BE AWARE

Bonn Agreement
Accord de Bonn

Technical sub-report 1: Methodology

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DOCUMENT TITLE: Method Note
TASK: C Methodology
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PUBLISHED ON: 26 November 2015

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Co-financed by the EU –
Civil Protection Financial Instrument

The Greater North Sea and its wider approaches is one of the busiest and most highly used maritime areas in the world. With the ever-increasing competition for space comes an increased risk of accidents that could result in marine pollution.

Currently the area has no overall risk assessment for marine pollution; risk is mapped with a variety of national risk assessments which are undertaken with differing methodologies; thus reducing comparability.

The BE-AWARE project is therefore undertaking the first area-wide risk assessment of marine pollution using a common methodology that allows the risk to be mapped and compared under different scenarios.

The project outcomes will be subregional risk management conclusions, which will identify priority future risk reduction and response senarios for each sub region, oil impact and damage assessments and a region wide environmental and socioeconomic vulnerability analysis.

The project is a two year initiative (2013-2015), co-financed by the European Union (DG ECHO), with participation and support from the Bonn Agreement Secretariat, Belgium, Denmark, France, Germany, Ireland, the Netherlands, Norway, Sweden and the United Kingdom.

Contents

1. Introduction

The present version of the method note represents the methodology as per the present stage of the project. The method evolves as a logical consequence as the project develops and the method note has therefore to be seen as a living document that reflects the ongoing discussion among the Project Partners and hence the commonly elaborated understanding.

1.1 Background

The Greater North Sea and its wider approaches is one of the busiest and most highly used maritime areas in the world. Currently the area has no overall risk assessment for marine pollution and risk is mapped with a variety of national risk assessments, which are undertaken with differing methodologies, thus reducing comparability.

In 2010, the Bonn Agreement recognised the need for an area-wide risk assessment and the associated benefits (Bonn Agreement Dublin Declaration). The Bonn Agreement Secretariat, in collaboration with Bonn Contracting Parties, undertook the BE-AWARE I and II projects, with part funding from the EU Civil Protection Mechanism, to achieve this aim.

The BE-AWARE I project (2012-2014), assessed the risk of oil pollution both now (2011) and in the future (2020) and the likely size of any spills. However in order to assess which methods and technologies will be most effective in reducing and responding to oil pollution further analysis were required.

BE-AWARE II models the outflow of oil from the spills predicted in BE-AWARE I for ten different response, or risk reducing scenarios, taking into consideration the hydrodynamics of the North Sea Region. The model is combined with an analysis of the environmental and socioeconomic sensitivity of the region to assess the impact of the different scenarios. Based upon these and the cost of implementing the measures, risk management conclusions are developed for each of the 5 project sub-regions.

The project is a two year initiative (2013-2015), co-financed by the European Union (DG ECHO), Ireland and Germany, with participation from the Bonn Agreement Secretariat, Belgium, Denmark, France, Germany, Ireland, the Netherlands, Norway, Sweden and the United Kingdom.

The Environmental Liability Directive 2004/35/EC of the European Parliament and of the Council of 21 April 2004 on environmental liability with regard to the prevention and remedying of environmental damage (ELD) establishes a framework based on the polluter pays principle to prevent and remedy environmental damage. The Directive defines "environmental damage" as damage to protected species and natural habitats, damage to water and damage to soil. It therefore is in line with the part a) of the present analysis that looks at

a) environmental,
b) socio-economic and
c) combined environmental and socio- economic damages.

1.2 Scope

The present methodology note describes the applied methodology commonly agreed by partner countries participating in the BE-AWARE project group including the external consultants. The methodology principles are taken from the methodology of the BRISK project (BRISK method, 2012) and adjusted to the specific conditions of the North Sea area.

The present Methodology Note is part of the BE-AWARE II project dealing with the modelling and sensitivity analyses in the Bonn Agreement area. It builds upon the work done in the BE-AWARE I project, where one output, was estimates of spill frequencies, based on modelled incidents depending on several conditions, and involving calculated occurrences of oil spillage.

