



**CROMARTY FIRTH PORT
AUTHORITY**

**SHIP-TO-SHIP OIL TRANSFER
LICENCE**

**OIL AND BALLAST WATER DISCHARGE
MODELLING**

Briefing Note Ref. P1946_BN3872_Rev1_AppB.docx

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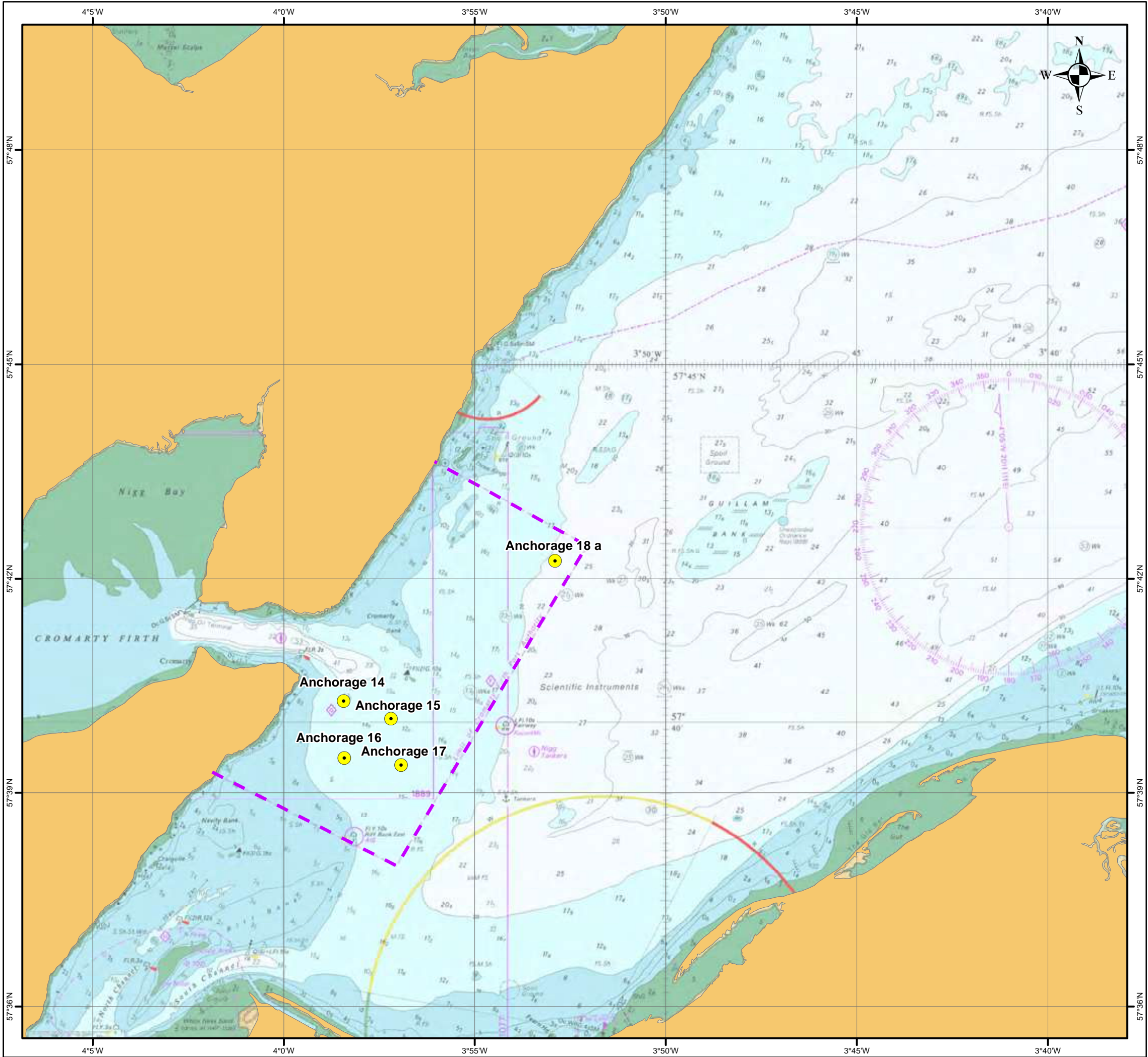
B.1 Introduction

The Maritime and Coastguard Agency (MCA) has advised that modelling should be undertaken to assess the risk from oil spill and; separately the risk from ballast water discharge as part of the supporting information to the Cromarty Firth Port Authority's (CFPA) Oil Transfer Licence (OTL) amendment. This Briefing Note was prepared by Intertek Energy and Water Consultancy Services (Intertek) and presents the findings of the oil spill and ballast water discharge assessments.

The assessments considered reasonable worst case discharges from five Ship to Ship (STS) anchorage locations identified within the CFPA OTL amendment (Table B-1 and Figure B-1). All anchorages are inside the Cromarty Firth Harbour Limit.

Table B-1: STS anchorage locations

Anchorage designation	Location (OSGB)	
	Easting	Northing
14	282365	866323
15	283583	865829
16	282343	864843
17	283810	864624
18a	287963	869820



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Figure B-1: STS anchorage locations

Legend

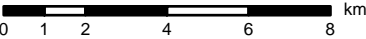
- STS Locations
- Cromarty Firth Harbour Limit

NOTE: Not to be used for Navigation

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Datum	D_WGS_1984
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File Reference	J:\P1946\Mxd\Report\Appendix_B\mxd STS_Locations
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Reviewed By	Ian Charlton
Approved By	Chris Mooij



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B.2 Hydrodynamic Model Specification

B.2.1 MIKE 21 Modelling System and Domain

The assessment was undertaken using Intertek's calibrated Inner Moray Firth Model (IMFM). This model was constructed using MIKE 21 Flexible Mesh (FM), which is a sophisticated two-dimensional dynamic modelling system. The IMFM has the capacity to run both hydrodynamic and water quality models. It may be used to predict the physical, chemical and biological properties of water, and interactions between these factors, for any specified coastal area.

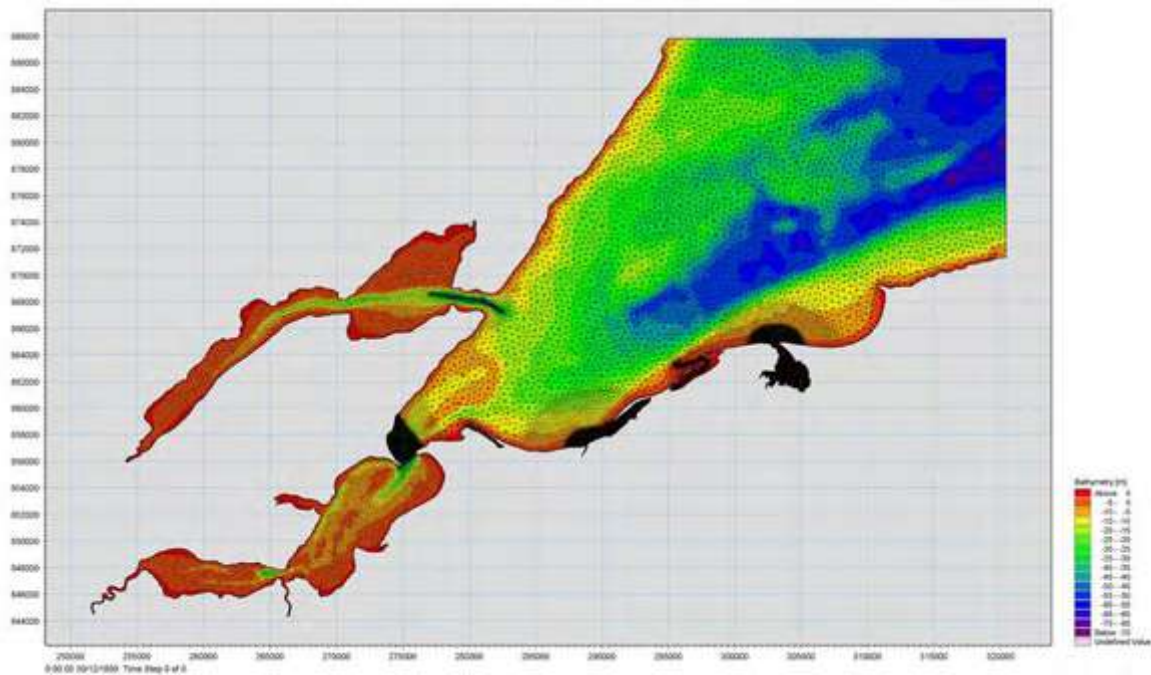
The IMFM was built with a resolution gradually varying from around 20 m to around 600 m near the offshore boundaries. This allows adequate representation of the physical processes in the areas of interest while delivering realistic model run times. The model mesh, extent and bathymetry are shown in Figure B-2.

Details of the model are summarised in Table B-2.

Table B-2: Hydrodynamic model specifications

Origin	250865E 843872N
Rotation angle	0°N
Mesh Element Size	Min 20 m, Max 600m
Mesh Area	70 km x 44 km
Vertical Datum	Mean Sea Level (MSL)
Bathymetry	Figure B-2
Boundary Data Type	Elevation
Bed Roughness	32 m ^{1/3} s ⁻¹
Time Step	Max 30 s
Boundary Time Step	600 s

Figure B-2: Inner Moray Firth Model (IMFM) Extent and Bathymetry



B.2.2 Boundary Conditions

IMFM boundary conditions were extracted from the calibrated Moray Coastal Modelling System (MCMS), which has a regular grid resolution of 1000 m. The MCMS was constructed, calibrated and validated in support of studies previously undertaken to investigate wastewater discharges.

B.2.3 River Inputs

Hydrodynamic behaviour may be influenced by larger river discharges. These have been accounted for by entering the key rivers as sources of flow in the hydrodynamic model. The rivers Alness, Peffery, Conan, Newhall Burn, Farrar, Glass, Ness, Nairn, Findhorn and Mosset Burn have been included in this way.

B.3 Oil Spill Modelling

The oil spill module includes representation of a wide variety of oil weathering processes or a range of different oils and environmental conditions. The underlying model is the Inner Moray Firth hydrodynamic model of current flows, which are driven by tidal and wind forcing. The processes incorporated in the oil spill module may be broadly summarised as:

- advection (due to tidal currents and wind drift);
- spreading;
- evaporation;
- dissolution;
- vertical dispersion;
- settling;
- biodegradation, and
- photo-oxidation.

B.4 Model Set-up

B.4.1 Oil Types

Medium crude was selected as being representative of the cargo oil involved in the STS transfer operations. Within the model the oil composition is specified in terms of the relative mass of four different components:

- Volatile oil fractions (weight below 160 g/mol, boiling point well below 300°C);
- Heavy oil fractions (weight above 160 g/mol, boiling point above 300°C);
- Wax;
- Asphaltenes.

Table B-3 shows the modelled total masses of these components.

Table B-3: Fractional Composition by Mass of Modelled Oil

Component	Mass (kg)
Volatile oil fraction	80
Heavy oil fraction	783
Wax	22
Asphaltenes	115
Total	1000

In addition to the mass composition, each oil type was modelled with suitable weathering parameters (the physical constants that describe the rate and nature of such processes as evaporation, dispersion, dissolution, etc.).

B.4.2 Oil Spill Mass

The assessment considered a reasonable worst case discharge that could occur during STS oil transfer operations. During a previous OTL application,

discussions were held between the Maritime & Coastguard Agency (MCA) and Scottish Natural Heritage (SNH) regarding the operational risks of oil spill during STS transfer. These concluded that a 1,000 kg (1 tonne) spill is a reasonable worst case and could result from a fractured transfer hose.

It should be noted that the purpose of the modelling assessment is to determine where the spill may be advected to, rather than attempting to predict the concentration of the oil upon impact. Therefore, the actual mass of oil is not critical to the prediction.

B.4.3 Discharge Regime

In order to simulate a near-instantaneous release of oil, the full mass of oil was released over a period of ten minutes. In the model the discharge was represented by a release of 10,000 particles every minute (100,000 particles in total).

B.4.4 Model Run Period

Each simulation was run for a full spring neap cycle of 15 days.

B.4.5 Tide Conditions

All releases were modelled as occurring at High Water (HW) on a mean spring tide (Invergordon). This was selected as a spring tide will produce greater advection of the slick than a neap tide, thereby minimising the time to impact and potentially impacting a larger area.

B.4.6 Wind Conditions

Model wind conditions were derived from the analysis of Metocean statistics from the Met Office WAVEWATCH III™ wave model archive. These data originate from the 8km resolution European model domain, which covers the period 1st January 2001 to 31st December 2010 in hourly intervals.

The yearly mean wind speed from all directions was used during the modelling to ensure consistency between scenarios. The wind directions applied in the models were selected to correspond to: the yearly predominant; towards the nearest northern shore; and towards the nearest southern shore.

B.5 Oil Spill Scenarios

Spills from three of the five STS anchorages were modelled as these adequately covered the range of potential impacts. These were the nearest location to the shoreline; the furthest from the shoreline and location 18a.

Table B-4 shows the wind scenarios and STS locations selected for modelling.

