant sediment stressors and the way in which they are evaluated. Field data was used to generate the majority of the features of the model, including via the UKOOA JIP on drill cuttings, Phases 1-3 and the ERMS JIP. During model development, validation experiments were also conducted that tested aspects of the model. Input data for the model has been taken from known sources of information or recognised industry sources and contains several conservative assumptions that would overestimate the outputs.

5.0 RESULTS

5.1 Terminology

The results of the modelling runs are presented in the following sections in relation to seabed sediment impacts and water column impacts.

The following terms are used throughout:

- The maximum instantaneous risk is the area (in the case of seabed sediment) or the volume (in the case of the water column) where the risk to over 5% of the most sensitive species is greatest at a specific point in time during the simulation;
- The total risk is the overall area (seabed) or volume (water column) where there has been a risk to over 5% of the most sensitive species at any point in time during the simulation. This can also be referred to as the cumulative risk; and
- The maximum instantaneous risk and the total risk can be computed for individual stressors or for all stressors combined. Thus, combined sediment risk is the sum of the individual risks resulting from burial thickness, grain size change, oxygen depletion and toxicity of the cuttings.

5.2 Cuttings Thickness

Scenario 1 (100% disturbance)

The model predicts a maximum estimated thickness of cuttings around the discharge points after the end of dredging operations of 0.715 m (715 mm) (Figure 5-1 and Figure 5-2). Significant thicknesses (over 6.5 mm) are predicted to occur over an area of 0.0256 km^2 (up to approximately 250 m from the discharge locations). *A. islandica* have a high resilience to smothering up to 30 cm (Tyler-Walters & Sabatini, 2017) and thicknesses of over 30 cm are predicted to occur over an area of 0.004 km^2. To put this into context, a typical exclusion zone around a platform of 500 m radius is equivalent to an area of 0.785 km^2. Over time the area where thickness is greater than 6.5 mm gradually reduces, this is discussed in Section 5.3.

Very fine particles will spread over larger distances, extending beyond the model domain (4 km x 4 km) however, their distribution does not change significantly over time. If these very fine particles were to reach the Norwegian Boundary Sediment Plain NCMPA, which is located *c.* 15 km west of the discharges, any sediment that could settle would result in a depth of burial of <0.5 mm.

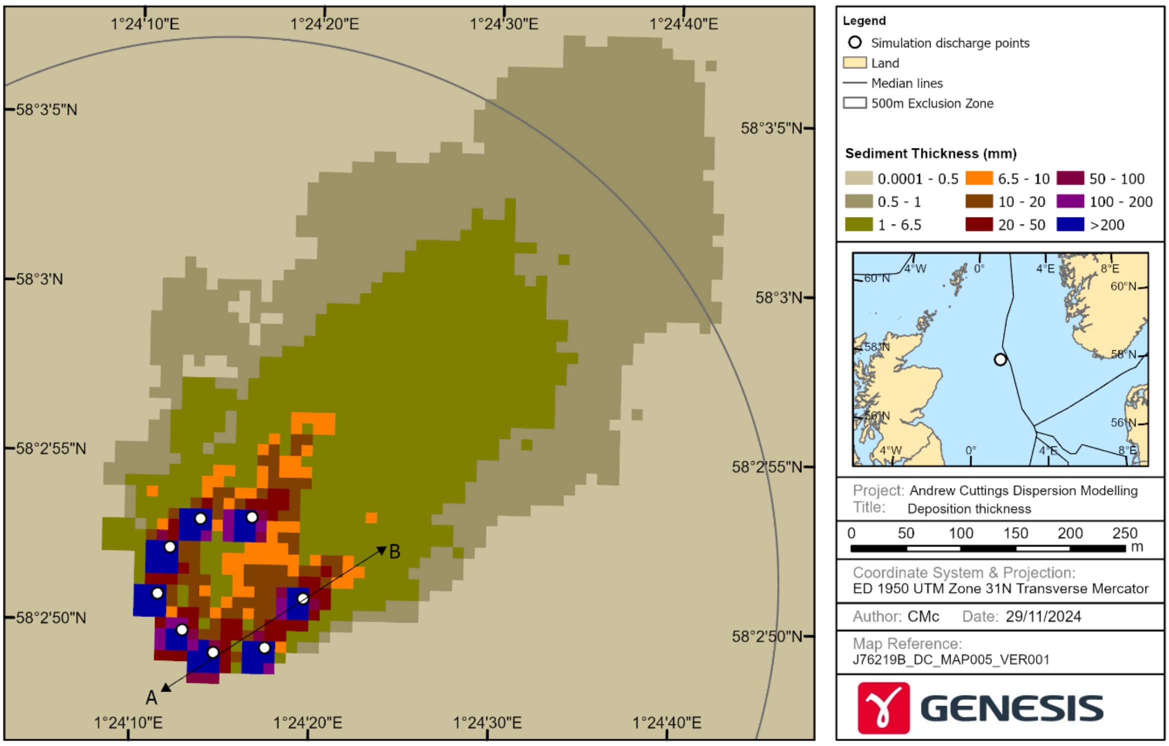
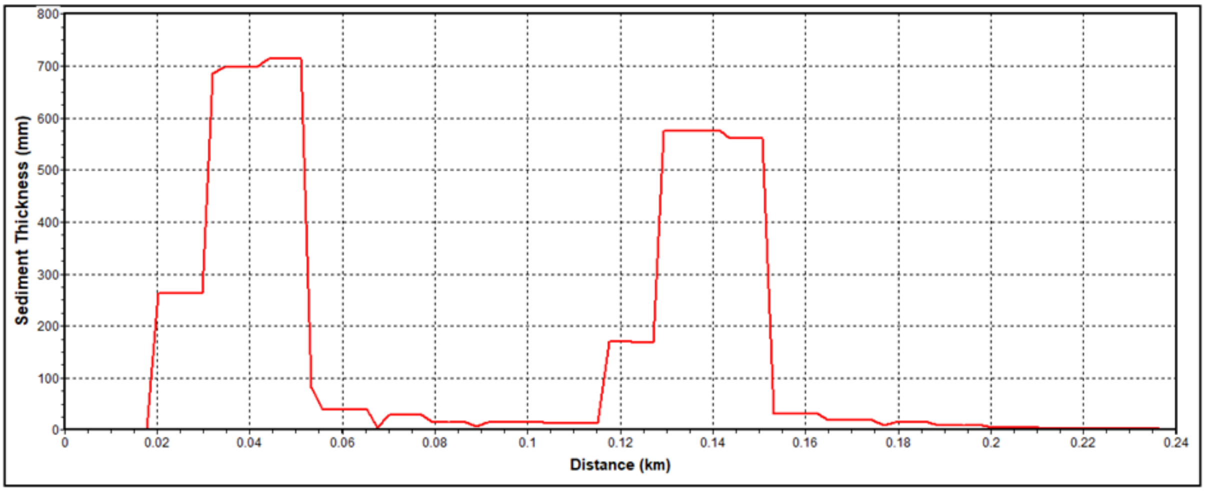


Figure 5-1 Deposition thickness around the discharge locations at the end of dredging – Scenario 1



Note: Coordinates of cross section: start point (1°24’06”E, 58°02’46”N) and end point (1°24’18”E, 58°02’50”N).

Figure 5-2 Cross section (A-B as shown in Figure 5-1) of deposition thickness at the end of dredging – Scenario 1

Scenario 2 (40% disturbance)

As expected, for the 40% disturbance case, deposition extends over a smaller distance given the smaller volume of cuttings relocated.

The model predicts a maximum estimated thickness of cuttings around the discharge points after the end of dredging operations of 0.334 m (334 mm) (Figure 5-3 and Figure 5-4). Significant thicknesses (over 6.5 mm) are predicted to occur over an area of 0.0106 km^2 (up to approximately 250 m from the discharge locations). *A. islandica* have a high resilience to smothering up to 30 cm (Tyler-Walters & Sabatini, 2017) and thicknesses of over 30 cm are predicted to occur over an area of 0.0001 km^2. Over time the area where thickness is greater than 6.5 mm gradually reduces, this is discussed in Section 5.3.

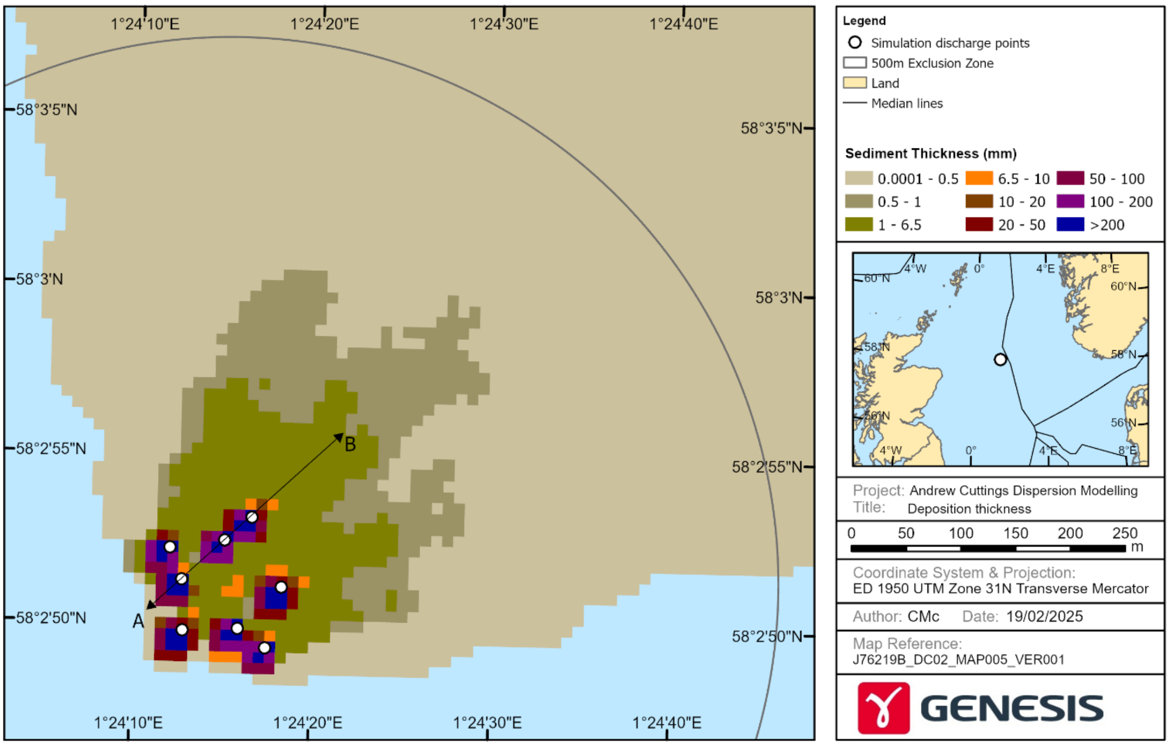
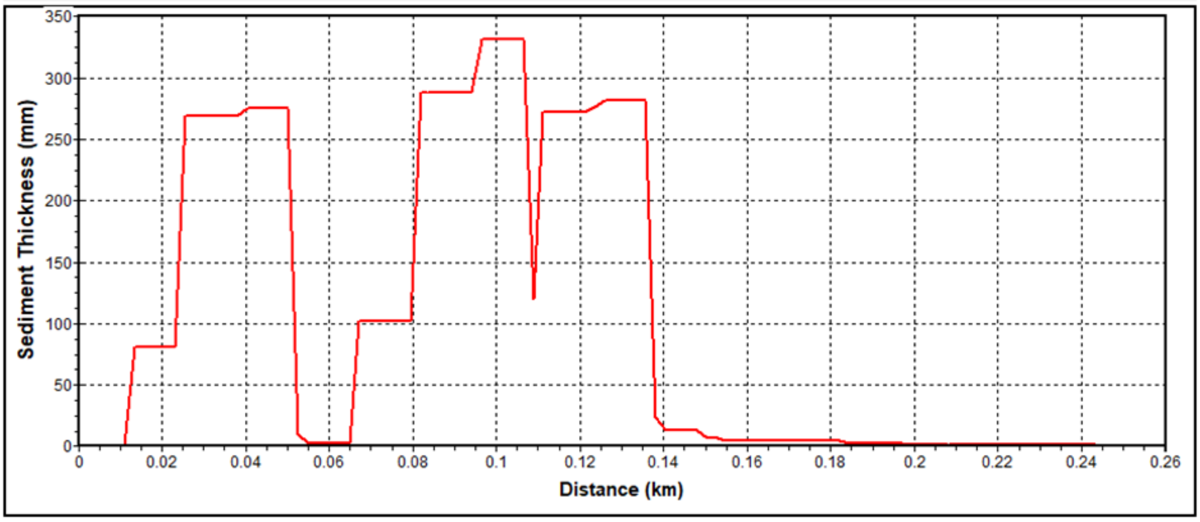