BE-AWARE II consists of the following work steps:

- A Project management and communication
- B Publicity
- C Methodology
- D Project resource database
- E Oil Spill / Response modelling
- F Environmental and Socioeconomic vulnerability
- G Project workshop
- H Area-wide risk assessment of impacts for the selected scenarios
- I Risk management conclusions
- J Project conference

Work step C, which is documented by the present Methodology Note, prepares the grounds for the project execution (Work step D, E and F).

The data and calculation flow of the risk assessment model is illustrated in Figure 1-1.

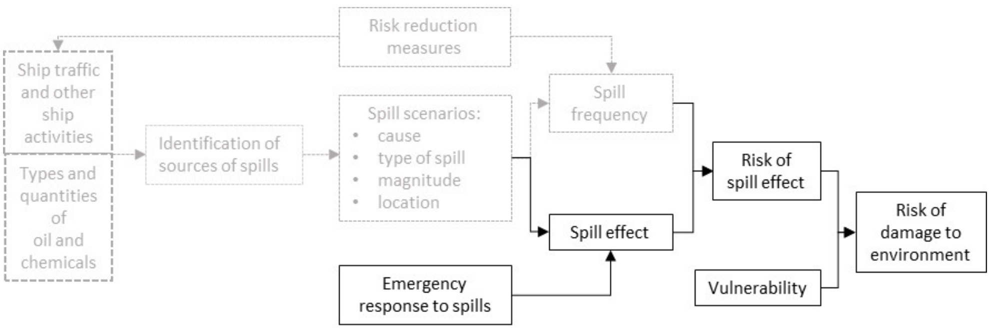


Figure 1-1 Flow of the risk assessment model (BE-AWARE II work steps are indicated in solid black, work steps of the previous project phase I are indicated in dashed gray)

Correspondingly, the present Methodology Note is divided into the chapters listed in Table 1-1.

Table 1-1 Methodology note chapters and corresponding BE-AWARE II tasks.

Chapter	Title	Corresponding BE-AWARE II task
2	Data collection	Task D.1
3	Oil spill modelling	Task E
4	Mapping of vulnerability and classification of damage	Task F
5	Risk reducing measures and response scenarios	Task C.3
6	Evaluation of model scenario analyses	Task H, I

Key input meteorological and oceanographic data where supplied to the project by the Belgian research institute MUMM and reported in (MUMM, 2014).

In order to verify the results of the system of models in the present project by state-of-the-art models and methods, selected processes and cases has been modelled independently. These independent modelling and investigations are outlined for the following topics:

- Review of physical and oceanography in the area of the Bonn Agreement (MUMM, 2015a),
- 3D modelling study of the drift and fate of large oil spills in seven sub regions of the North Sea and the English Channel (MUMM, 2015b).
- A study to assess and validate the shape and size of potentially impacted areas (MUMM, 2015c)

2. Data collection

An important part of BE-AWARE II is to collect data for the risk assessment. The majority of the environmental and socioeconomic data was collected from central sources such as EU institutions, NGO's and international conventions and organisations. Data on response measures and capabilities and some socioeconomic issues were collected from Bonn Agreement Contracting Parties. All collected data were kept in a centrally held project resource database with geo-reference data, where applicable.

During the data collection, contracting parties are updated regularly on the progress of the data collection and potential data gaps or other issues related to data are discussed. When all available data were collected, they were sorted and congregated before approval by contracting parties and included in the further assessment work.

2.1 Data request

Data from the project partners was requested through a data request note (COWI, 2014). The data request note has two parts, an MS Excel workbook and an MS Word document guidance. The workbook was divided into multiple worksheets each of which required completion. It included data on existing response capabilities and scenario related information. Instructions for completing the MS Excel workbook were included in the guidance document.

The data request note specifies the work to be carried out during the data collection for the project in terms of the type of data requested, data format, possible sources of information and allocation of tasks between Project Partners and Bonn Agreement Secretariat.