Table B-4: Oil spill model discharge scenarios and rationale

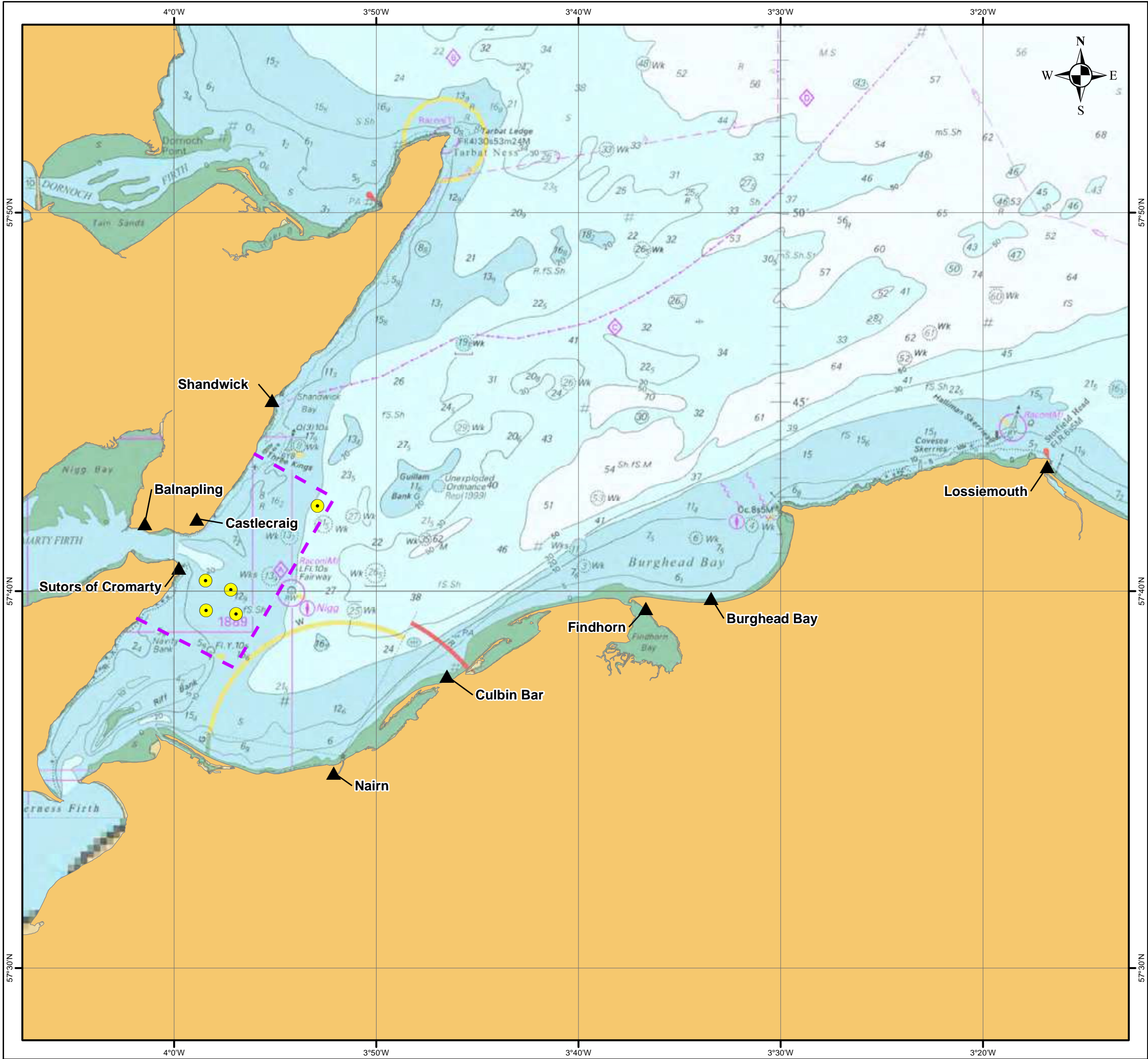
Scenario Number	Anchorage location	Wind direction (°)	Wind Speed* (knots)	Rationale
1	16	255	10	Yearly mean wind speed and direction. The wind direction corresponds to an offshore wind along the Moray Firth
2	18a	255	10	

3	14	135	10	Yearly mean wind speed. Wind direction towards the nearest northern shoreline. Anchorage locations selected as those closest to the shore.
4	16	135	10	
5	18a	135	10	
6	15	315	10	Yearly mean wind speed. Wind direction towards the nearest southern shoreline. Anchorage locations selected as those closest to the shore.
7	17	315	10	
8	18a	315	10	

*The mean yearly wind speed for all wind directions has been used in all scenarios to ensure consistency in magnitude for each wind direction assessed (see Section B.4.6)

B.6 Model Results

This section provides the modelling results for an oil spill under the wind conditions shown in Table B-4. It should be noted that the results are strongly dependent on the wind conditions, and as such variation in wind direction may result in a change in beaching information. Figure B-3 shows the locations referred to in this section.



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Oil Transfer Licence Application Figure B-3: Locations referenced within the modelling results

Legend

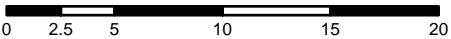
- ▲ Locations
- STS Locations
- Cromarty Firth Harbour Limit

NOTE: Not to be used for Navigation

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Datum	D_WGS_1984
Data Source	UKHO, CFPA, OSOD
File Reference	J:\P1946\Mxd\Report\Appendix_B\mxd Geo_Overview
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Reviewed By	Ian Charlton
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B.6.1 Scenarios 1 and 2 (west-south-westerly wind (255°))

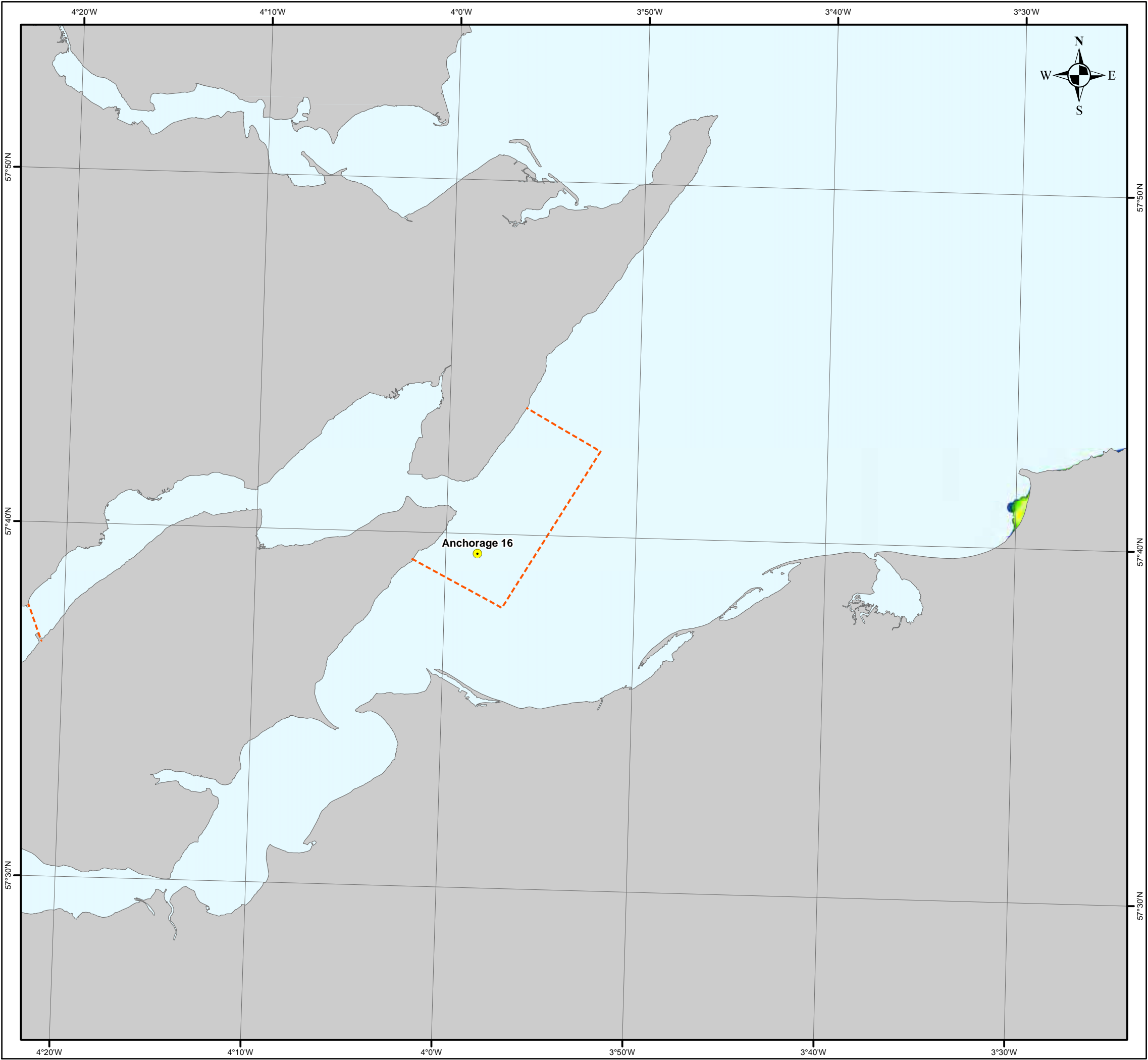
Scenario 1

Figure B-4 indicates that the initial beaching of oil will occur along the coastline of Burghead Bay after approximately 15 hours.

Scenario 2

The discharge from anchorage 18a was predicted to travel outside the model domain after approximately 16 hours. At this time the oil mass had been reduced to less than 0.0000025 kg/m^2 , and was located close to the coastline at Lossiemouth (Figure B-5).

The path of the slick is similar to that shown for the discharge at anchorage 16; and although the tracks showed some influence from the currents, the wind was the driving force for the oil transport.



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Figure B-4: Scenario 1, Initial Beaching Location from an Oil Discharge from Anchorage 16

Legend

- STS Locations
- - - Cromarty Firth Harbour Limit

Oil mass (kg/m²)

- Below 0.00000075
- 0.00000075 - 0.0000025
- 0.0000025 - 0.0000075
- 0.0000075 - 0.000025
- 0.000025 - 0.000075
- 0.000075 - 0.00025
- 0.00025 - 0.00075
- 0.00075 - 0.0025
- 0.0025 - 0.0075
- Above 0.0075



NOTE: Not to be used for Navigation

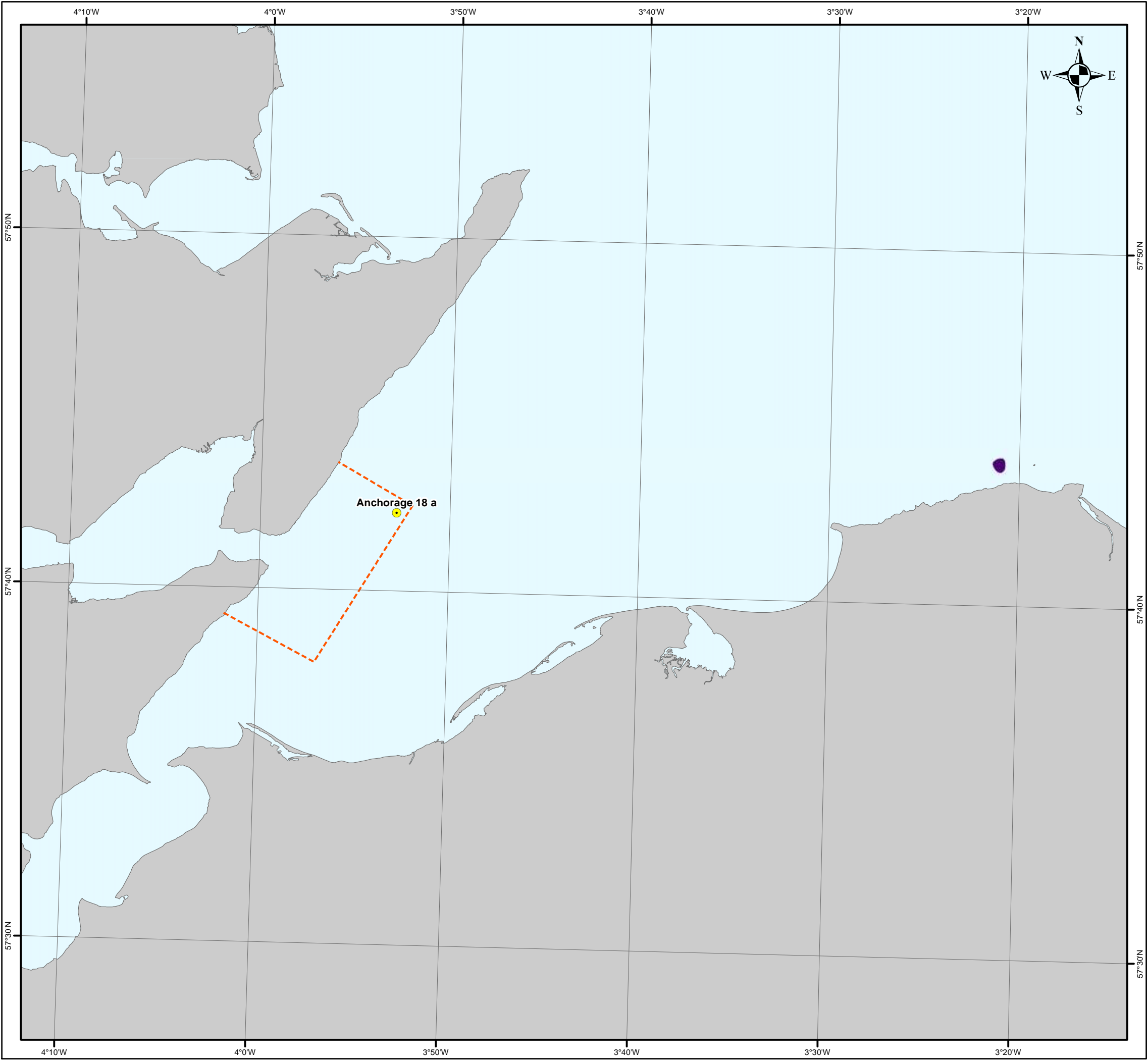
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Figure B-5: Scenario 2, Oil Discharge from Anchorage 1

Legend

- STS Locations
- - - Cromarty Firth Harbour Limit

Oil mass (kg/m²)

- Below 0.00000075
- 0.00000075 - 0.0000025
- 0.0000025 - 0.0000075
- 0.0000075 - 0.000025
- 0.000025 - 0.000075
- 0.000075 - 0.00025
- 0.00025 - 0.00075
- 0.00075 - 0.0025
- 0.0025 - 0.0075
- Above 0.0075

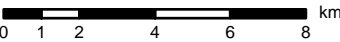


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B.6.2 Scenarios 3 - 5 (south-easterly wind (135°))

Scenario 3

A discharge at anchorage 14 with a south easterly (135°) wind is predicted to result in beaching in the vicinity of Castlecraig (Figure B-6). Initial beaching is predicted to occur after 1.3 hours (80 minutes).

The modelled discharge, as with all scenarios, was timed to coincide with high water (see Section B.4.5). Therefore, in the initial period following the discharge, currents would be moving from a slack tide to an ebb tide (i.e. out of the Cromarty Firth). The model shows that during this period the slick direction is determined primarily by the applied wind. Opposing wind and surface current conditions will increase the surface roughness, which could potentially increase the rate of the processes acting on the oil (evaporation, dispersion, emulsification etc.). However, as the model considers a group four oil, it is felt that this will not significantly impact the results of the model (due to the low percentage of volatile fractions and low potential for water uptake etc.)