Figure 5-3 Deposition thickness around the discharge locations at the end of dredging – Scenario 2



Note: Coordinates of cross section: start point (1°24’05”E, 58°02’48”N) and end point (1°24’16”E, 58°02’53”N).

Figure 5-4 Cross section (A-B as shown in Figure 5-3) of deposition thickness at the end of dredging – Scenario 2

5.3 Risk to the Seabed Sediment

Risk to the sediment has been modelled for the duration of dredging operations and over a 10-year period post dredging. The following sections summarise the predicted risk around the discharge locations as well as the components making up that risk.

As noted in Section 2.2, combined risk to the seabed sediment is made up of risk contributions resulting from the following stressors:

- Burial thicknesses greater than 6.5 mm;
- A median grain size change greater than 52.7 µm;
- Oxygen content depletion greater than 20%; and
- Toxicity where chemical concentration exceeds the PNEC.

A risk of less than 5% to the most sensitive species is considered to be tolerable. Figure 5-5 and Figure 5-6 show the total combined risk around the discharge locations for 100% disturbance and 40% disturbance, respectfully[3].

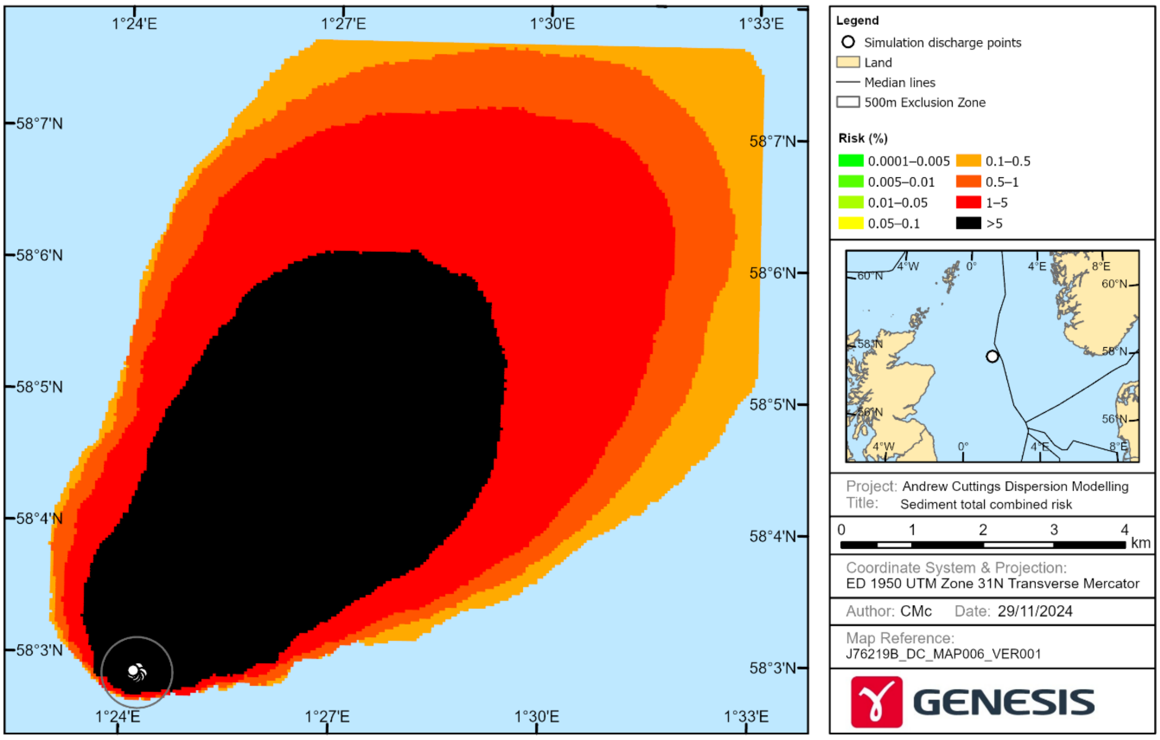


Figure 5-5 Predicted total cumulative risk to sediments – Scenario 1

[3] The model output is restricted to the size of the grid to optimise model run times without sacrificing model quality as described in Section 3.9. The grid sizes were determined to capture the area of risk >5% (the black area in Figure 5-5 & Figure 5-6).

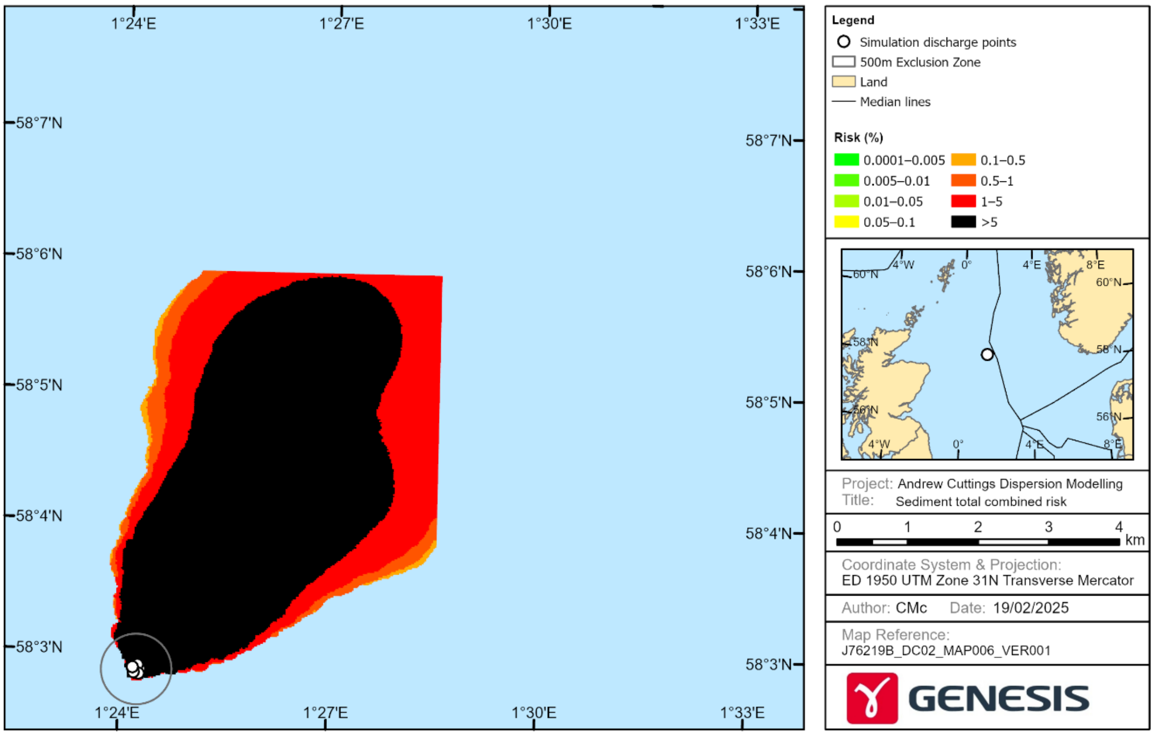


Figure 5-6 Predicted total cumulative risk to sediments – Scenario 2

The contribution to the combined risk can be broken down to establish which stressors are the key contributors. This is shown in Figure 5-7 for 100% disturbance and Figure 5-8 for 40% disturbance.

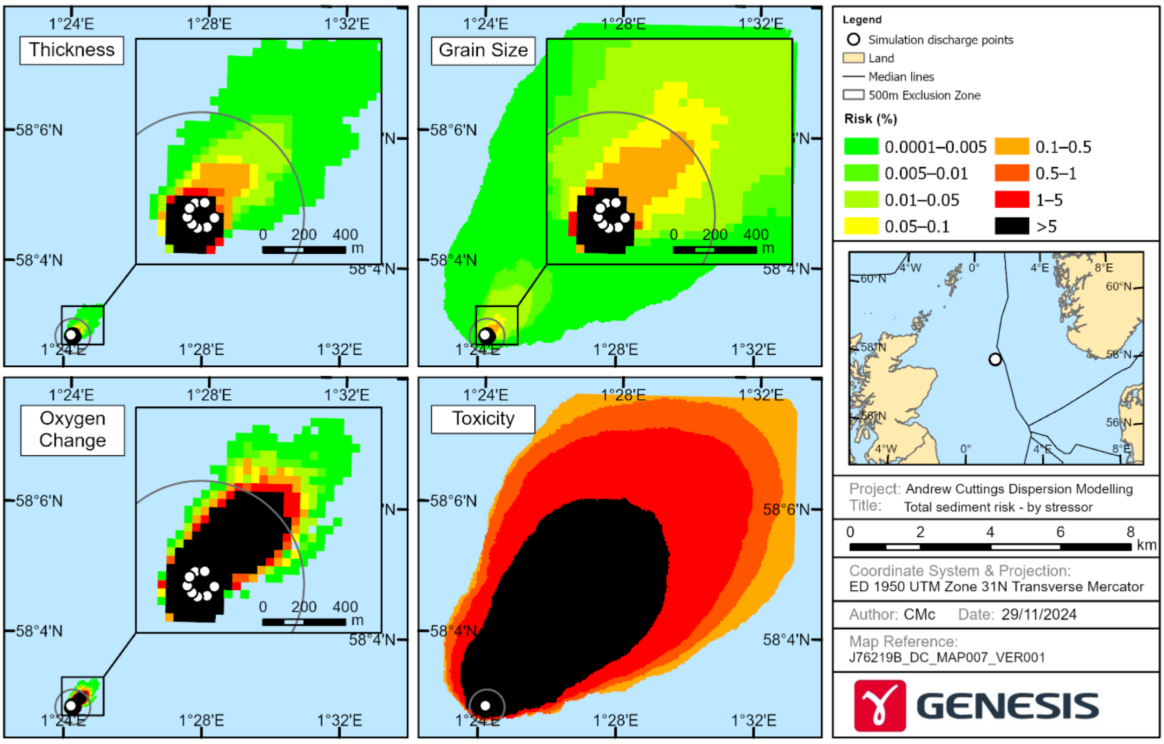


Figure 5-7 Predicted total risk contributions from individual seabed stressors – Scenario 1