The requested data will be used for modelling and describing the response preparedness and the environmental and socio-economic sensitivity towards oil spills. The note describes the additional data requirements of the BE-AWARE II project, based on the method modifications, which have arisen from the BE-AWARE project. The development of the note has been built on the outcome of the method seminar held between the project partners in Southampton on April 8-9 2014.

2.2 Data from Contracting Parties

The Bonn Agreement Contracting Parties were requested to collect the following types of data:

- Data on response capacity to oil spills
- Data required for the scenarios to be modelled
- Data on selected socioeconomic features
- Data on selected ecological features

2.2.1 Data on response capacity to oil spills

The data in the request note on response capacity to oil spills included information on existing response capabilities and locations of equipment. This included the following information on oil spill combat vessels:

- Number of vessels, home port, response time, speed, capacity

- Information on equipment (booms, skimmers and storage)
- Wave restriction (wind speed, fetch, wave height 1.5 m)
- Daylight restriction (seasonal) and bad visibility restriction (regional)

Equally important is knowledge on the amount and type of equipment, which can be deployed from a given vessel. Additionally, availability of additional storage capacity of recovered oil is included in the request.

2.2.2 Data required for the scenarios to be modelled

Data is requested to describe the specific information required for the 10 model scenarios, which were decided. A brief overview of the scenarios is given in Table 2-1.

Table 2-1 Overview of the selected risk reducing and response measure model scenarios and related data requests from contracting parties.

Scenario classes	Data required	Measures
1 Two Reference (Ref.) scenarios	Descriptions of the response measures (RM) in the reference scenario for the year 2011 (now situation) and for the year 2020 (future situation).	
2 Five Risk Reducing Measure (RRM) scenarios	Descriptions of additional RRM in the year 2020.	Vessel Traffic Services (VTS) in selected areas (shape files and estimates of cost) Traffic Separation Schemes (TTS) in selected areas (shape files and estimates of cost) AIS guard rings around Wind Farms (shape files and estimates of cost) E-Navigation (estimates of cost) Additional Emergency Towing Vessels (ETV) (locations and estimates of cost)
3 Three Response Measure (RM) Scenarios	Descriptions of additional RM in the year 2020	Improved night visibility (ID of vessel to be applied and cost) Further use of dispersants (extent of dispersant use) 50% increase in response equipment (see appendix 1)

2.2.3 Socio-economical features

The Project Partner Countries were requested the collect socio-economical information on the following features:

- Location of shellfish/seaweed (algae) harvesting
- Location of aquaculture facilities including fish farms, shellfish cultures and alga-cultures
- Location of tourism sites including amenity beaches (including blue flag beaches), marinas, tourism activity (Ireland) and recreational fishing location
- Location of coastal facilities with water inlets including energy plants onshore fish farms and industrial activities (incl. oil and chemical industry)
- Location of heritage sites

The remaining socio-economic parameters are collected from central sources by Bonn Agreement and COWI.

2.3 Centrally collected data

Bonn Agreement and COWI collect data on environmental and socio-economic features centrally from central sources. The data are specified in the data request note, where possible sources of information also are described.

2.3.1 Environmental features

Environmental data collected by Bonn Agreement and COWI from central sources included:

- Data for habitat mapping
- Data for mapping of bird areas
- Data for mapping marine mammal areas
- Data for mapping spawning and nursery areas for fish
- Data on location of protected areas
- Data on selected socioeconomic sites

2.3.2 Socio-economic features

Bonn Agreement and COWI collected the following data on socioeconomic features:

- Location of offshore fisheries and coastal fisheries (data on fishing effort for different species in ICES statistical squares. Alternatively value of catch of different species in ICES squares)
- Location of fishing harbours
- Location of tourism activity
- Location of densely populated town and communities
- Location of ports
- Location of cruise liner stops
- Location of mineral extraction areas
- Locations of wind farms

3. Oil spill modelling

3.1 Introduction

This part of the method note describes the proposed methodology for modelling the impact from oil spills in the ocean.