Although the time of the discharge, in relation to the currents, may have a small impact on the timing of the beaching event, the modelled wind is likely to remain the dominant factor. It therefore follows that a discharge during a south easterly wind (90°) will result in oil entering the Cromarty Firth, and potentially beaching.

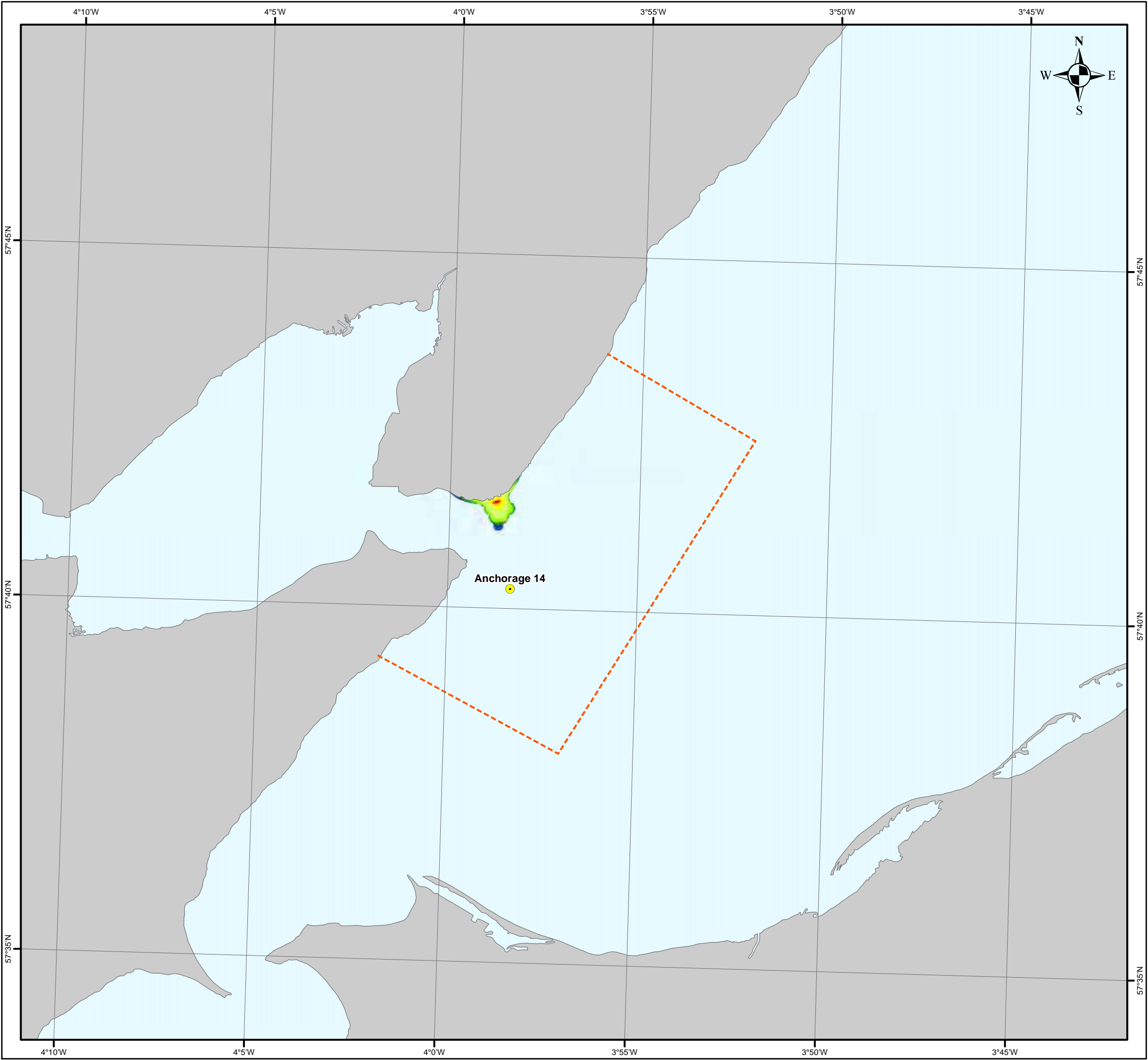
Scenario 4

A discharge at anchorage 16 in a south easterly (135°) wind is predicted to result in an initial beaching event in the vicinity of the Sutors of Cromarty (Figure B-7). This event is predicted to occur after 1.3 hours (80 minutes). A section of oil was seen to break away from the main slick and beach on the northern shore of the entrance to Cromarty Firth (in the vicinity of Castlecraig) after 4.3 hours.

As with all scenarios, a change in wind direction may result in a subsequent change in the predicted beaching location. However, it is considered that an incursion of oil into Cromarty Firth past Nigg is unlikely even during low wind speeds.

Scenario 5

The oil discharge at anchorage 18a during a south easterly wind is predicted to result in the beaching of oil in the vicinity of Shandwick) after approximately 2.7 hours (Figure B-8). The oil is predicted to leave the harbour limit after approximately 1 hour.



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Figure B-6: Scenario 3, Initial Beaching Location from an Oil Discharge form Anchorage 14

Legend

- STS Locations
- - - Cromarty Firth Harbour Limit

Oil mass (kg/m²)

- Below 0.00000075
- 0.00000075 - 0.0000025
- 0.0000025 - 0.0000075
- 0.0000075 - 0.000025
- 0.000025 - 0.000075
- 0.000075 - 0.00025
- 0.00025 - 0.00075
- 0.00075 - 0.0025
- 0.0025 - 0.0075
- Above 0.0075

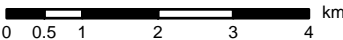


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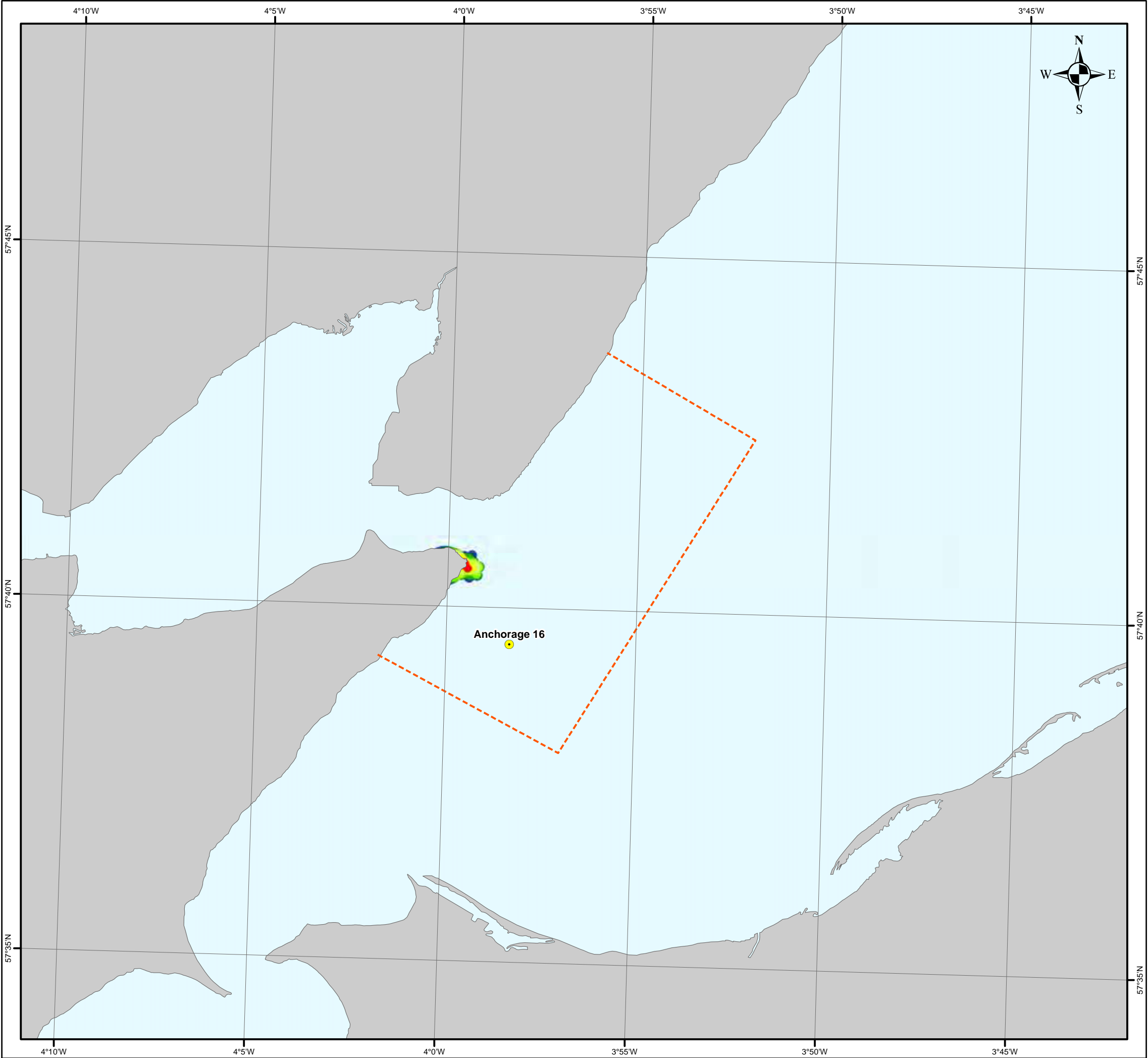
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Figure B-7: Scenario 4, Initial Beaching Location from an Oil Discharge form Anchorage 16

Legend

- STS Locations
- - - Cromarty Firth Harbour Limit

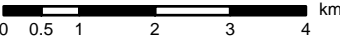
Oil mass (kg/m²)

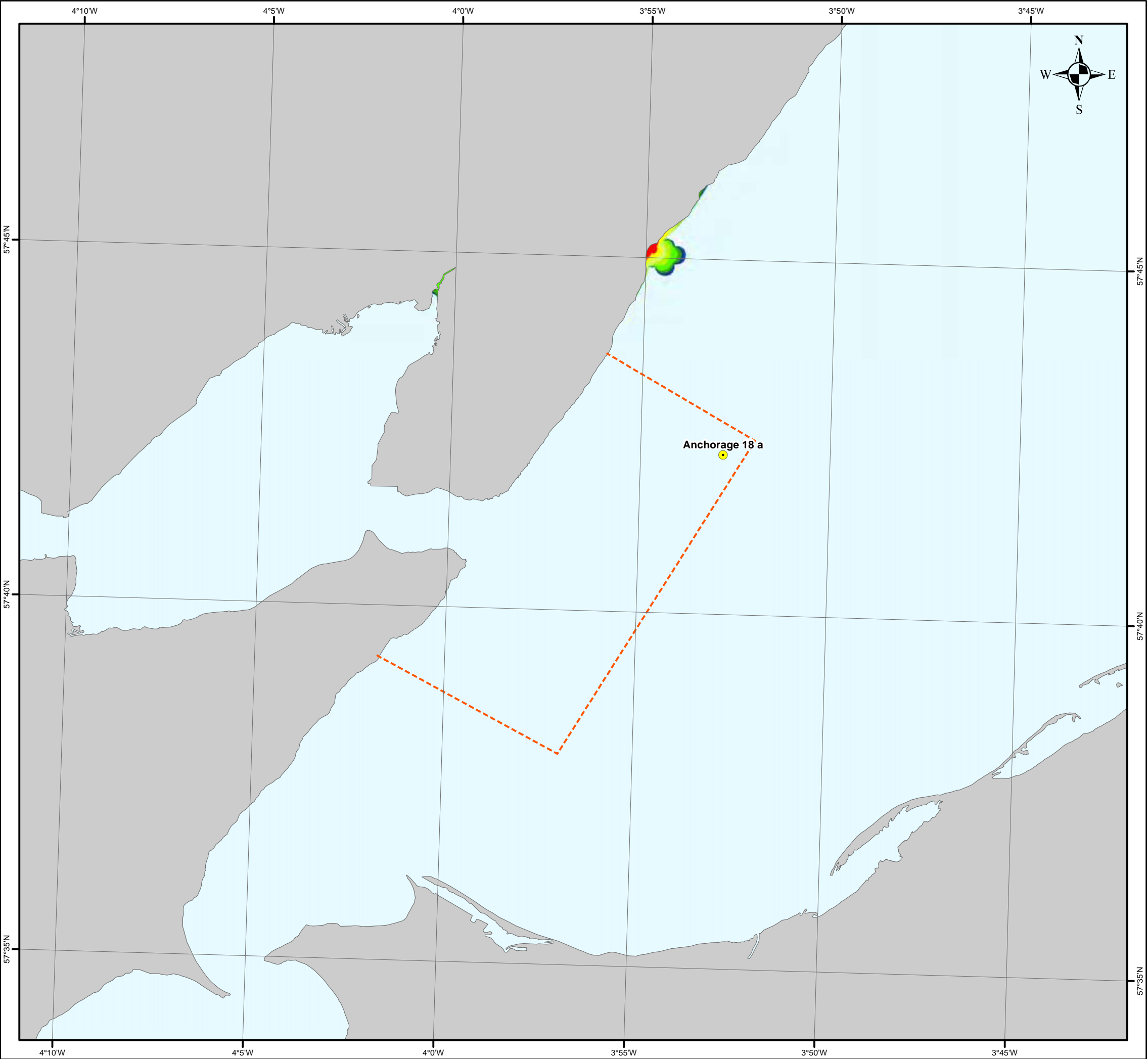
- Below 0.00000075
- 0.00000075 - 0.0000025
- 0.0000025 - 0.0000075
- 0.0000075 - 0.000025
- 0.000025 - 0.000075
- 0.000075 - 0.00025
- 0.00025 - 0.00075
- 0.00075 - 0.0025
- 0.0025 - 0.0075
- Above 0.0075



NOTE: Not to be used for Navigation

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Reviewed By	Ian Charlton
Approved By	Chris Mooij





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Figure B-8: Scenario 5, Initial Beaching Location from an Oil Discharge form Anchorage 18a

Legend

- STS Locations
- - - Cromarty Firth Harbour Limit

Oil mass (kg/m²)

- Below 0.00000075
- 0.00000075 - 0.0000025
- 0.0000025 - 0.0000075
- 0.0000075 - 0.000025
- 0.000025 - 0.000075
- 0.000075 - 0.00025
- 0.00025 - 0.00075
- 0.00075 - 0.0025
- 0.0025 - 0.0075
- Above 0.0075

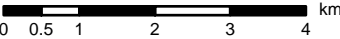


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Created By	Emma Langley
Reviewed By	Ian Charlton
Approved By	Chris Mooij



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B.6.3 Scenarios 6 - 8 (north-westerly wind (315°))

Scenario 6

A discharge at anchorage 15 during a north-westerly (315°) wind is predicted to result in an initial beaching event on Culbin Bar after approximately 5 hours (Figure B-9). A secondary beaching location is predicted to occur behind the bar. However, this secondary location will be of a smaller mass of oil.