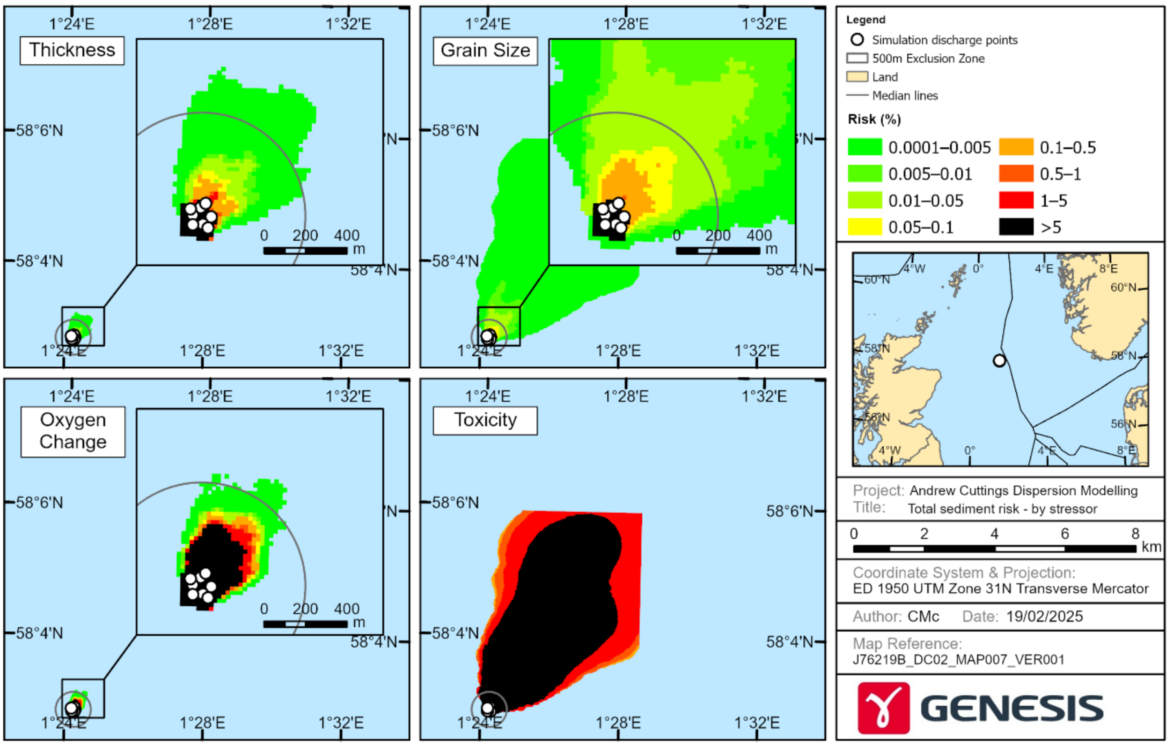


Figure 5-8 Predicted total risk contributions from individual seabed stressors – Scenario 2

Time-averaged contributions to risk for Scenario 1 (100% disturbance) are summarised in Figure 5-9 and Figure 5-10. The main contributor to the risk is chemical toxicity (77.5%). Oxygen change and grain size change contribute to 10.7% and 9.2% of the total risk respectively. There is a small contribution of 2.5% from deposition thickness. The risk from chemical toxicity is driven by UCMs (99.6%) (Figure 5-10). There is zero risk contribution from PAHs (not including NPDs) and heavy metals. Metals (in this case cadmium, copper, mercury, lead and zinc) that are strongly attached to the barite are not available to benthic organisms.

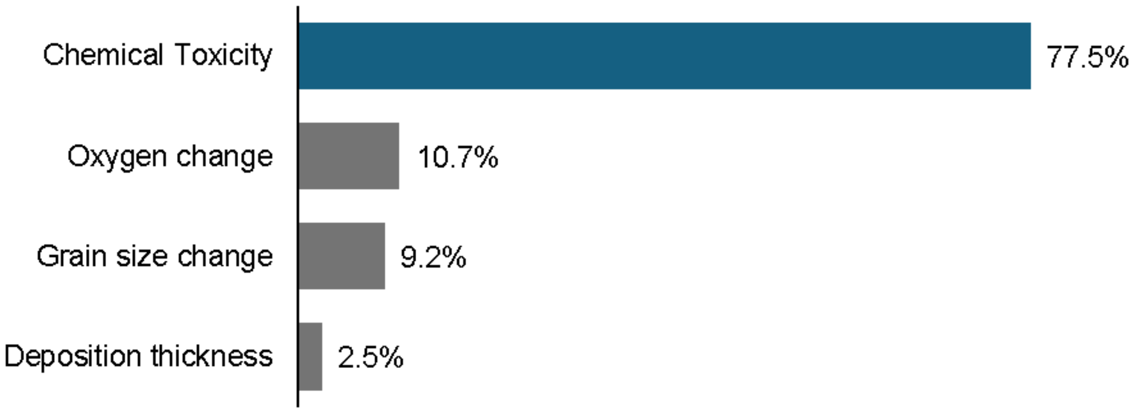


Figure 5-9 Weighted contributions to time averaged risk

Note: Other comprises of chemicals that contribute to <0.1% of the chemical risk (nonylphenol, dispersed oil and octylphenol).

Figure 5-10 Weighted contributions to time averaged risk from chemical toxicity

The time-averaged contributions to risk for Scenario 2 (40% disturbance) have not been presented here due to the similarity to Scenario 1. However they are, as expected, comparable to Scenario 1 with chemical toxicity (specifically from UCMs) as the main contributor to the risk. Full results for both scenarios are summarised in Section 5.5.

The area of seabed where there is a risk to over 5% of sensitive species varies over time as shown in Figure 5-10 for Scenario 1 and Figure 5-12 for Scenario 2.

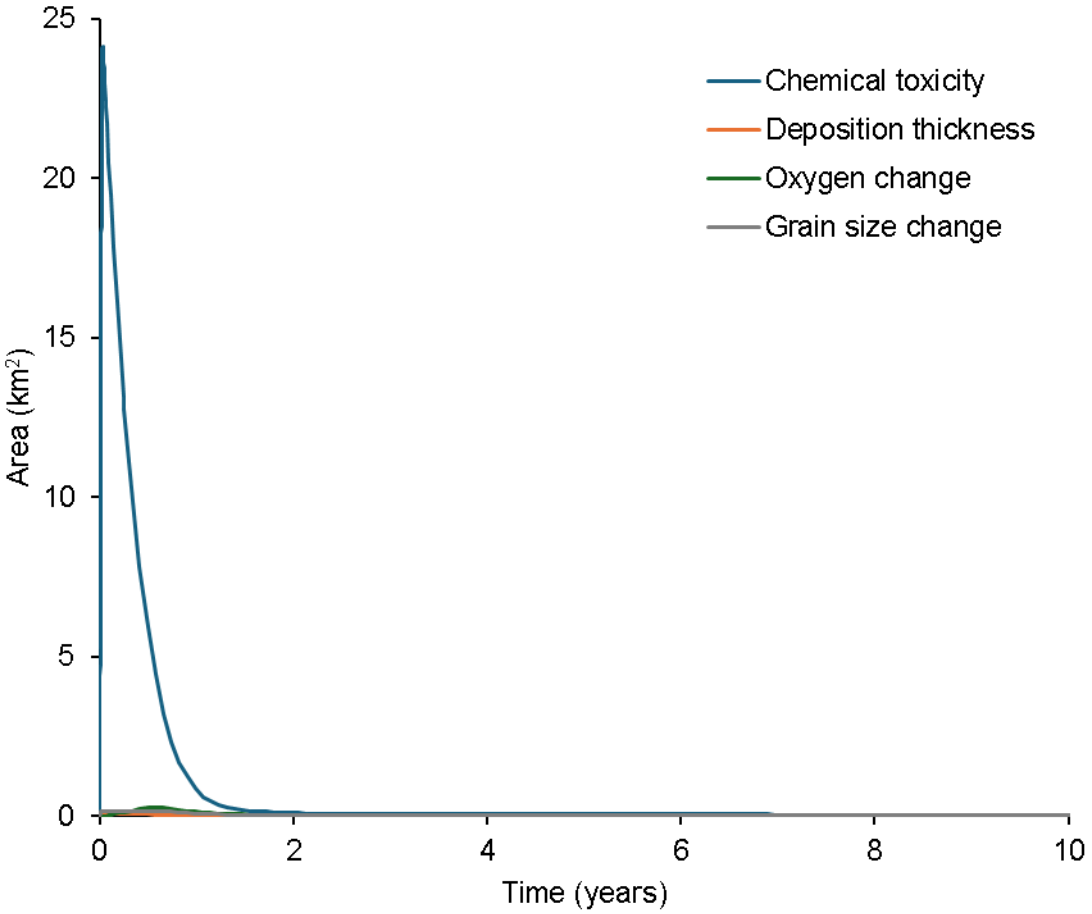


Figure 5-11 Contribution to area where there is a risk to more than 5% of sensitive species over the whole model period for each sediment stressor – Scenario 1