The term 'impact' from oil spills to the marine environment is in the present context used to describe the quantity of oil within the marine environment during a spill event.

The modelling of the impact involves numerical modelling of the transport and dispersion of oil in the ocean while subject to changing characteristics, natural dispersion and degradation. The effect of the response measures (recovery or dispersants) to the spills is included in the model system.

In contrast to many traditional oil spill models that simulate the trajectory and the fate of a specific oil spill and that are used for operational oil spill response, the present system of models is to be understood as a strategic model. This means that it provides the risk of spilled oil at a certain place in the model area where the oil can originate from a series of likely and unlikely accidents at any part of the model area in any weather condition taking into account the effect of the response capacity on site. The present model system can therefore not be used for operational oil spill response. For this purpose, most countries have developed national oil spill trajectory models or invested in commercial models and solutions.

The principles of the modelling are shown in Figure 3-1. The key processes are selected and parameterised and form the basis for a model system for spill simulations. The advantage of such model system is that it makes it possible to model a large number of scenarios, which is required for the overall risk assessment.

Detailed modelling of selected individual spill events were carried out by the scientific Belgian institution RBINS-MUMM, using advanced numerical models (OSERIT forced by MyOcean/Copernicus and UK Met Office met-ocean forcings). These results are compared with partial results of the model system in order to verify the results of model system for partial processes (i.e. a specific spill size of a specific oil type at a specific site under specific meteorological conditions but without response).

The purpose of the simulations with the integrated model system is to describe the impact for all conditions so that the result can form the basis for strategic decisions regarding the development of the existing preparedness and response capacities. The results will take into account the effects of future developments of changed ship traffic as well as the effect of introducing risk reduction measures and enhanced oil recovery means.