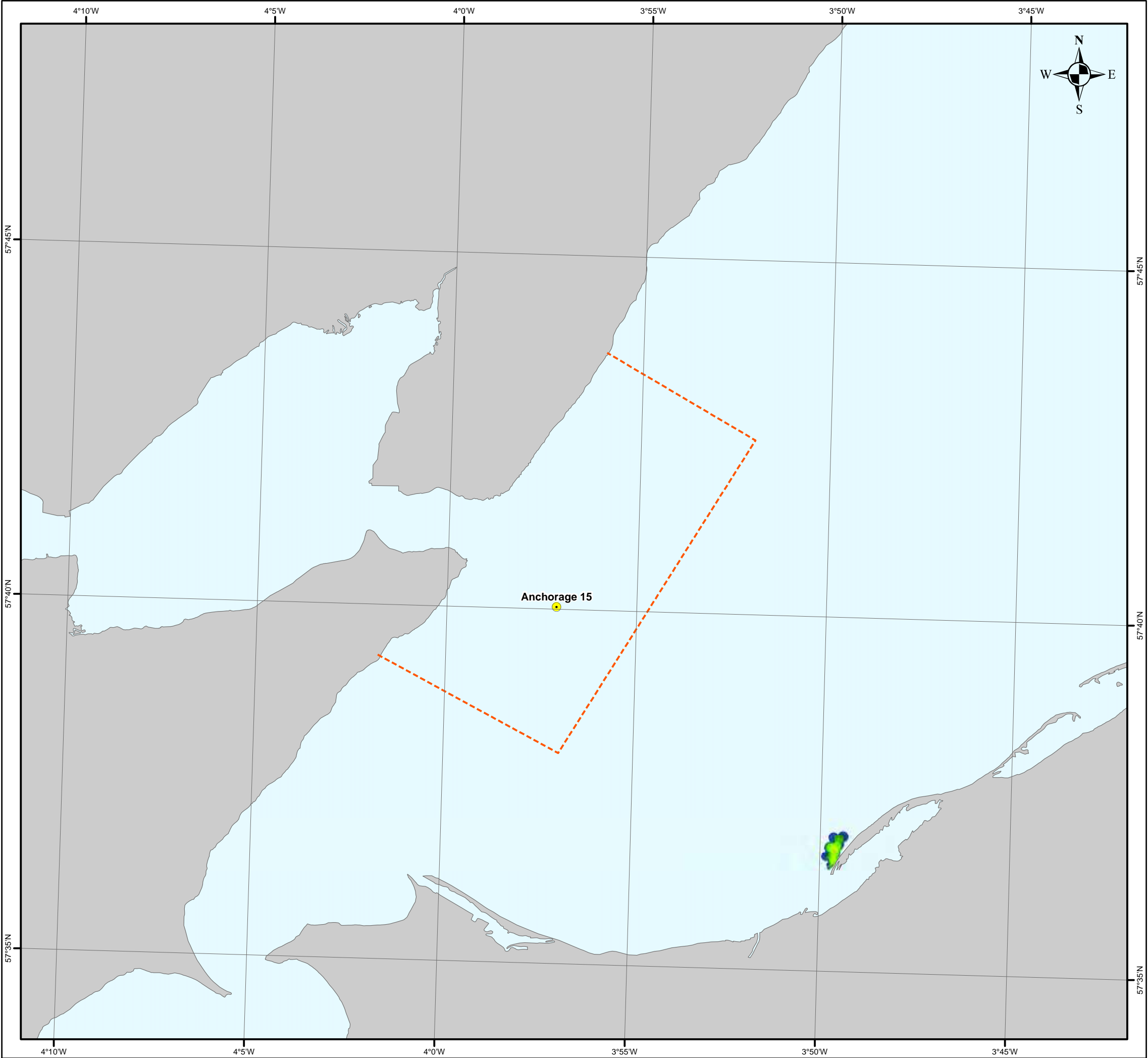
The oil slick is predicted to move beyond the harbour limits after 1.7 hours.

Scenario 7

The discharge at anchorage 17 is predicted to move beyond the harbour limits within 1 hour. The initial beaching event is predicted to occur after 4.7 hours, at Culbin Bar (Figure B-10). This beaching/stranding is predicted to occur whilst the sand banks are exposed. A secondary beaching event is predicted to occur after approximately 11 hours, as the tidal height increases.

Scenario 8

The discharge at anchorage 18a is predicted to move beyond the harbour limits within 1.3 hours. The initial beaching event is predicted to occur after 5.3 hours, along the eastern end of Culbin Bar. Figure B-11 show the oil mass located slightly off of the Culbin Bar, which is thought to be due to it initially beaching location being exposed during low water. The model indicated that the oil would subsequently move onto the north eastern end of the Dunlin Bar.



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Figure B-9: Scenario 6, Initial Beaching Location from an Oil Discharge form Anchorage 15

Legend

●

 STS Locations

 Cromarty Firth Harbour Limit

Oil mass (kg/m²)

Below 0.00000075

0.00000075 - 0.0000025

0.0000025 - 0.0000075

0.0000075 - 0.000025

0.000025 - 0.000075

0.000075 - 0.00025

0.00025 - 0.00075

0.00075 - 0.0025

0.0025 - 0.0075

Above 0.0075

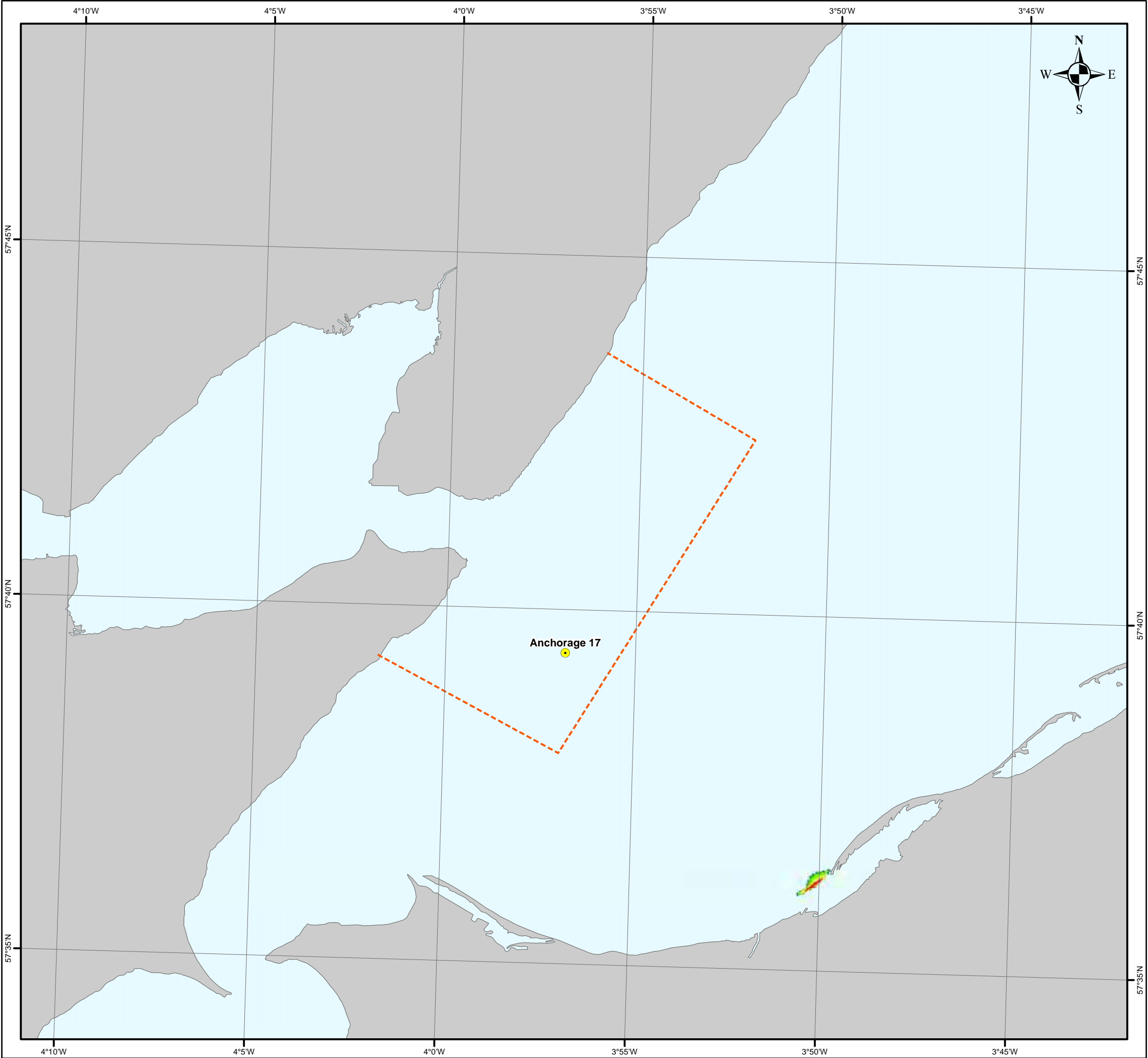
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Created By	Emma Langley
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00.51234

km

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Figure B-10: Scenario 7, Initial Beaching Location from an Oil Discharge form Anchorage 17

Legend

- STS Locations
- - - Cromarty Firth Harbour Limit

Oil mass (kg/m²)

- Below 0.00000075
- 0.00000075 - 0.0000025
- 0.0000025 - 0.0000075
- 0.0000075 - 0.000025
- 0.000025 - 0.000075
- 0.000075 - 0.00025
- 0.00025 - 0.00075
- 0.00075 - 0.0025
- 0.0025 - 0.0075
- Above 0.0075

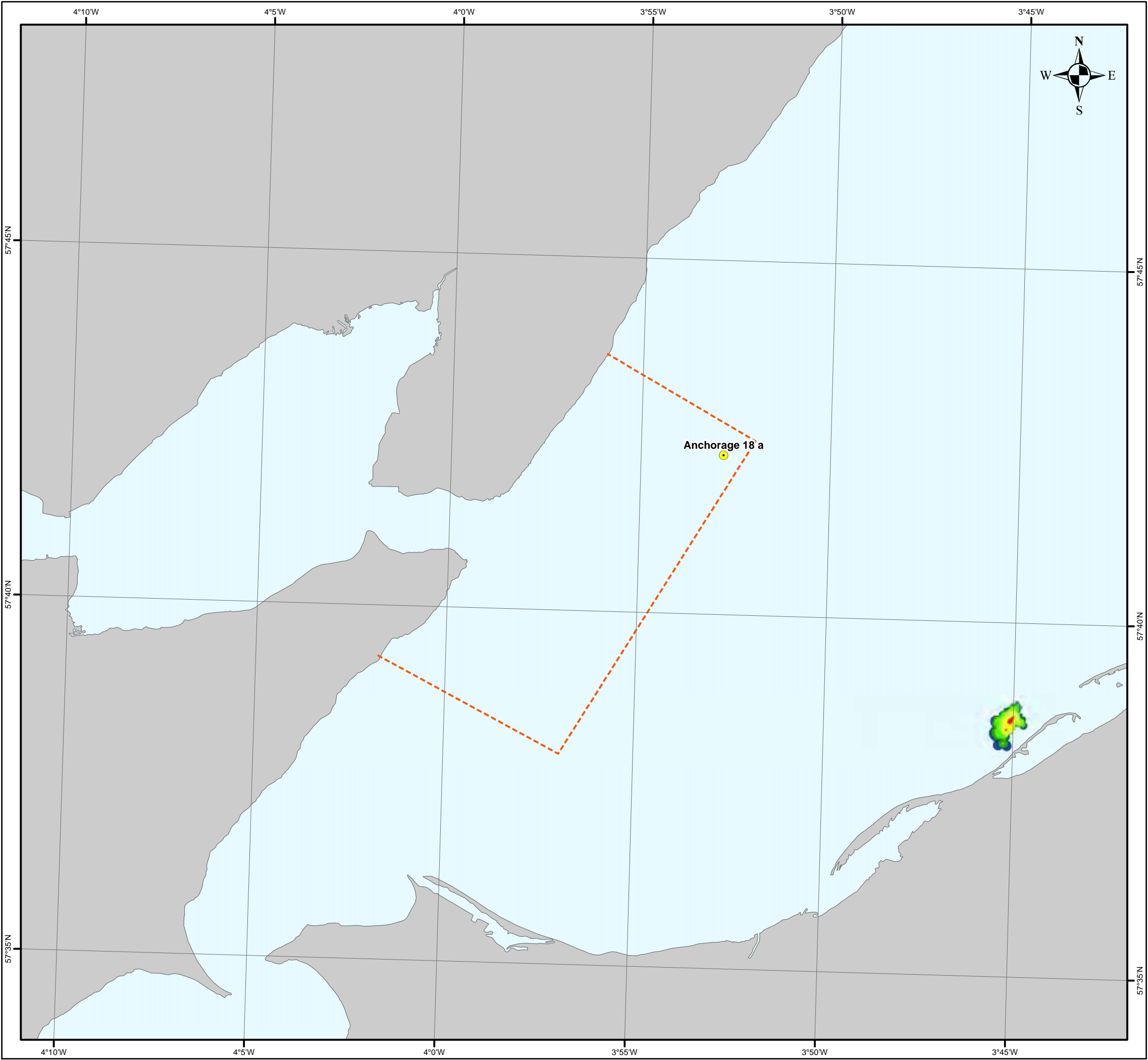


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0 0.5 1 2 3 4 km



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Figure B-11: Scenario 8, Initial Beaching Location from an Oil Discharge form Anchorage 18a