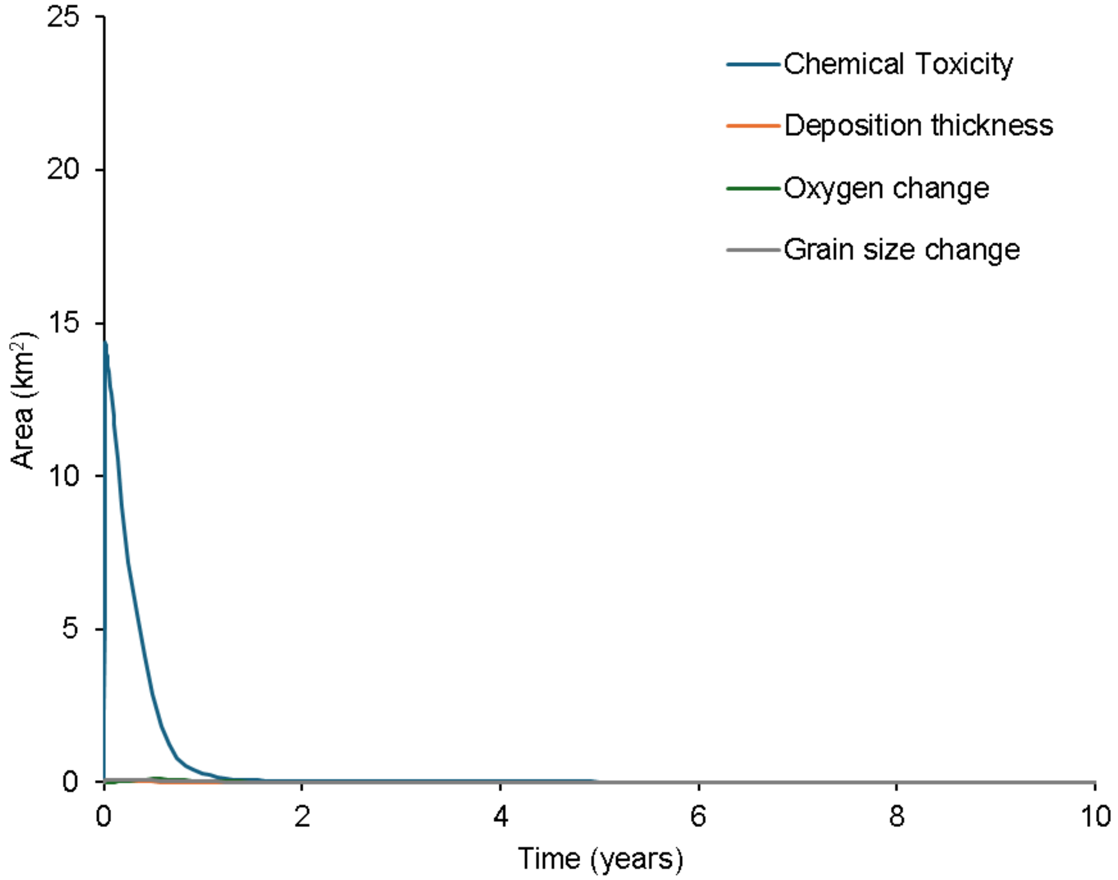


Figure 5-12 Contribution to area where there is a risk to more than 5% of sensitive species over the whole model period for each sediment stressor – Scenario 2

For Scenario 1 (100% distribution), the evolution of predicted combined risk (at 11 days (i.e. 2 days post dredging operations), two years, five years and ten years post dredging operations) is shown in Figure 5-13 and summarised in Table 5-1.

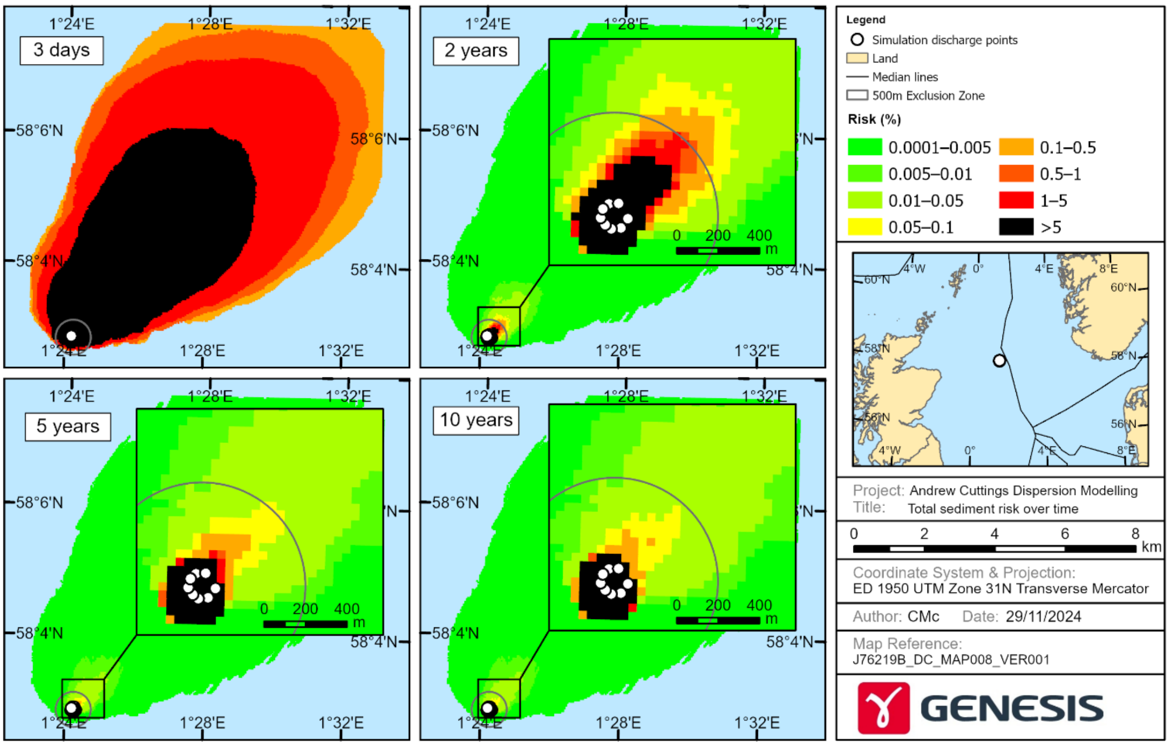


Figure 5-13 Predicted combined risk to the sediment over time – Scenario 1

The maximum area where there is a risk to more than 5% sensitive species is 24.312 km^2 2 days post dredging operations. The area reduces to 0.149 km^2 after two years, 0.078 km^2 after 5 years and 0.075 km^2 after 10 years.

For Scenario 2 (40% distribution), the evolution of predicted combined risk (at 4.5 days (i.e. 1.5 days post dredging operations), two years, five years and ten years post dredging operations) is shown in Figure 5-14 and summarised in Table 5-1.

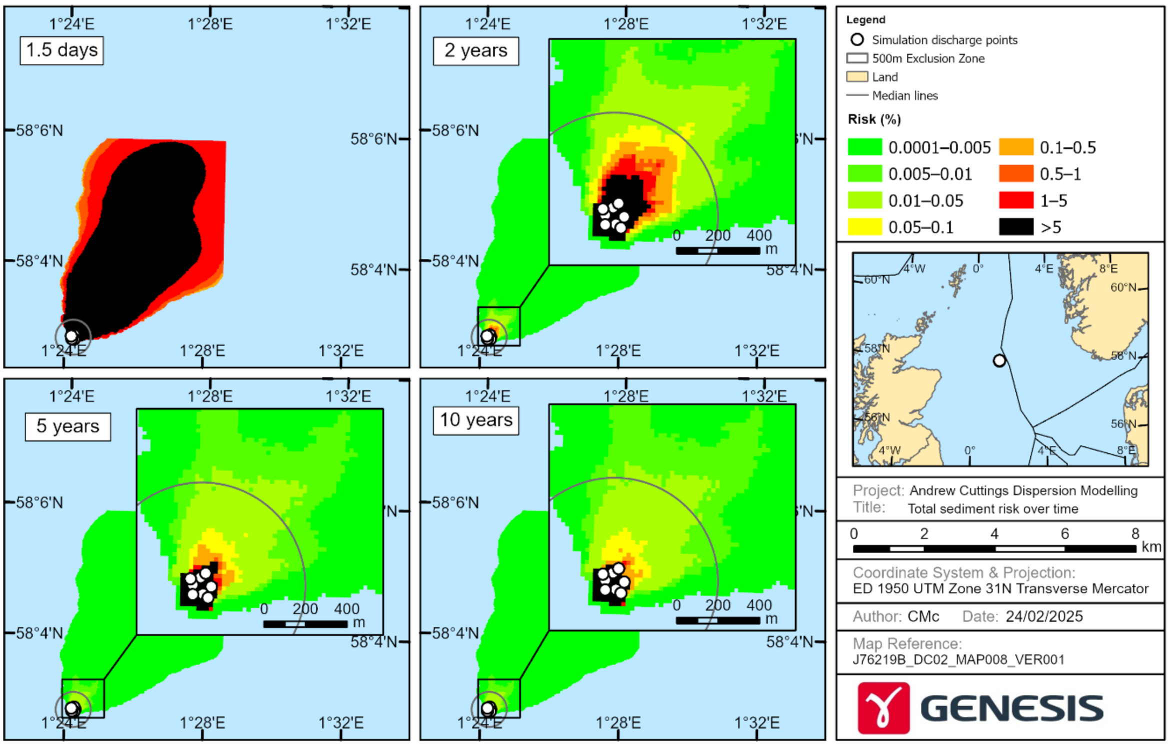


Figure 5-14 Predicted combined risk to the sediment over time – Scenario 2

The maximum area where there is a risk to more than 5% sensitive species is 14.488 km^2 1.5 days post dredging operations. The area reduces to 0.062 km^2 after two years, 0.033 km^2 after 5 years and 0.028 km^2 after 10 years.

Table 5-1 Predicted combined risk over time

Time period	Description	Scenario 1		Scenario 2	
		Area where combined risk is >5% (km^2)	Percentage change in area (%)	Area where combined risk is >5% (km^2)	Percentage change in area (%)
4.5 days	1.5 days post dredging operations (maximum risk)			14.488	-
11 days	3 days post dredging operations (maximum risk)	24.312	-		
0.5 years	*6 months post dredging operations*	*6.406*	*73.7*	*3.084*	*78.7*
1 year	*1 year post dredging operations*	*1.110*	*95.4*	*0.392*	*97.3*
2 years	2 years post dredging operations	0.149	99.4	0.062	99.6
5 years	5 years post dredging operations	0.078	99.7	0.033	99.8
10 years	10 years post dredging operations	0.075	99.7	0.028	99.8

As noted above the main risk stressor as a result of the modelled discharges is chemical toxicity from UCMs.

It is worth noting that the model calculates the risk resulting from burial thickness based on the areas of the seabed where the thickness of cuttings exceeds 6.5 mm (see Section 2.2). This thickness reduces over time as a result of bioturbation and re-suspension. Both these processes are included in the model. However, the model does not account for recolonization of the sediment over time. Therefore, the area where there is a risk to over 5% of the species is likely to reduce faster than shown and the areas shown in Table 5-1 are conservative.

5.4 Risk to the Water Column

The total risk in the water column for Scenario 1 (100% disturbance) is shown in Figure 5-15. Although the volume of water where the risk to the most sensitive species exceeds 5% appears relatively extensive (1.27 km^3), it should be noted that this plot shows the cumulative risk (that is all areas where risk is greater than 5% at any point in time during the entire model run). In practice, the area where risk exceeds 5% at any instance in time would be much smaller than that shown in Figure 5-15. The area of 5% risk and above mostly occurs in the lower water column with a small amount of risk occurring near the surface where the lower sections are discharged, as shown in the cross section (Figure 5-16).

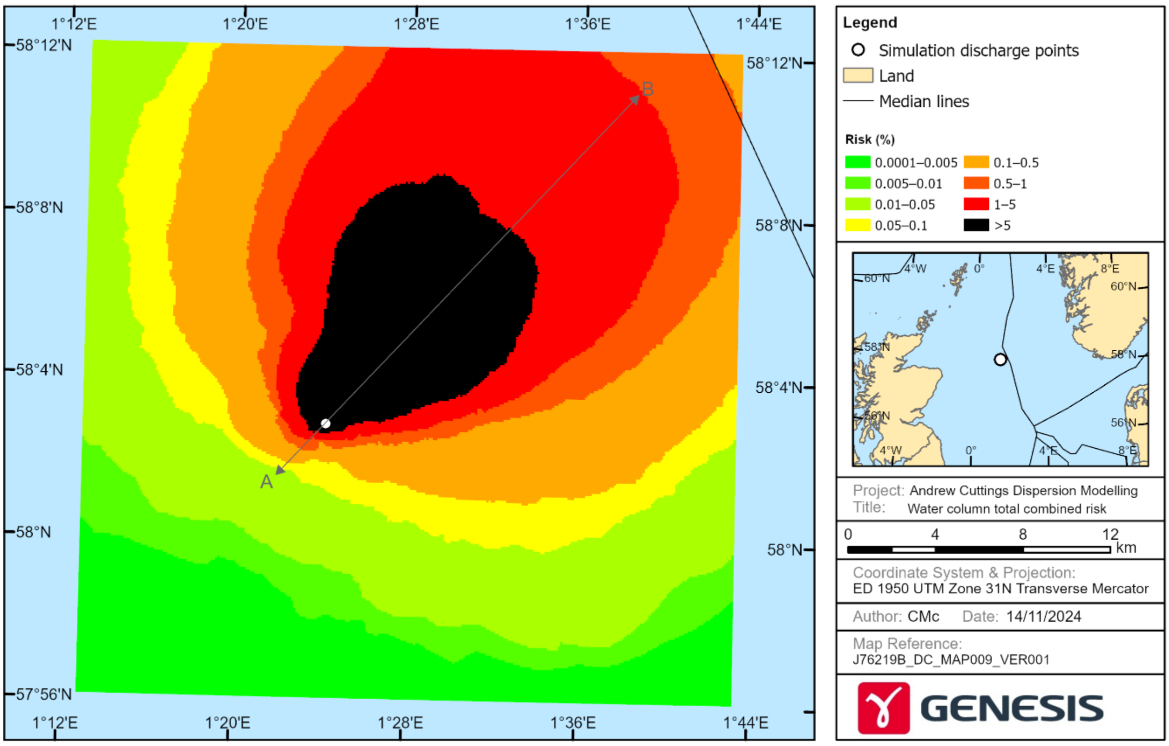


Figure 5-15 Total cumulative risk to the water column – Scenario 1

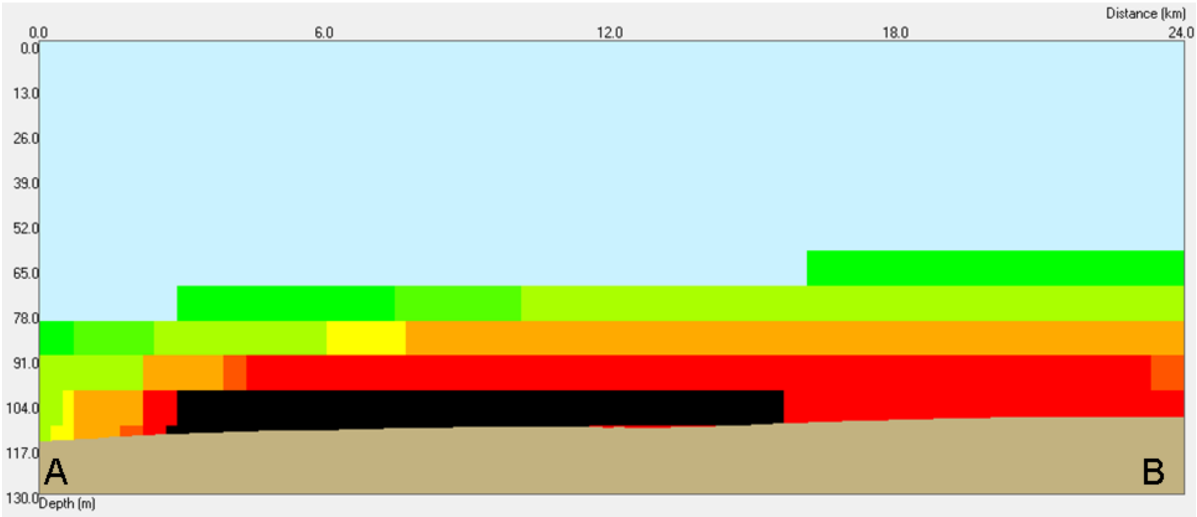


Figure 5-16 Cross section (A-B) of total cumulative risk – Scenario 1

Figure 5-17 and Figure 5-18 show a snapshot of risk in the water column during the dredging operations. The maximum instantaneous volume where there is a risk to more than 5% of sensitive species is 0.47 km^3. The area of high risk occurs in the lower part of the water column where the cuttings from the dredger are discharged.

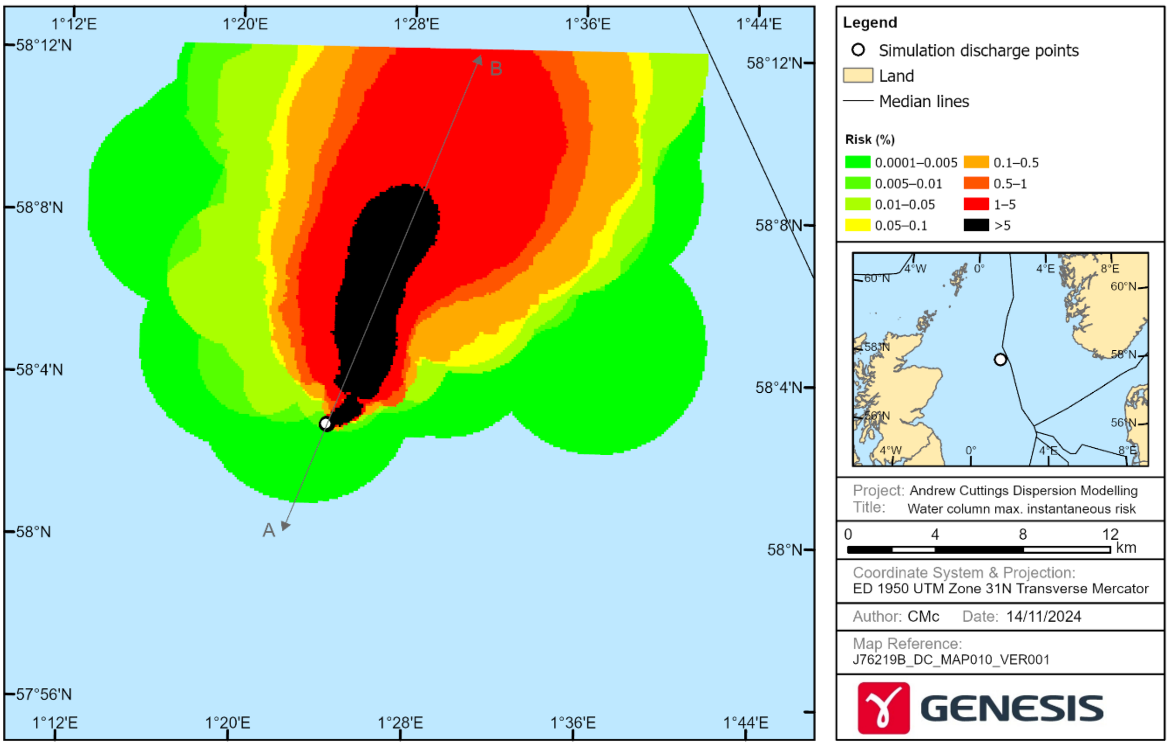


Figure 5-17 Instantaneous risk to the water column during dredging operations – Scenario 1

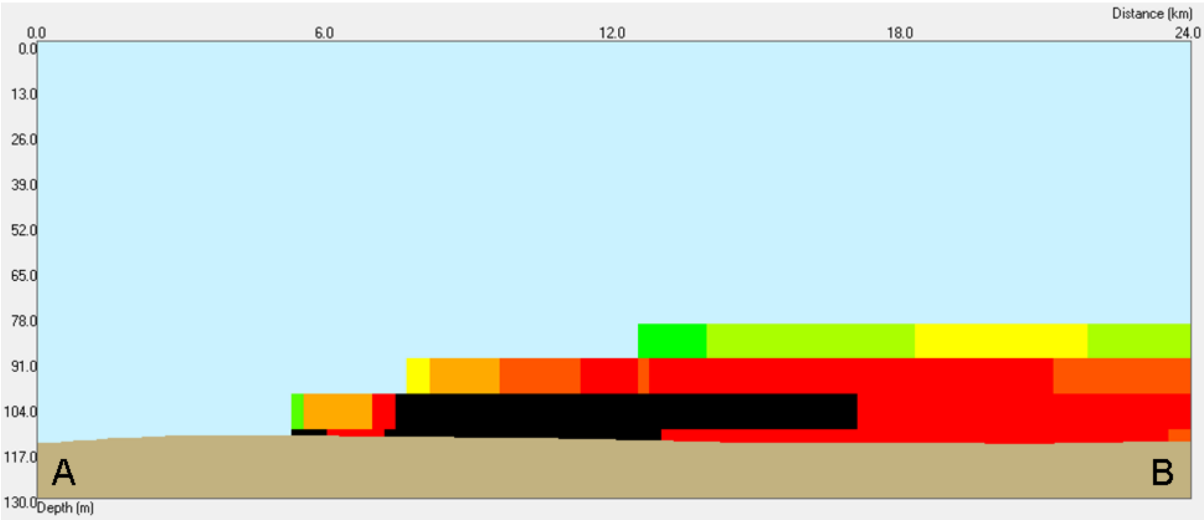


Figure 5-18 Cross section (A-B) of instantaneous risk during dredging operations – Scenario 1

The total risk in the water column for Scenario 2 (40% disturbance) is shown in Figure 5-19 and spans a volume of 1.12 km³.