Legend

- STS Locations
- - - Cromarty Firth Harbour Limit

Oil mass (kg/m²)

- Below 0.00000075
- 0.00000075 - 0.0000025
- 0.0000025 - 0.0000075
- 0.0000075 - 0.000025
- 0.000025 - 0.000075
- 0.000075 - 0.00025
- 0.00025 - 0.00075
- 0.00075 - 0.0025
- 0.0025 - 0.0075
- Above 0.0075

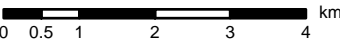


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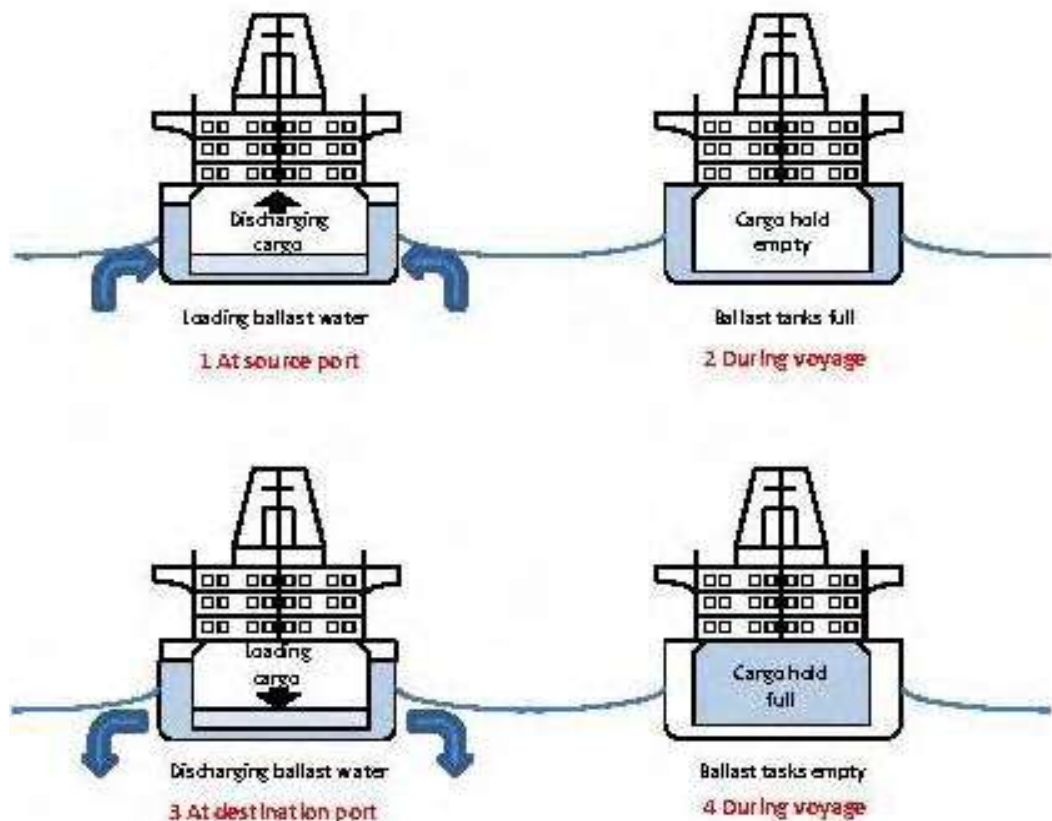
B.7 Ballast Water Discharge Modelling

B.7.1 Ballast Water

Ballast water is fresh or salt water that is held in, or discharged from, specially constructed and segregated tanks (i.e. meaning that ballast water cannot mix with other cargo, such as oil). Ballast water is used to provide stability and manoeuvrability during vessel transit, especially when the vessel is not carrying cargo.

When ballast water is taken on-board it may contain organisms and chemicals from the source port. This ballast water will then be retained by the vessel for reasons of stability and will be transported to the destination port (e.g. Cromarty Firth). At the destination port, the ballast water may get discharged to compensate for the weight of cargo taken on-board. Many of the organisms in the ballast water will have died during the voyage, some will die due to the change in environment after discharge, and some will die naturally following discharge. Others may survive. These are referred to as non-native species (NNS). Depending on the origin, many of the discharged organisms are likely to pose no environmental risk. The transport and discharge of ballast water is summarised in Figure B-12.

Figure B-12: Transport and Discharge from Segregated Ballast Water Tanks



B.8 Pathways for Non-Native Species

There are numerous potential vectors for the introduction of NNS, which include: ballast water discharge, attachment to vessel hulls; natural migration, aquaculture, and leisure craft.

This Briefing Note considered the ballast water discharge pathway. Vessels discharging ballast water can have direct impacts through the introduction of NNS (e.g. that prey on native species, change the food web, decrease biodiversity).

B.9 International Maritime Organisation Ballast Water Management Convention

The International Maritime Organisation (IMO) Ballast Water Management (BWM) Convention provides numeric targets/standards for phytoplankton and zooplankton concentration. These standards are used for reference as European legislation does not provide specific targets.

The BWM Convention is summarised to provide a reference point for quantitative environmental.

B.9.1 Background

The International Convention for the Control and Management of Ships Ballast Water and Sediments (BWM Convention), was adopted by consensus in February 2004 at the IMO. The BWM Convention will come into force 12 months after ratification by 30 States. CFPA wishes to operate in accordance with the BWM Convention.

B.9.2 General Requirements

The ballast water management regulations will be phased in over a period of time. As an intermediate solution, ships should exchange ballast water mid-ocean. However, eventually most ships will need to install an on-board ballast water treatment system.

B.9.3 Exchange

The BWM Convention recommends ballast water exchange until reliable on board treatment facilities are developed and available. Under the BWM Convention, ballast water exchange will be required to comply with Regulation D-1 (Ballast Water Exchange Regulation) as set out below.

Compliance with Regulation D-1 means.....

exchanging with an efficiency of at least 95 per cent volumetric exchange of ballast water. Ships exchanging water by the pumping through method should pump through three times the volume of each ballast water tank to meet the requirements for 95 per cent volumetric exchange, unless they can demonstrate that at least 95 per cent volumetric exchange is met

In addition, Regulation B-4 states that all ships using ballast water exchange should, whenever possible, exchange water at least 200 nautical miles from the nearest land and in water of at least 200 meters in depth, and in all cases at least 50 nautical miles from the nearest land and in water at least 200 meters in depth. When this cannot be met the port state may designate a ballast water exchange zone.

Guidelines adopted by the IMO (G14) *Guidelines on designation of areas for ballast water exchange* provides guidance for identification, assessment and designation of sea areas where ships may conduct ballast water exchange (Resolution MEPC 151(55)). *Guidelines for ballast water exchange design and construction standards* (G11) outline recommendations for the design and construction of ships to assist in compliance with Regulation D-1 (Resolution MEPC 149(55)).

B.9.4 Treatment

Treatment is the end goal of the BWM Convention and the Convention and its associated guidelines set out regulations and advice on the development and standards for ballast water treatment systems.

Under the BWM Convention, ballast water treatment is required to be compliant with Regulation D-2 (Ballast Water Performance Regulation) as set out below.

Compliance with Regulation D-2 means.....

discharge of less than 10 viable organisms per cubic metre greater than or equal to 50 micrometres in minimum dimension, and less than 10 viable organisms per millilitre less than 50 micrometres in minimum dimension and greater than or equal to 10 micrometres in minimum dimension. Discharge of indicator microbes shall not exceed specified concentrations.

B.10 Hydrodynamic Connectivity Index

Intertek defined a quantitative scale to determine the degree of hydrodynamic connectivity that exists between a release site and impact site. This scale is known as the Hydrodynamic Connectivity Index (HCI) and is presented in Table B-5. The lower HCI score represents a higher degree of connectivity and therefore a higher potential for NNS.

While the IMO Regulations D-1 and D-2 provide the official ballast water regulations, the HCI is primarily based on the recommendations in the SGBOSV document (MEPC, 2003). The recommendations in the SGBOSV document are more conservative than IMO Regulations D-1 and D-2, and were as a precautionary measure. The SGBOSV document recommends that, on discharge, ballast water concentrations must be at least 1,000 times lower than median values in raw ballast water, through treatment or management. This recommendation has been adopted to define a Reduction Standard of 1,000 reductions for discharged ballast waters. This Reduction Standard is equivalent to a value of 1 on the HCI scale.

Reduction Standard = 3 orders of magnitude reduction = 1,000 dilutions = 1 HCI

This Reduction Standard has been applied as an environmental standard, rather than a discharge standard. In other words, it is assumed that this target must be achieved at sensitive sites through treatment/management of the ballast water discharge and through subsequent dilution in the environment. In fact, the modelling has just considered reductions through dilution, and not through other measures such as treatment.

Table B-5: HCI with the associated dilution factor for each band

Connectivity (HCI)	Dilution Factor	Minimum times greater than Reduction Standard	Orders of magnitude reduction
10,000	> 10,000,000	10,000	>7
3,000	10,000,000-3,000,000	3,000	6.5
1,000	3,000,000-1,000,000	1,000	6
300	1,000,000-300,000	300	5.5
100	300,000- 100,000	100	5
30	100,000-30,000	30	4.5
10	30,000-10,000	10	4
3	10,000-3,000	3	3.5
1	3,000-1,000	1	3
< 1	1,000-1	Less than the Reduction Standard	< 3

The HCI scale has been used in the legend of the contour plots of impact. The assessment adds further precaution with the maximum connectivity/lowest HCI band/fewest dilutions being used across the range. For example, the 3,000 – 10,000 dilution factor band is assigned an HCI of 3 in the plot legend. If any cell within the model is predicted to have an HCI of less than 1 then it is said to have not met the Reduction Standard.

B.11 Organism Concentrations

In accordance with suggestions from Scottish Natural Heritage (SNH) on a previous assessment of ballast water impacts all modelling was presented in terms of the HCI. The rationale for this was to determine the degree of connectivity between release sites and protected sites. HCI is independent of species and therefore can be used to determine the number of reductions achieved for any species. Therefore, it follows that HCI can be used for both zooplankton and phytoplankton.

HCI is limited by factors such as species mortality that are not accounted for, as this would require species-specific information. Therefore, all organisms released are taken to be immortal despite a large body of evidence stating that the vast majority of organisms will die following release.

In addition to concentrations, the HCI value is presented to allow species-independent calculations. It should be noted that zooplankton are the more limiting factor when put into the context of Regulation D-2.

In order to provide context, results were compared to Regulation D-2 of the IMO BWM Convention. Regulation D-2 specifies that treated and discharged ballast water must have:

(A): fewer than ten viable organisms greater than or equal to 50 micrometres in minimum dimension per cubic metre (assumed as zooplankton in this assessment)

(B): fewer than ten viable organisms less than 50 micrometres in minimum dimension and greater than or equal to 10 micrometres in minimum dimension per millilitre (assumed as phytoplankton in this assessment)

The HCI scale resolves impacts to 10,000,000 dilutions (i.e. 10,000 HCI). Dilutions explicitly reflect impact concentrations for a given discharge concentration. The HCI legend on the contour plot resolves impacts to 300 (300,000 dilutions) which are undetectable concentrations in modern laboratories.

The assessment used a recommended ballast tank concentration (MEPC, 2003). Discharges were made at this concentration and their impacts compared directly with the BWM Convention D-2 Regulation. This approach allowed ballast water discharge impacts to be expressed as concentrations and HCI values simultaneously which can be compared directly with Regulation D-2 (i.e. concentration) and guidance provided to the IMO (i.e. HCI/dilutions).

The conventions used in the impact assessment are shown in Table B-6.

Table B-6: Conventions in assessment plot legends

HCI Band	Concentration		Comment
	Zooplankton/m ³	Phytoplankton/m ³	
300 – 30	0.001 – 0.01	33-333	A minimum of 1000 times better than the IMO BWM D-2 Regulation. This concentration cannot be detected in laboratories.
30 -3	0.01 – 0.1	333-3325	A minimum of 100 times better than the IMO BWM D-2 Regulation. This concentration cannot be detected in laboratories.
3 – 0.3	0.1 – 1	3325-33250	A minimum of 10 times better than the IMO BWM D-2 Regulation. This concentration cannot be detected in laboratories.
0.3-0.03	1-10	33250-333250	Compliant with the IMO BWM D-2 Regulation. This concentration can only be detected in specialist laboratories.
<0.03	>10	>332500	NOT compliant with the IMO BWM D-2 Regulation.

Concentrations which are presented as yellow and turquoise are below the detectable limits of laboratories. Orange, yellow and turquoise are compliant with the BWM Convention D-2 regulation. Red is not compliant with the BWM Convention. The processed concentrations assume a median concentration of zooplankton in the unexchanged ballast tank. The equivalent HCI banding has been presented in the legend of the plots.

B.12 Model Limitations

Despite the IMFM replicating the physical processes and movements of the bodies of water, it is not able to replicate the complex and dynamic biological systems present. The model is not able to quantify the following:

- Predation
- Grazing
- Disease
- Nutritional demands
- Reproduction
- Movement (swimming) or
- Potential 'stepping stone' processes

It has been assumed that single-celled organisms (phytoplankton and zooplankton) are not capable of independent movement, such as swimming (i.e. *active transport*) and are moved by currents only (i.e. *passive transport*). In addition, it is not possible to model or quantify the ability of these organisms to colonise structures and subsequently move to the next structure – the 'stepping stone' process. To account for this, conservative parameters have been used (e.g. assuming zero mortality of organisms) and in the final analysis we estimate how much worse things would need to get under active transport in order to approach the IMO D2 Regulation standards.

B.13 IMFM set-up

The hydrodynamic model was used to drive a water quality model, based on a particle tracking approach. This water quality model allowed predictions to be made of the transport and fate of pollutants (i.e. ballast water) discharged from selected locations over a specified time period.

B.13.1 Ballast Water Discharge

The ballast water discharge was modelled as a continuous discharge over a period of 12 hours, at a rate of 3,333 tonnes per hour (0.926 m³/s). This was modelled as a conservative tracer (i.e. no decay was applied), and under calm conditions (i.e. no winds).

B.13.2 Model Run Period

All discharges were tracked for two months (60 days), four spring-neap tidal cycles) in order to fully assess the transport pathways. This is considered a conservative period due to the likelihood of high mortality rates once released to the environment.