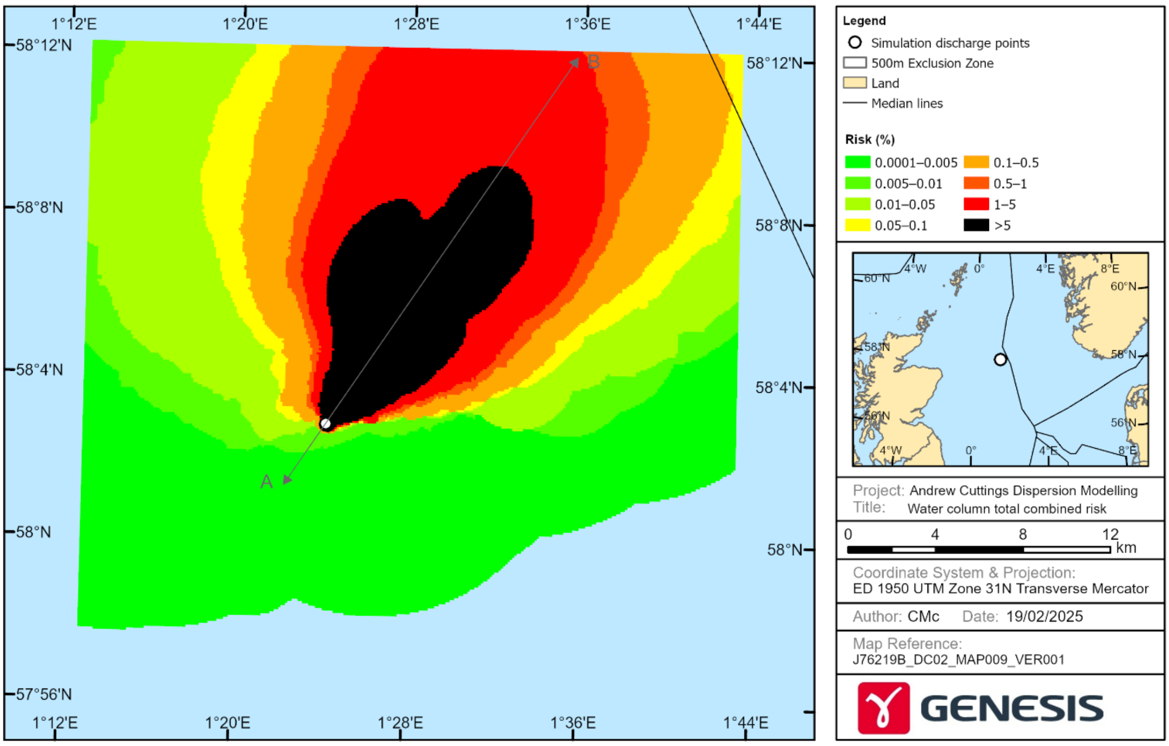


Figure 5-19 Total cumulative risk to the water column – Scenario 2

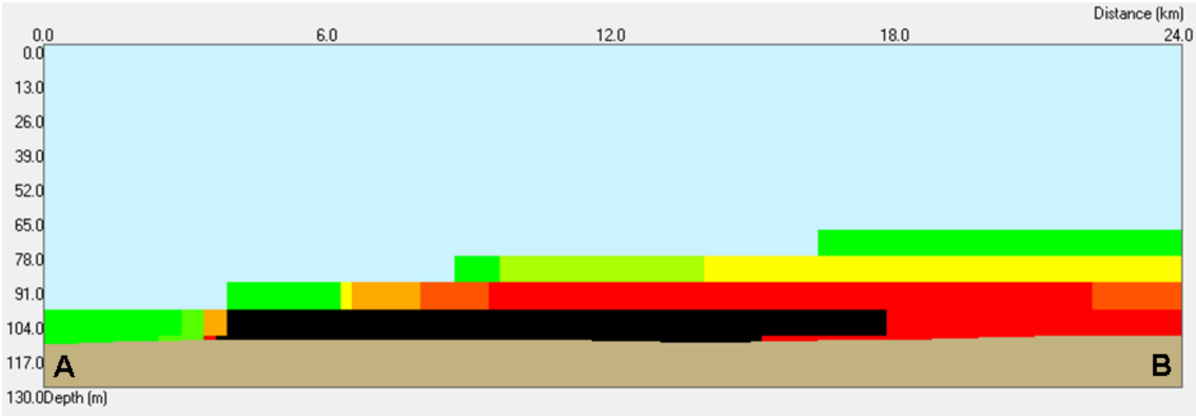


Figure 5-20 Cross section (A-B) of total cumulative risk – Scenario 2

Figure 5-21 and Figure 5-22 show a snapshot of risk in the water column (40% disturbance). The maximum instantaneous volume where there is a risk to more than 5% of sensitive species is 0.41 km³. The area of high risk occurs in the lower part of the water column where the cuttings are discharged.

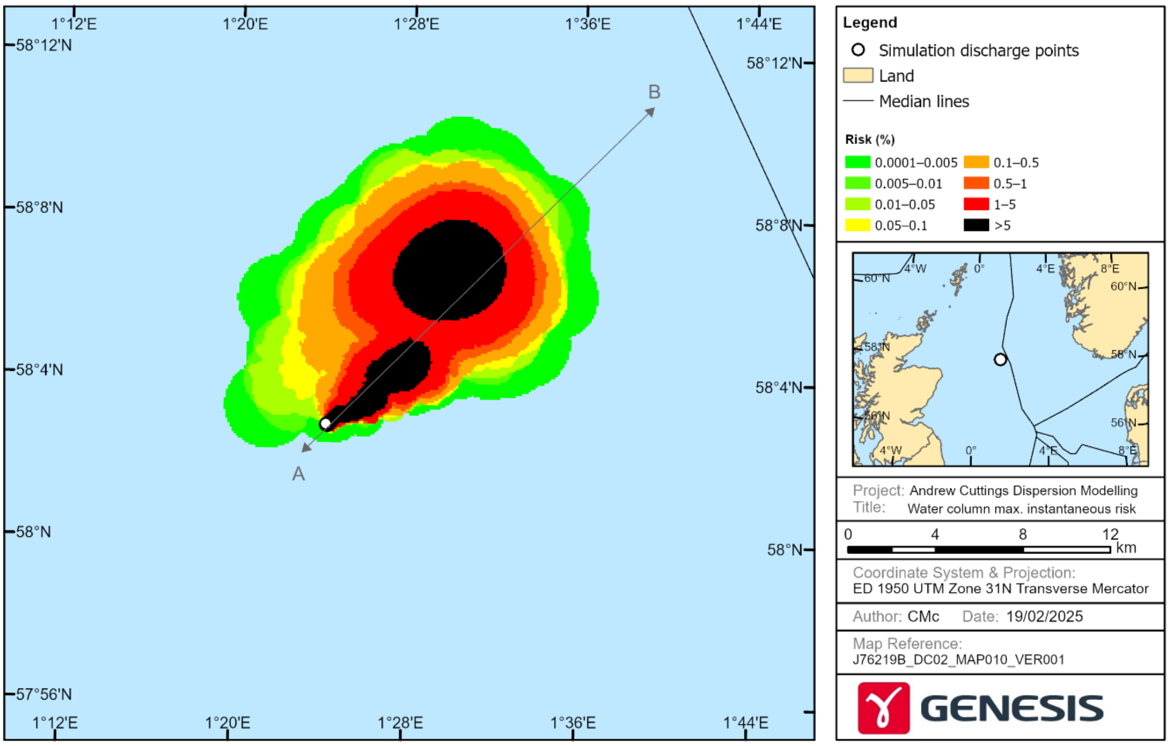


Figure 5-21 Instantaneous risk to the water column during dredging operations – Scenario 2

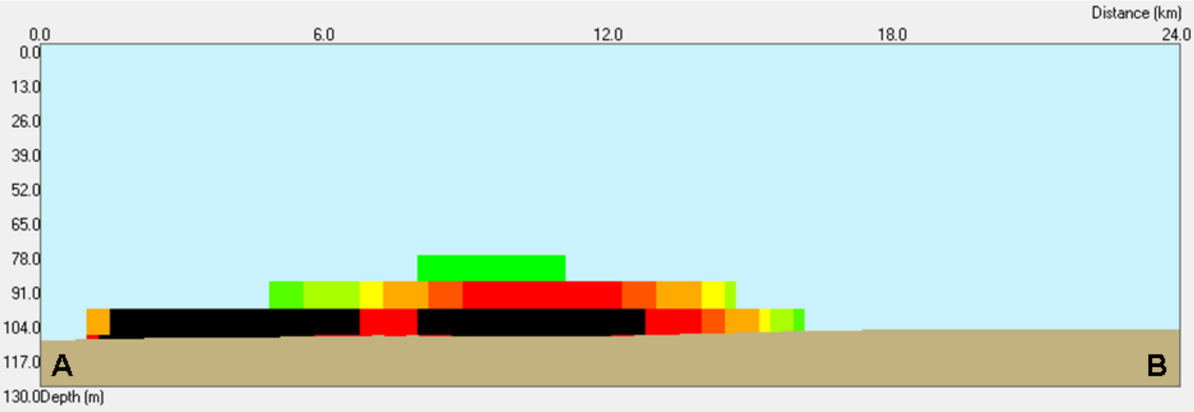


Figure 5-22 Cross section (A-B) of instantaneous risk during dredging operations – Scenario 2

For Scenario 1 (100% disturbance), the primary contributors to the water column risk are from bentonite particles (49.8%), chemicals (33.9%) and barite particles (16.2%) as shown in Figure 5-23. The breakdown of individual chemicals contributing to the chemical risk to the water column is shown in Figure 5-24.

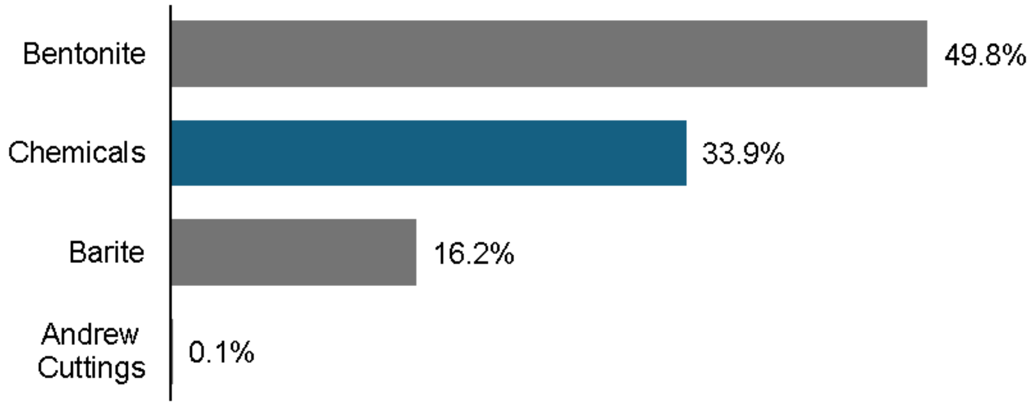
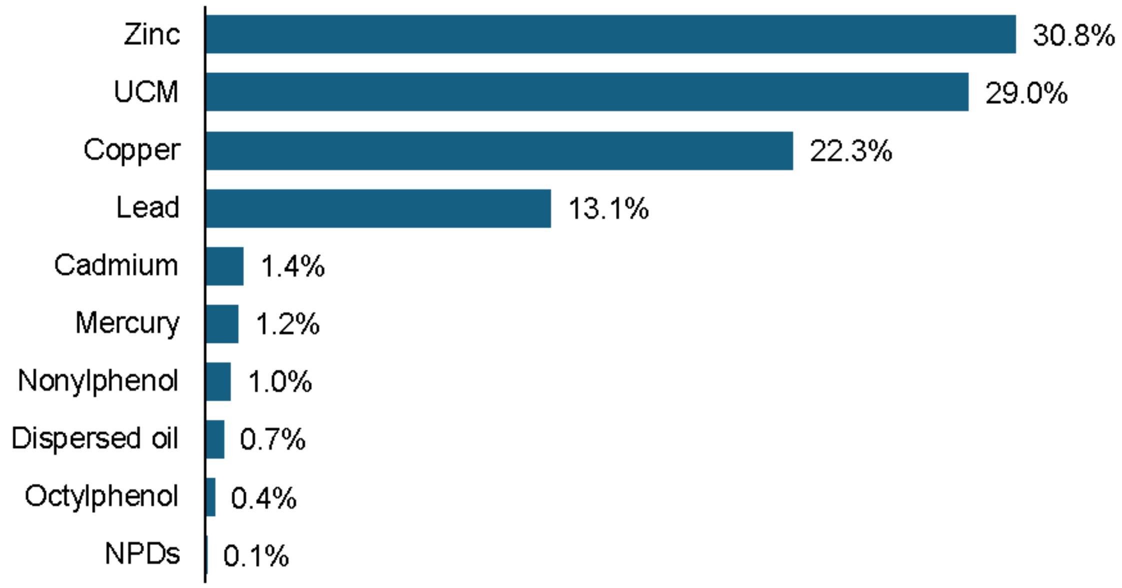


Figure 5-23 Time-averaged contributions to risk in the water column



Note: PAHs (excluding NPDs) do not contribute to the risk.