B.13.3 Wind Conditions

The model was run under calm conditions (i.e. no wind)

B.14 Model Scenarios

B.14.1 STS Discharge

The model considered discharge of a large transfer (40,000 tonnes) over a 12 hour period at each of the five anchorage locations (See Table 1-1 for location details). The model was run under calm (no wind) conditions to provide the worst case scenario in terms of ballast water dilution (i.e. low dilution).

B.14.2 In-combination Discharge

For the in-combination assessment of discharge of ballast water from vessels at Nigg Oil Terminal a volume of 35,000 tonnes was released over a 12 hour period at the Nigg Oil Terminal jetty. Two scenarios were run for the Nigg Oil Terminal ballast water release: one assuming no exchange or treatment of the ballast water and one assuming discharge of exchanged ballast water, in accordance with the IMO BWM Convention (see section B.9.3).

In addition at Invergordon Service Base, Admiralty Pier, Queens Dock, Phase 3 Berth and Saltburn Pier a small volume of 3,000 tonnes was released over a two hour period at each location. This represents a worst case in-combination discharge of ballast water from smaller vessels operating within the Harbour waters. Simultaneous discharge at all these locations in the harbour is unlikely to occur in reality. For these discharges ballast water release was modelled assuming no exchange or treatment.

The model was run under calm (no wind) conditions to provide the worst case scenario in terms of ballast water dilution (i.e. low dilution).

B.15 Model Results

B.15.1 STS Discharge

The model results for the discharge of exchanged ballast water at STS locations are shown in terms of the HCl band and the predicted zooplankton and phytoplankton concentrations per cubic metre (Figure B-13 to Figure B-17). The figure's contours show the maximum value (HCl/concentrations) predicted at any point in time for every location in the modelled 60 day period. The maximum concentration at each model point will not occur at the same time in reality. Therefore, contours show a composite of all maximum concentrations.

Inner Plume:

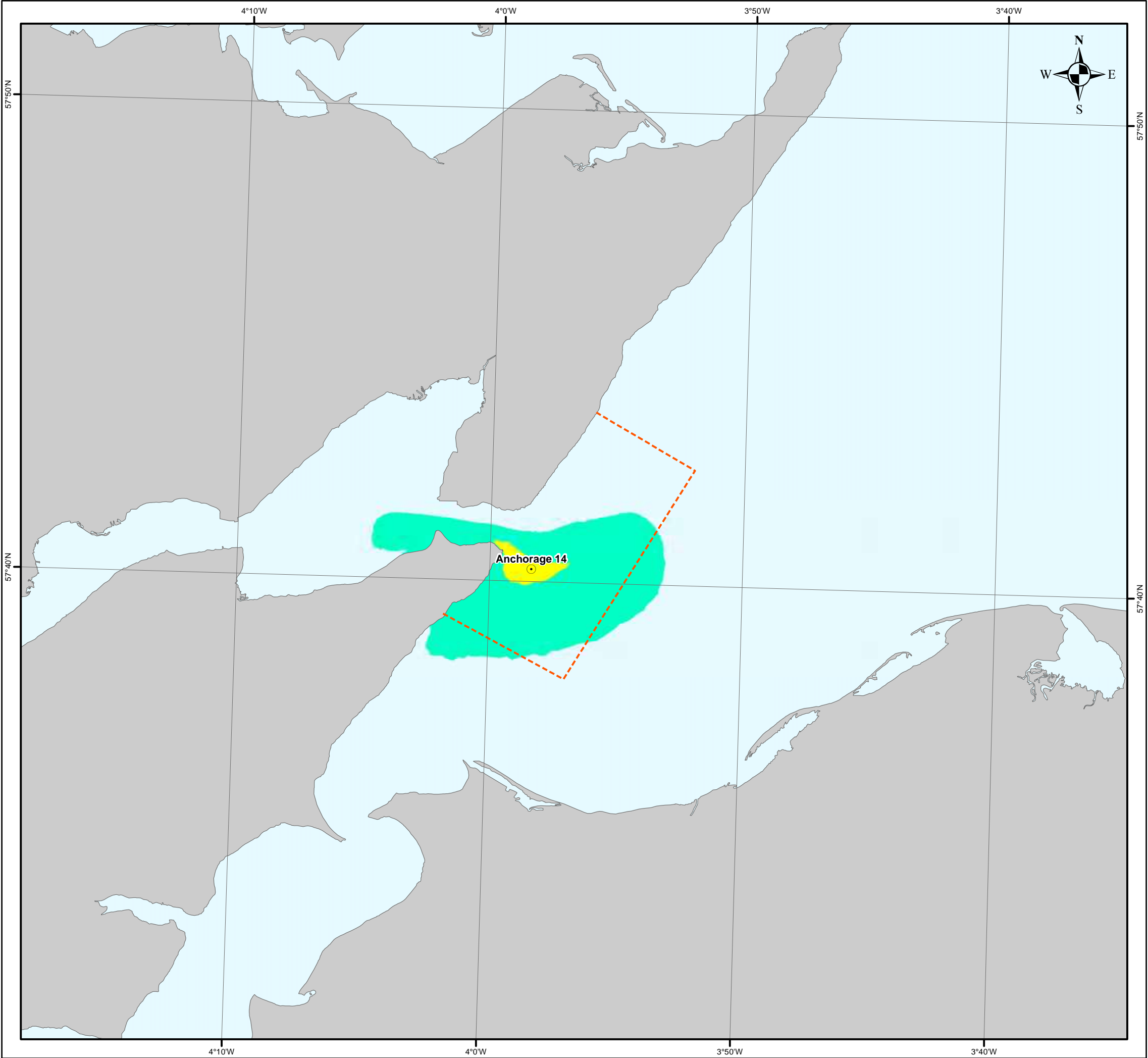
In all scenarios the model predicts a maximum HCl of 3 close to the centre of the plume. This means concentrations are at least three times lower (i.e. three times better) than the reduction standard.

Worst case zooplankton concentrations are predicted to be 0.1 per m³. Which is approximately 100 times lower (i.e. better) than the BWM D-2 standard.

Outer Plume:

The outer edge of the plume is delineated by:

- 300 HCl (i.e. 300 times better than the reduction standard)



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Figure B-13: Maximum Plot of Exchanged
Ballast Discharge at Anchorage 14

Legend

- STS Locations
- Cromarty Firth Harbour Limit

HCI Band	Zooplankton/m ³	Phytoplankton/m ³
300 - 30	0.001 - 0.01	33 - 332
30 - 3	0.01 - 0.1	332 - 3,325
3 - 0.3	0.1 - 1	3,325 - 33,250
0.3 - 0.03	1 - 10	33,250 - 332,500
<0.03	>10	> 332,500

FOR CONTEXT

Reduction Standard : HCI 1

BWM Convention Regulation D-2 :
Zooplankton : <10 per m³
Phytoplankton : <10,000,000 per m³

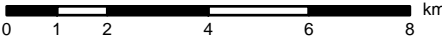


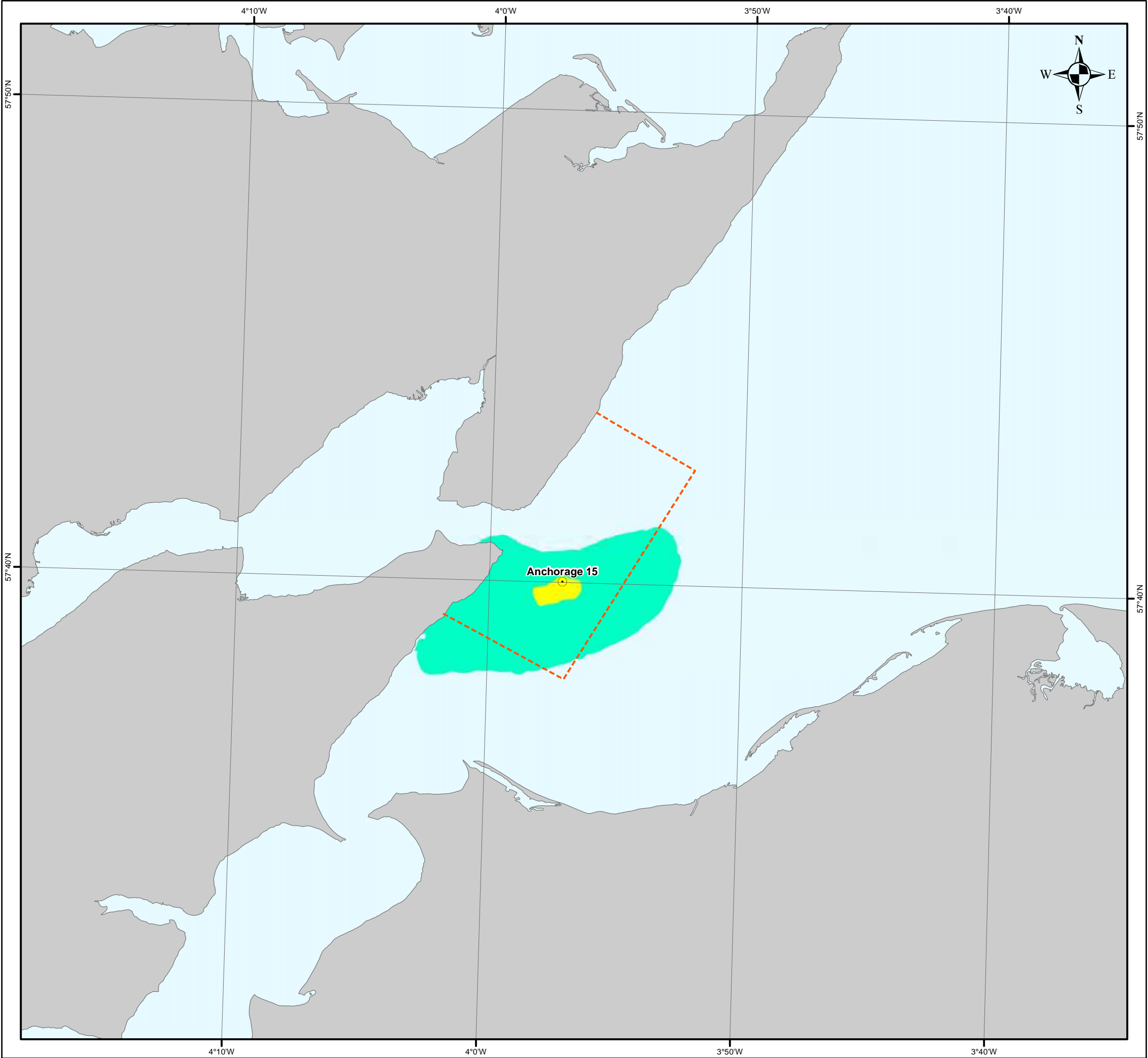
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Reviewed By	Ian Charlton
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Figure B-14: Maximum Plot of Exchanged Ballast Discharge at Anchorage 15

Legend

- STS Locations
- - - Cromarty Firth Harbour Limit

HCI Band	Zooplankton/m ³	Phytoplankton/m ³
300 - 30	0.001 - 0.01	33 - 332
30 - 3	0.01 - 0.1	332 - 3,325
3 - 0.3	0.1 - 1	3,325 - 33,250
0.3 - 0.03	1 - 10	33,250 - 332,500
<0.03	>10	> 332,500

FOR CONTEXT

Reduction Standard : HCI 1

BWM Convention Regulation D-2 :
Zooplankton : <10 per m³
Phytoplankton : <10,000,000 per m³

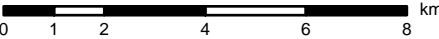


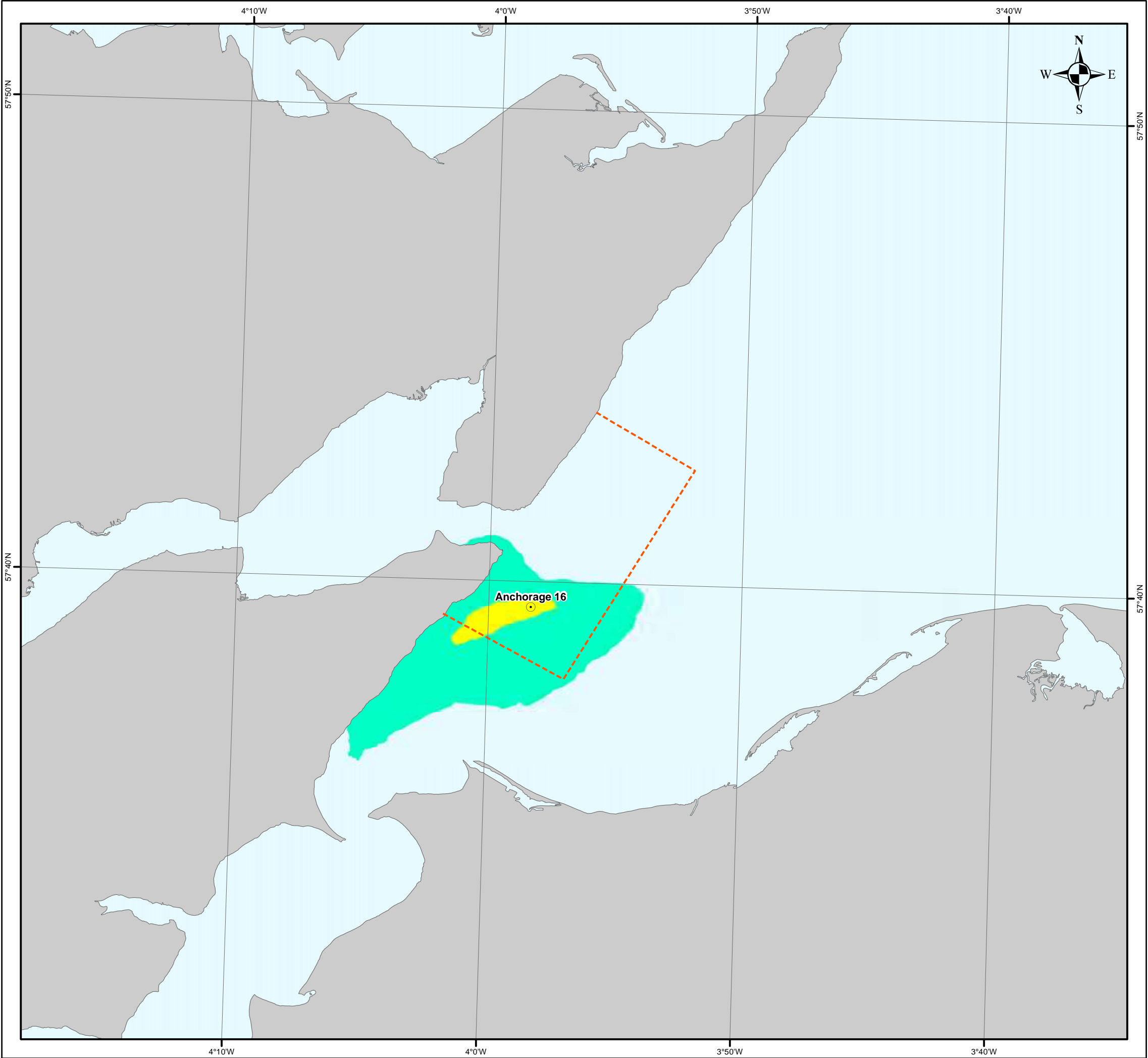
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Figure B-15: Maximum Plot of Exchanged Ballast Discharge at Anchorage 16