Figure 5-24 Breakdown of time-averaged contributions to chemical risk in the water column

The primary contributors to the water column risk for Scenario 2 (40% disturbance) are as expected, comparable to Scenario 1 where bentonite particles, chemical toxicity and barite particles are the primary contributors to the water column risk. Full results for both scenarios are summarised in Section 5.5.

The volume of water column where there is a risk to over 5% of sensitive species varies over time as shown in Figure 5-25 for Scenario 1 and Figure 5-26 for Scenario 2. The volume at risk reduces to zero within 3 days after dredging operations have finished for Scenario 1 and two days after dredging operations for Scenario 2.

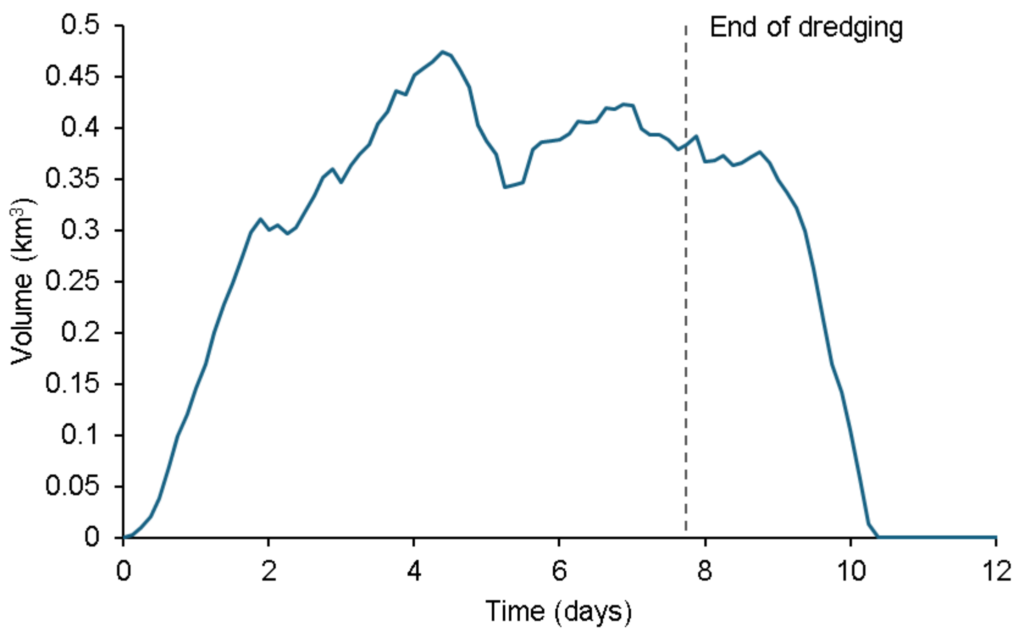


Figure 5-25 Volume of water where there is risk to over 5% of species over time – Scenario 1

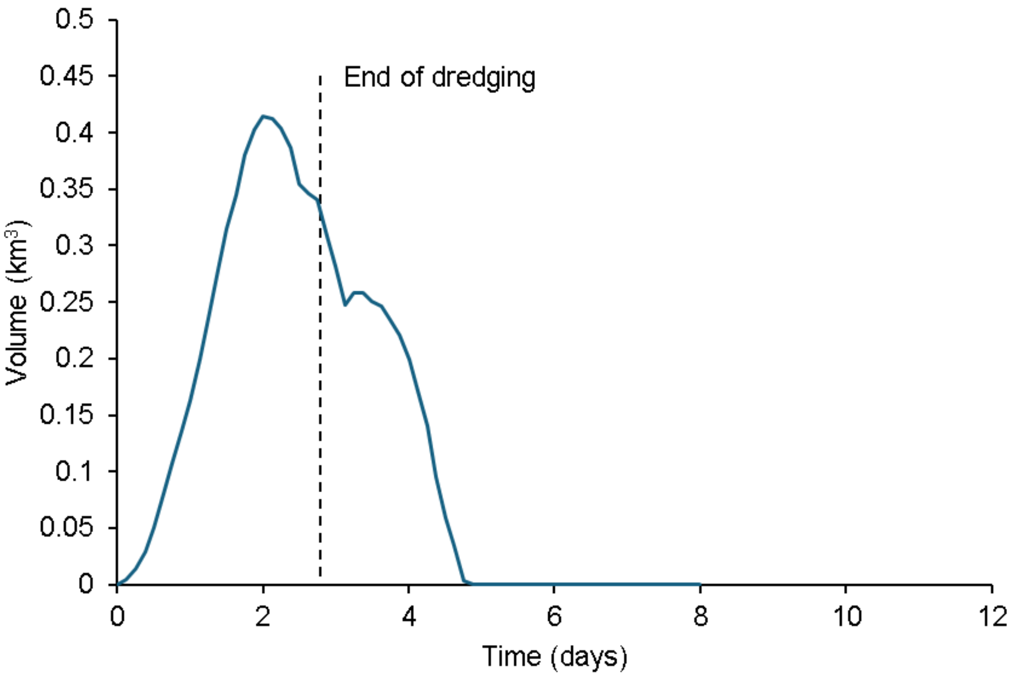


Figure 5-26 Volume of water where there is risk to over 5% of species over time – Scenario 2

5.5 Summary of Outputs

Model outputs are summarised in Table 5-2.

Scenario 1, 100% disturbance

The potential impact to the seabed initially covers an area of 24.3 km^2 which is significantly greater than a typical 500 m exclusion zone (>0.785 km^2), however this decreases to <0.785 km^2 within 14 months after the completion of dredging operations. The key contributor to risk in sediments is chemical toxicity and is driven by UCMs. Ten years after the completion of dredging operations, the risk to the seabed is reduced to an area of 0.08 km^2. The potential risk to the water column is transient, disappearing shortly after the final discharge stops.

Scenario 2, 40% disturbance

The potential impact to the seabed initially covers an area of 14.5 km^2 which is significantly greater than a typical 500 m exclusion zone (>0.785 km^2), however this decreases to <0.785 km^2 within 10 months after the completion of dredging operations. The key contributor to risk in sediments is chemical toxicity and is driven by UCMs. Ten years after the completion of dredging operations, the risk to the seabed is reduced to an area of 0.03 km^2. The potential risk to the water column is transient, disappearing shortly after the final discharge stops.

Table 5-2 Summary of model outputs

Model output	Criteria	Scenario 1 (100% disturbance)	Scenario 2 (40% disturbance)
Cuttings deposition			
Thickness	Maximum thickness – end of dredging operations (m)	0.715	0.334
	Area where thickness >6.5 mm - end of dredging (km^2)	0.026	0.011
	Area where thickness >300 mm - end of dredging(km^2)	0.004	0.0001
Risk to sediment			
Deposition Thickness (%)	>6.5 mm	2.53	2.38
Grain size change (%)	>52 µm	9.20	8.78
Oxygen depletion (%)	>20%	10.74	10.13
Chemical concentration (toxicity)	Toxicity (PNEC exceeded)	77.54	78.72
Contributors to chemical toxicity	UCMs	99.58	97.45
	NPDs	0.36	0.29
	Nonylphenol	0.04	1.08
	Dispersed oil	0.03	0.83
	Octylphenol	0.01	0.36
Area where there is a total combined risk (>5%) to the most sensitive species (km^2)	Maximum risk	24.312	14.488
	2 years (after end of dredging operations)	0.149	0.062
	5 years (after end of dredging operations)	0.078	0.033
	10 years (after end of dredging operations)	0.075	0.028
Risk to water column			
Bentonite (%)	Physical effect of particles	49.78	47.58
Barite (%)	Physical effect of particles	16.17	15.66
Cuttings (%)	Physical effect of particles	0.13	0.16
Chemical concentration (toxicity)	Toxicity (PNEC exceeded)	33.92	36.57
Contributors to chemical toxicity	Zinc	30.78	29.61
	UCMs	28.98	30.90
	Copper	22.32	21.52
	Lead	13.12	12.72
	Cadmium	1.44	1.42
	Mercury	1.24	1.56
	Nonylphenol	0.97	1.23
	Dispersed oil	0.71	0.66
	Octylphenol	0.35	0.33
	NPDs	0.09	0.05
Volume where combined risk to >5% most sensitive species (km^3)	Maximum instantaneous volume	0.47	0.41
	Total cumulative volume	1.27	1.12

Note: for comparison 500 m safety zone area is equivalent to 0.785 km^2. and footprint of contamination associated with existing cuttings piles (area where concentration of THCs is greater than 50 mg/kg) is 0.26 km^2.

6.0 LEGACY ISSUES

Consideration needs to be given to potential future disturbance of the area through natural erosion as a result of seabed currents or potential for disturbance as a result of fishing interaction. None of these factors have been modelled, but key conclusions from previous studies and their applicability to the Andrew cuttings pile have been summarised below. Collapse of remaining infrastructure such as platform footings does not apply in this case as the complete structure will be recovered.

As part of the UKOOA JIP on drill cuttings (UKOOA, 2002) laboratory studies were undertaken to determine the response of cuttings piles to wave and current action (Sintef Fisheries and Aquaculture, 2001). The study found that relatively strong seabed currents (0.35 m/s to 0.40 m/s) are required to move the cuttings; conditions that are infrequent in most parts of the Central and Northern North Sea. This suggests that left undisturbed, the cuttings pile at Andrew is likely to remain on the seabed for a considerable length of time.

Where infrastructure has been removed but cuttings are left *in situ* there is the potential for trawling activities to disturb the cuttings at a later date (once the 500 m safety zone has been removed), potentially resulting in the snagging of nets and the release of contamination within the pile into the water column. The amount of sediment disturbed depends on the type of fishing gear, the hydrodynamic conditions, and the sediment type. A range of experimental studies have been undertaken to determine the potential depth of disturbance of fishing gear (OSPAR, 2019) as discussed below.