Legend

- STS Locations
- - - Cromarty Firth Harbour Limit

HCI Band	Zooplankton/m ³	Phytoplankton/m ³
300 - 30	0.001 - 0.01	33 - 332
30 - 3	0.01 - 0.1	332 - 3,325
3 - 0.3	0.1 - 1	3,325 - 33,250
0.3 - 0.03	1 - 10	33,250 - 332,500
<0.03	>10	> 332,500

FOR CONTEXT

Reduction Standard : HCI 1

BWM Convention Regulation D-2 :
Zooplankton : <10 per m³
Phytoplankton : <10,000,000 per m³

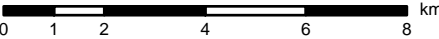


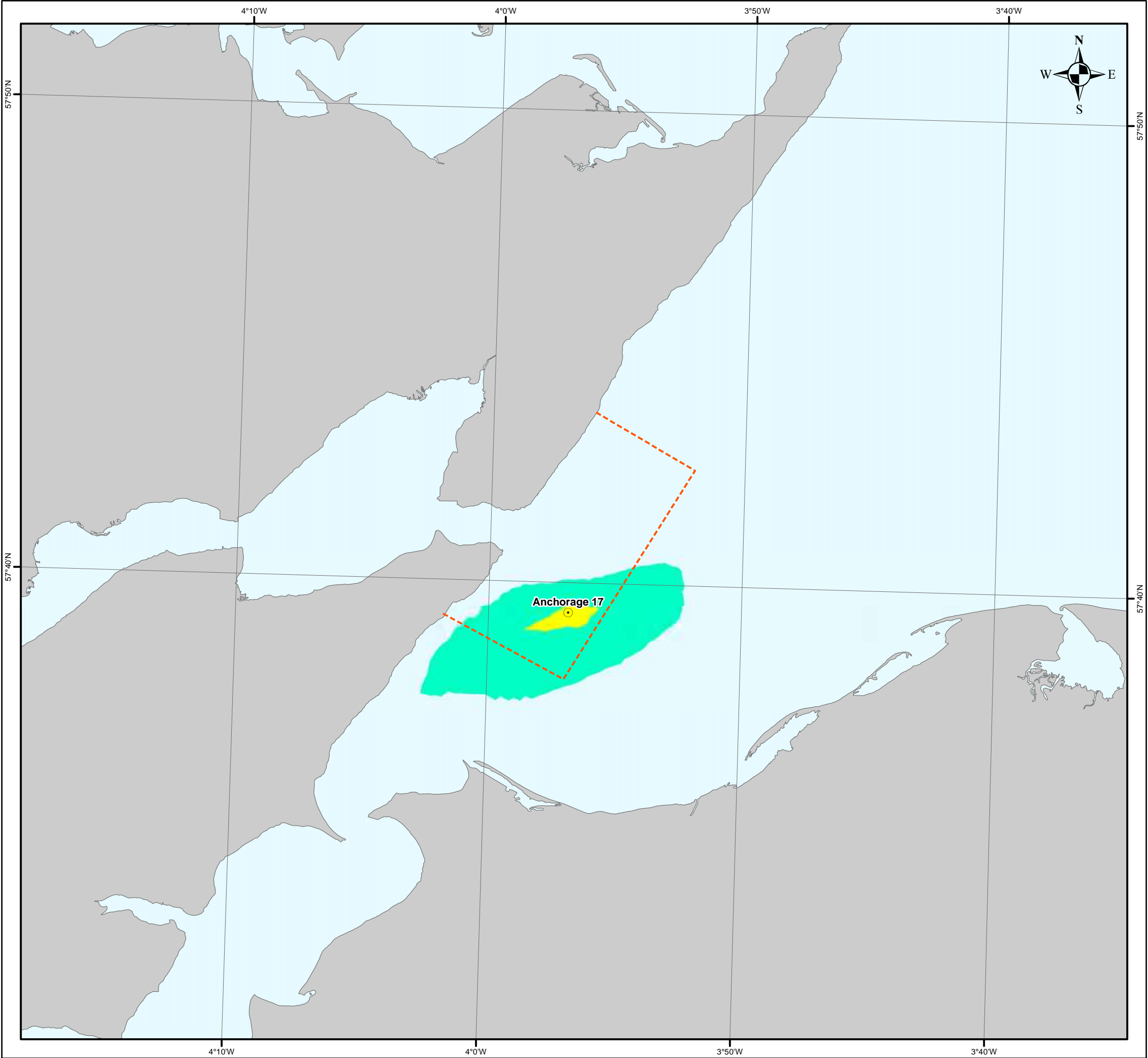
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Figure B-16: Maximum Plot of Exchanged Ballast Discharge at Anchorage 17

Legend

- STS Locations
- - - Cromarty Firth Harbour Limit

HCI Band	Zooplankton/m ³	Phytoplankton/m ³
300 - 30	0.001 - 0.01	33 - 332
30 - 3	0.01 - 0.1	332 - 3,325
3 - 0.3	0.1 - 1	3,325 - 33,250
0.3 - 0.03	1 - 10	33,250 - 332,500
<0.03	>10	> 332,500

FOR CONTEXT

Reduction Standard : HCI 1

BWM Convention Regulation D-2 :
Zooplankton : <10 per m³
Phytoplankton : <10,000,000 per m³

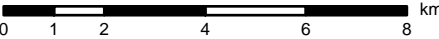


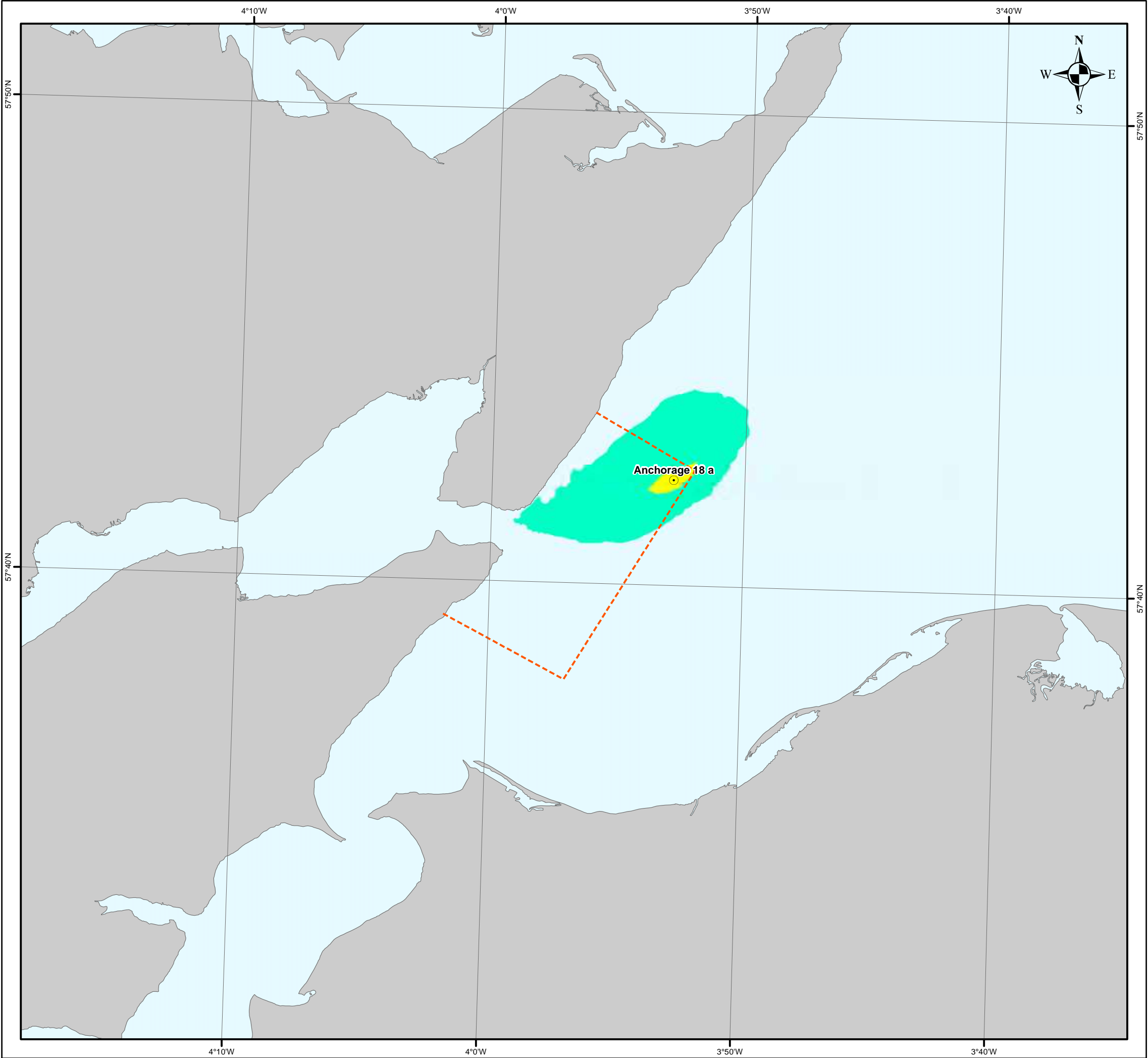
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Figure B-17: Maximum Plot of Exchanged Ballast Discharge at Anchorage 18a

Legend

- STS Locations
- Cromarty Firth Harbour Limit

HCI Band	Zooplankton/m ³	Phytoplankton/m ³
300 - 30	0.001 - 0.01	33 - 332
30 - 3	0.01 - 0.1	332 - 3,325
3 - 0.3	0.1 - 1	3,325 - 33,250
0.3 - 0.03	1 - 10	33,250 - 332,500
<0.03	>10	> 332,500

FOR CONTEXT

Reduction Standard : HCI 1

BWM Convention Regulation D-2 :
Zooplankton : <10 per m³
Phytoplankton : <10,000,000 per m³

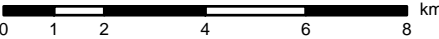


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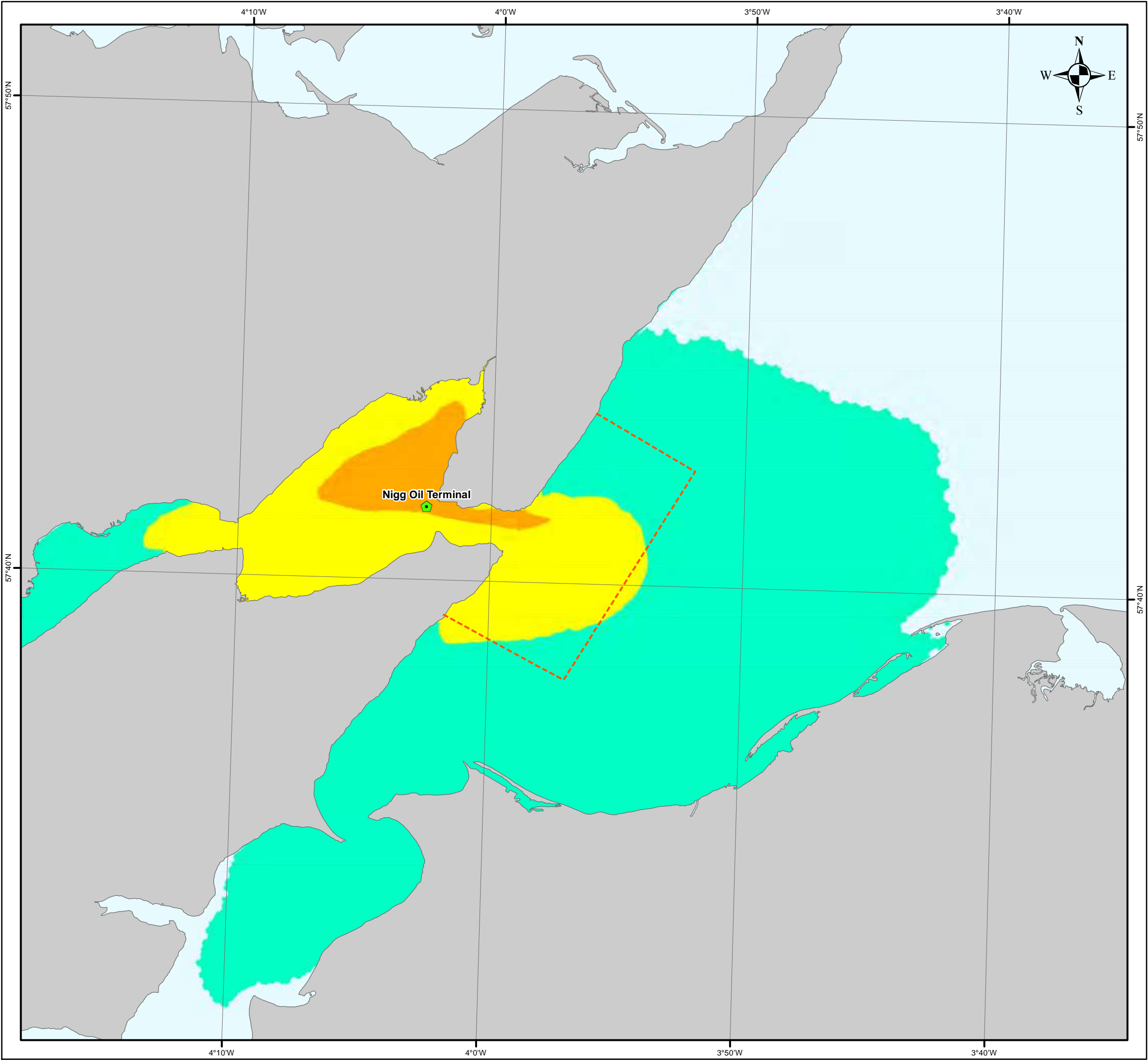
B.15.2 In-combination Discharge

The model results for in-combination ballast water discharges are shown in terms of the HCl band and the predicted zooplankton and phytoplankton concentrations per cubic metre (Figure B-18 to Figure B-20). The figure's contours represent the maximum value (HCl/concentrations) for each of the modelled time steps within the modelled 60 day period (i.e. a composite of maximum concentrations).