Durrieu de Madron *et al.* (2005) found that the particulate matter load resulted from the resuspension of less than the equivalent of 1 mm thickness of the sediment over the area of the trawl. It is therefore unlikely that trawling gear will re-suspend large quantities of a cuttings pile and as the surface layer of a cuttings pile is typically depleted of contaminants, this implies that over-trawling is unlikely to release significant levels of contaminants into the water column. This agrees with other experimental evidence (OSPAR, 2009c) (Kaiser *et al*., 2006) which showed that the spatial extent of disturbed material from trawling was small and resettled material was at low concentrations. The Fisheries Research Service (FRS) also undertook studies which showed that no significantly increased environmental risk is likely to arise from the spread of contamination caused by fishing over piles (FRS, 2005). The exception might be if a cuttings pile is frequently over-trawled without recovery time so that material with higher metal and hydrocarbon concentrations from deeper in the pile was disturbed. Results also suggest that scallop dredging gear has the greatest potential for sediment disturbance (Kaiser *et al.,* 2006), (OSPAR, 2016), but there is no scallop dredging around Andrew (Scottish Government, 2023).

As noted in the Scenario 1 (100% disturbance) modelling results, the maximum residual thickness following spreading of the whole Andrew cuttings pile is 715 mm. Given that within 2 years post dredging operations the area where there is a risk from elevated toxicity is very small (well within the equivalent of a 500 m exclusion zone) the potential for contamination of trawling gear from interaction with contaminated sediment is expected to be limited. Furthermore, in the scenario of only 40% disturbance the maximum thickness is 334 mm, with a smaller area where there is a risk to the seabed from elevated toxicity which decreases slightly faster (Section 5.3).

7.0 CONCLUSIONS

This assessment has been undertaken to support the BAT/BEP assessment for the management of the Andrew cuttings pile and the EAs supporting the Andrew area DPs.

This modelling study assesses the following two scenarios for the dispersion of the cuttings pile at Andrew:

- Scenario 1: The anticipated worst-case scenario of spreading 100% of the cuttings pile (3,212.93 m^3) to support the assessment of the option of spreading the whole pile to promote the natural breakdown of hydrocarbons; and
- Scenario 2: Relocation of 40% of the cuttings pile (1,285.17 m^3) to recover the jacket, drilling template and pipeline and umbilical ends covered with cuttings. These modelling results will be used to support the assessment of the option to leave the cuttings pile in situ after the decommissioning activities are completed.

Modelling of the redistribution of the Andrew cuttings pile was undertaken using DREAM to predict environmental risks to the seabed and the water column as a result of the disturbance of cuttings during the removal and recovery of the jacket and drilling template at the Andrew platform.

The maximum estimated deposited sediment thickness (cuttings pile height) at each deposition site varied from 0.577-0.715 m in Scenario 1 and 0.251-0.334 m in Scenario 2, reducing in distance from the Andrew centre.

The following risks were predicted:

- In Scenario 1, the model predicted that the spreading of the cuttings could result in a risk to more than 5% sensitive species in a maximum area of seabed sediment of 24.3 km^2 three days after the end of dredging operations. This area reduces significantly over time, to 0.149 km^2 two years after the end of dredging operations, to 0.078 km^2 five years after the end of dredging operations, then to 0.075 km^2 ten years after the end of dredging operations. In reality re-colonisation by benthic organisms would result in a faster seabed recovery.

  In Scenario 2, the maximum area of seabed at risk drops to 14.5 km^2. This area reduces significantly over time, to 0.062 km^2 two years after the end of dredging operations, to 0.033 km^2 five years after the end of dredging operations, then to 0.028 km^2 ten years after the end of dredging operations.
- The risk to the sediment mainly results from chemical toxicity which is driven by UCMs.
- In Scenario 1, the volume of the water column where there is a risk to over 5% sensitive species reaches up to 0.47 km^3 at any one point in time but is transient in time and space. The risk to the water column disappears within three days of the cessation of dredging operations.

  In Scenario 2, the volume of water column at risk reduces to 0.41 km3 at any one point in time and disappears two days after the cessation of dredging operations.
- The primary contributors to the water column risk are from the physical impacts of resuspension of bentonite and barite particles as well as the combined toxicity of the chemicals.

Overall, the modelling shows that spreading of the entire cuttings pile would not result in a long-term risk to seabed sediments. There is a short-term risk to the seabed sediments however, this is driven by the chemical toxicity of the dispersed cuttings which were modelled on the worst-case assumption that the maximum concentration of each chemical from the five available surface samples has been used to determine the chemical composition of the entire cuttings pile. It is therefore expected that, in reality, the extent of the risk as a result of the chemical toxicity of the cuttings pile will be lower than predicted by the model. In comparison to spreading 100% of the cuttings pile, Scenario 2 (40% disturbance) would result in a lower area of seabed sediments where risk is >5% and the seabed is predicted to recover faster when there is a lower percentage of the cuttings pile disturbed.

8.0 REFERENCES

Aquatera. (2007). Initial Screening Assessment of BP's UKCS Cuttings Piles

Berx, B. and Hughes, S. (2009). Climatology of Surface and Near-bed Temperature and Salinity on the North-West European Continental Shelf for 1971–2000 dataset. DOI: 10.7489/1900-1

Brownawell, B., Dick, J., & McElroy, A. (2007). The environmental implications of the UCM in sediments of the New York Harbor complex. A Final Report to the Hudson River Foundation on Contract 002/003A.

DNV. (2017a). Drill cuttings piles management and environmental experiences. Report no 2017-4056, rev01.

DNV. (2017b). Environmental impact study of planned Ekofisk 2/4A drill cuttings relocation.

Durrieu de Madron, X., Ferre, B., Le Corre, G., Grenz, C., Conan, P., Pujo-Pay, M., Bodiot, O. (2005). Trawling-induced resuspension and dispersal of muddy sediments and dissolved elements in the Gulf of Lion (NW Mediterranean). Cont. Shelf Res. 25, 2387–2409.

Environment Canada. (2009). Screening Assessment for n-hexane, Chemical Abstracts Service Registry Number 110-54-3.

FRS. (2005). Environmental Impacts of the oil and gas industry.

Fugro. (2019). BP Andrew Decommissioning Consultancy Desk Study Report | UKCS Block 16/28 Central North Sea

Hayes, S., & Galley, L. (2013). Modelling the Options for Managing Drill Cuttings Piles on Decommissioning. Society of Petroleum Engineers-164983-MS. Retrieved from https://www.onepetro.org/conference-paper/SPE-164983-MS?_ga=2.193893741.1110475283.1498726089-1903850131.1498726089

IOGP. (2003). Environmental aspects of the use and disposal of non-aqueous drilling fluids associated with offshore oil & gas operations. Report number 342.

IOGP. (2016). Environmental fate and effects of ocean discharge of drill cuttings and associated drilling fluids from offshore oil and gas operations.

Jakobsson, M., Cherkis, N. Z, Woodward, J., Macnab, R. and Coakley, B. (2008). New grid of Arctic bathymetry aids scientists and mapmakers; Eos, Transactions. American Geophysical Union. 81: 89, 93, 96.

Jødestøl, K. and Furuholt, E. (2010). Will drill cuttings and drill mud harm cold water corals? SPE126468.

Kaiser, M., Clarke, K., Austen, M., Sommerfield, P., & Karakassis, I. (2006). Global analysis of response and recovery of benthic biota to fishing. Marine Ecology Progress Series 311: 1-14.

Kjeilen-Eilertsen, G., Trannum, H., Jak, R., Smit, M., Neff, J. and Durell, J. (2004). Literature report on burial: derivation of PNEC as component in the MEMW model tool. ERMS Report no. 9B.

Neff, J.M. (2005). Composition, environmental fates, and biological effects of water based drilling muds and cuttings discharged to the marine environment: A Synthesis and Annotated Bibliography.

Neff, J. (2002). Bioaccumulation in Marine Organisms. Effect of Contaminants from Oil Well Produced Water.

Neff, J., & Ostazeski, S. (2000). Effects of weathering on the toxicity of three offshore Australian crude oils and a diesel fuel to marine animals.

Norsk Olje & Gass. (2016). Guidance document for characterisation of offshore drilling piles.

OSPAR. (2009a). Implementation report on Recommendation 2006/5 on a management regime for offshore cutting piles. Publication No. 451/2009

OSPAR. (2009b). Agreement on CEMP Assessment Criteria for the QSR 2010. Agreement no 2009-2.

OSPAR. (2009c). Assessment of the possible effects of releases of oil and chemicals from any disturbance of cuttings piles.

OSPAR. (2014). Establishment of a list of Predicted No Effect Concentrations (PNECs) for naturally occurring substances in produced water. OSPAR agreement 2014-05.

OSPAR. (2016). Impacts of Certain Pressures of the Offshore Oil and Gas Industry on the Marine Environment – Stocktaking Report.

OSPAR. (2019). Assessment of the disturbance of drill cuttings during decommissioning.

Rowland, S., Donkin, P., Smith, E. & Wraige, E. (2001). Aromatic hydrocarbon 'humps' in the marine environment: Unrecognized toxins? Environ. Sci. & Technol.

Rye, H., Johansen, Ø., Durgut, I., Reed, M., & Ditlevsen, M. (2006). Restitution of an impacted sediment. Sintef.

Rye. H. (2010). Calculation of stresses (depositions and water column concentrations) at the sea floor caused by drilling discharges. Presentation at the 2010 OLF cold-water coral workshop, held at IRIS, Stavanger.

Saga (1994). MiljØprogram I forbindelse med brØnn 7219/8-1s I Barentshavet". Report prepared by Saga Petroleum A.S., Division for Teknologi og utbygging datert 10. Mars 1994, Saga rapport R-TIY-0003. Written in Norwegian.

Scottish Government (2023). 2022 Scottish Sea Fisheries Statistics - Fishing Effort and Quantity and Value of Landings by ICES Rectangles. doi: 10.7489/12474-1

Sintef Fisheries and Aquaculture. (2001). UKOOA Phase II- Task 3. Large Scale Erosion Studies.

Smit, M.G.D., Jak R.G., Rye, H. and Frost T.K. (2006). Framework for the Environmental Impact Factor for drilling discharges. ERMS Report no. 3.

Subsea7. (2019) Andrew Drill Cuttings and Jacket Skirt Pile Survey. IS0072-SRV-00012

Trannum, H.C. (2004). Calculation of PNEC for changed grain size based on data from MOD. ERMS Report no. 9A.

Tyler-Walters, H. and Sabatini, M. (2017). Arctica islandica Icelandic cyprine. In Tyler-Walters H. and Hiscock K. (eds) Marine life information network: Biology and sensitivity key information reviews [online]. Marine Biological Association of the United Kingdom. Available at: http://www.marlin.ac.uk/species/detail/1519

UKOOA. (2002). Drill Cuttings Initiative Final Report of the Scientific Review Group.

UKOOA. (2005). Drill Cuttings Initiative Phase III Final Report. Report no 20132900.

Wentworth, C. (1922). A scale of grade and class terms for clastic sediments. Journal of Geology 30, no 5 p 377-392

Wolfe, D. (1976). Fate and Effects of Petroleum Hydrocarbons in Marine Ecosystems and Organisms: Proceedings of a Symposium, November 10-12.