Figure B-18 presents the results for the discharge of un-exchanged and un-treated ballast water at Nigg Oil Terminal. This demonstrates what currently occurs at Nigg Oil Terminal during a STS transfer process. The model predicts a maximum HCl of 0.03 at the centre of the plume. This means concentrations are compliant with the IMO BWM D-2 Regulation. Worst case zooplankton concentrations are predicted to be 1.5 per m³. The remaining plume is between has concentrations which are between 1000 and 10000 times lower than the D-2 standard.

Figure B-19 presents the results of exchanged ballast discharge at Nigg Oil Terminal. This demonstrates what will occur at Nigg Oil Terminal during a STS transfer process once the IMO BWM Convention enters into force, where by all ships will be required to exchange ballast water as an interim solution and eventually they will be required to treat ballast water before discharge. The model predicts a maximum HCl of 3 close to the centre of the plume. This means concentrations are at least three times lower (i.e. three times better) than the reduction standard. Worst case zooplankton concentrations are predicted to be 0.1 per m³, which is approximately 100 times lower (i.e. better) than the BWM D-2 standard. When ballast water is treated before release then the concentrations will be reduced further.

Figure B-20 presents the results of cumulative in-combination ballast water discharges at the six piers within the harbour area (at Invergordon Service Base, Admiralty Pier, Queens Dock, Phase 3 Berth and Saltburn Pier), Nigg Oil Terminal and at Anchorage 16. The scenario modelled was for un-exchanged and un-treated ballast water release at the six piers and Nigg Oil Terminal and exchanged ballast water release at Anchorage 16. This demonstrates the worst case in-combination discharge of ballast water. The model predicts a maximum HCl of 0.03 at the centre of the plume. This means concentrations are compliant with the IMO BWM D-2 Regulation. Worst case zooplankton concentrations are predicted to be 1.5 per m³. The rest of the plume is has concentrations between 1000 and 10000 times lower than the D-2 standard. This scenario demonstrates that the discharge of ballast water during STS transfers at the anchorages outside the Cromarty Firth will not contribute significantly to the existing concentrations.



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Figure B-18: Maximum Plot of untreated and unexchanged Ballast Discharge at Nigg Oil Terminal

Legend

- Nigg Oil Terminal
- Cromarty Firth Harbour Limit

HCI Band	Zooplankton/m ³	Phytoplankton/m ³
300 - 30	0.001 - 0.01	33 - 332
30 - 3	0.01 - 0.1	332 - 3,325
3 - 0.3	0.1 - 1	3,325 - 33,250
0.3 - 0.03	1 - 10	33,250 - 332,500
<0.03	>10	> 332,500

FOR CONTEXT

Reduction Standard : HCI 1

BWM Convention Regulation D-2 :
Zooplankton : <10 per m³
Phytoplankton : <10,000,000 per m³

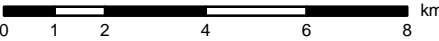


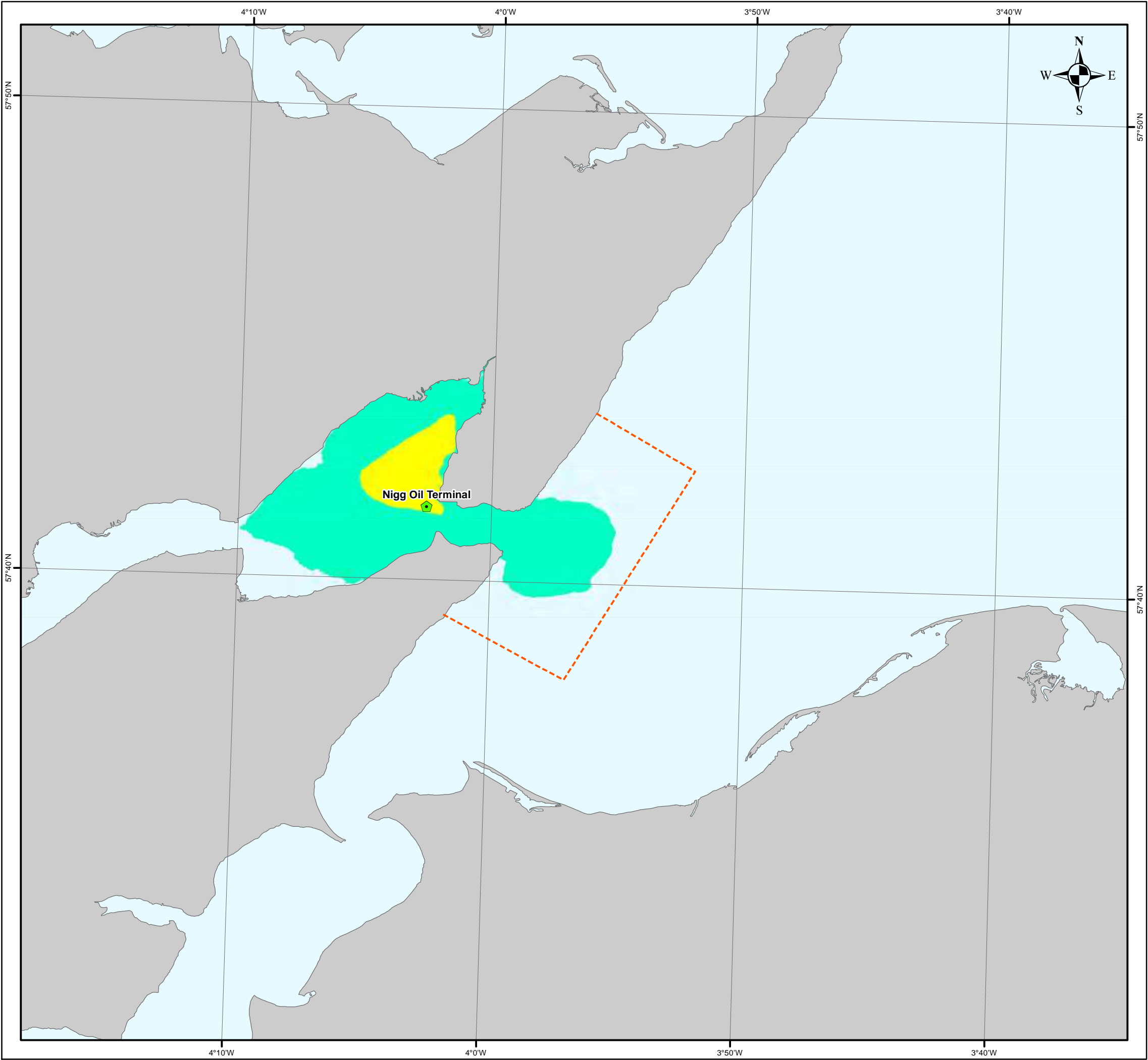
NOTE: Not to be used for Navigation

Date	Wednesday, December 2, 2015 08:12:54
Projection	British_National_Grid
Spheroid	Airy_1830
Datum	D_OSGB_1936
Data Source	OSOD, CFPA
File Reference	J:\P1946\Mxd\Report\Appendix_B\Ballast_Max_Nigg_untreated.mxd
Created By	Emma Langley
Reviewed By	Ian Charlton
Approved By	Chris Mooij



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Figure B-19: Maximum Plot of Exchanged Ballast Discharge at Nigg Oil Terminal

Legend

- Nigg Oil Terminal
- Cromarty Firth Harbour Limit

HCI Band	Zooplankton/m³	Phytoplankton/m³
300 - 30	0.001 - 0.01	33 - 332
30 - 3	0.01 - 0.1	332 - 3,325
3 - 0.3	0.1 - 1	3,325 - 33,250
0.3 - 0.03	1 - 10	33,250 - 332,500
<0.03	>10	> 332,500

FOR CONTEXT

Reduction Standard : HCI 1

BWM Convention Regulation D-2 :
Zooplankton : <10 per m³
Phytoplankton : <10,000,000 per m³

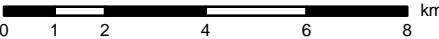


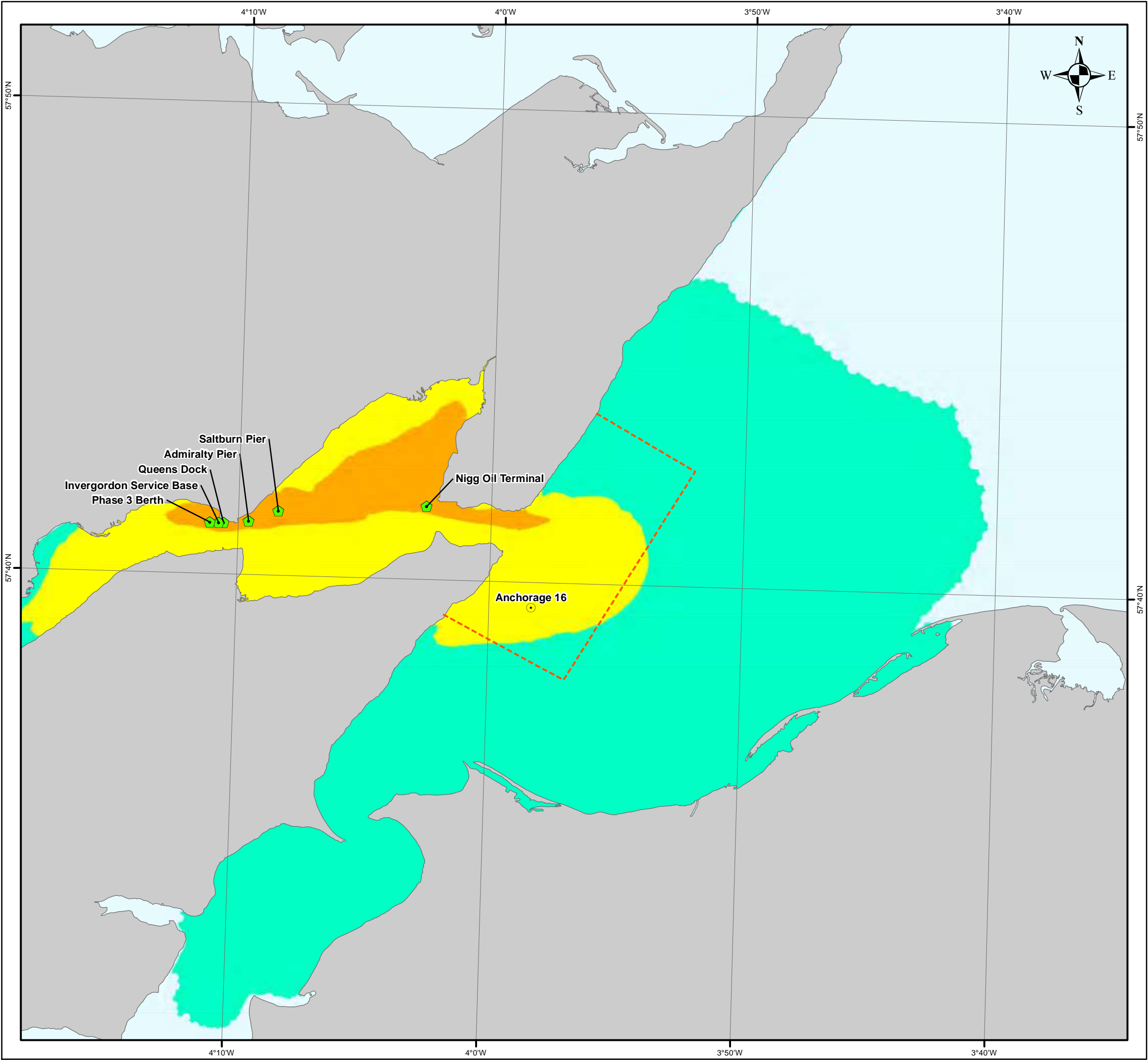
NOTE: Not to be used for Navigation

Date	Wednesday, December 2, 2015 08:06:59
Projection	British_National_Grid
Spheroid	Airy_1830
Datum	D_OSGB_1936
Data Source	OSOD, CFPA
File Reference	J:\P1946\Mxd\Report\Appendix_B\Ballast_Max_Nigg.mxd
Created By	Emma Langley
Reviewed By	Ian Charlton
Approved By	Chris Mooij



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Figure B-20: Maximum Plot of cumulative in-combination ballast discharges (Piers, Nigg Oil Terminal and Anchorage 16)

Legend

- STS Locations
- Cumulative Discharge Locations
- Cromarty Firth Harbour Limit

HCI Band	Zooplankton/m ³	Phytoplankton/m ³
300 - 30	0.001 - 0.01	33 - 332
30 - 3	0.01 - 0.1	332 - 3,325
3 - 0.3	0.1 - 1	3,325 - 33,250
0.3 - 0.03	1 - 10	33,250 - 332,500
<0.03	>10	> 332,500

FOR CONTEXT

Reduction Standard : HCI 1

BWM Convention Regulation D-2 :

Zooplankton : <10 per m³

Phytoplankton : <10,000,000 per m³

NOTE: Not to be used for Navigation

Date	Wednesday, December 2, 2015 08:31:28
Projection	British_National_Grid
Spheroid	Airy_1830
Datum	D_OSGB_1936
Data Source	OSOD, CFPA
File Reference	J:\P1946\Mxd\Report\Appendix_B\Ballast_Max_Cumulative.mxd
Created By	Emma Langley
Reviewed By	Ian Charlton
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