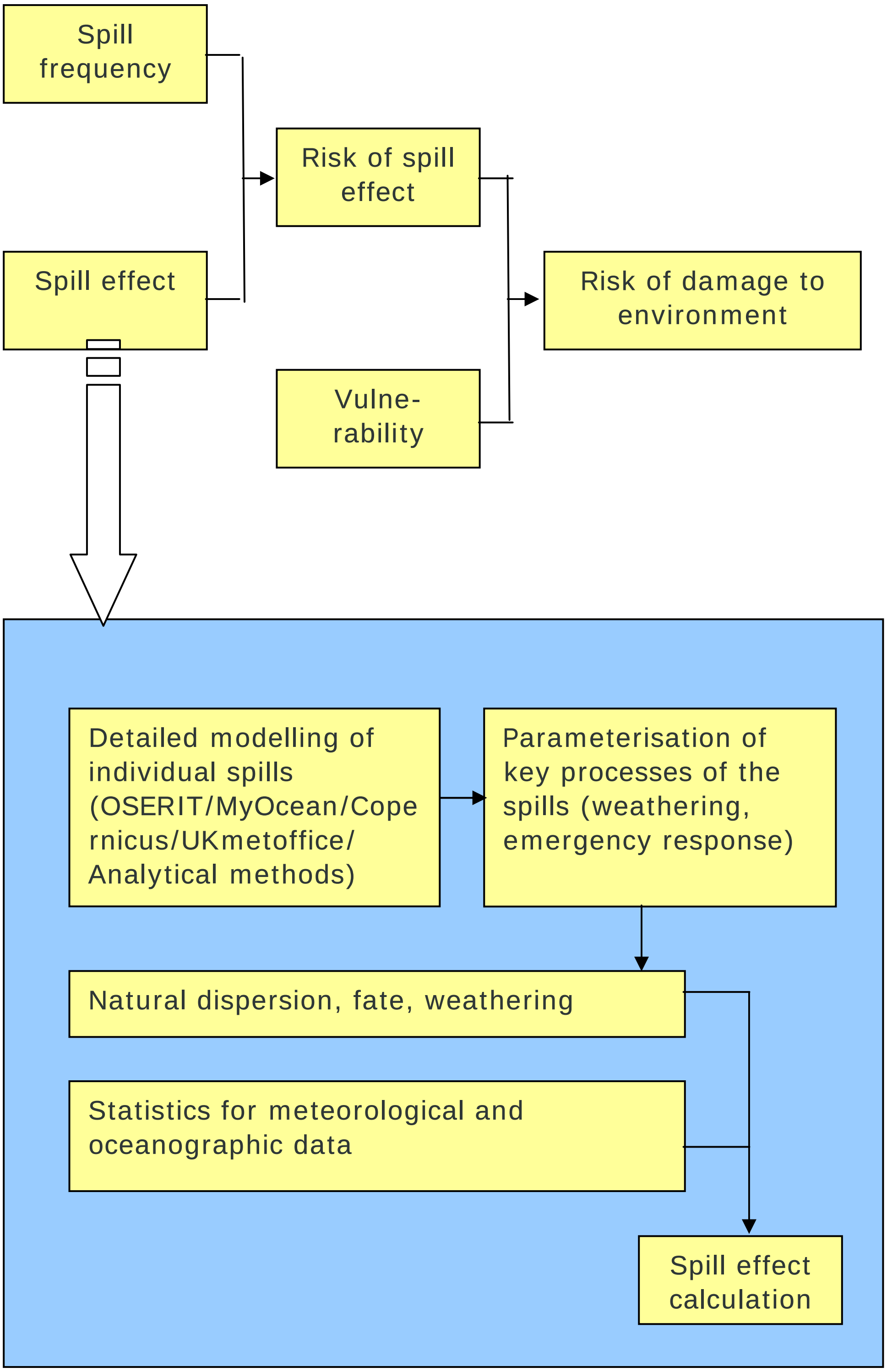


Figure 3-1 Principles of oil spill modelling used in BE-AWARE II.

Separate modelling tools are established for two types of spills:

- Oil on the ocean surface
- Oil dispersed into the upper water column

A 2x2 km grid was been applied throughout the North Sea for all impact modelling.

The same drift and fate modelling was used for all 4 seasons, since the effects of sea ice are considered to be of minor consequence for the North Sea.

The following parameters affect both the spreading and dispersion of oil as well as the emergency response:

- Sea temperature (minor influence)
- Frequency of wind velocity and direction
- Wave height (wind waves) related to wind speed
- Frequency of fog and mist (minor influence)
- The number of hours with sunlight

3.2 Preparation for the modelling

In this chapter the format of the output from BE-AWARE I is briefly described. Furthermore, this chapter describes the necessary sub-division of the project area into smaller units for meteorological and hydrographical data preparation. Finally, the chapter describes the appointment of locations for oil spill and outlines the methodology for selecting the simulation periods for the oil spill scenarios, which were modelled with the detailed model.

3.2.1 Input from BE-AWARE I

The calculation of the spill frequencies for various positions divided into different oil types and size classes were carried out in the BE-AWARE I project. The format of the output from this project is important for the definition and handling of the spills in the modelling of the spill effect and the overview is therefore given below.

Spill types

Table 3-1 List of substances used in the modelling of oil spills in the Greater North Sea.

Type	Representative substance
19	Crude oil
20	Fuel oil
21	Gasoil, diesel, petroleum, jet fuel and light fuel oil
22	Gasoline

Spill sizes

Table 3-2 Spill size classes used in the BE-AWARE I results (all values in tonnes)

Spill size class	Lower limit [t]	Upper limit [t]	Representative size [t]
0	0	0	0.0
1	0	1	0.3
2	1	15	4.0
3	15	300	67.0
4	300	5,000	1,200.0
5	5,000	15,000	8,700.0
6	15,000	50,000	27,000.0
7	50,000	150,000	87,000.0
8	150,000	350,000	230,000.0

3.2.2 Division of meteorological areas

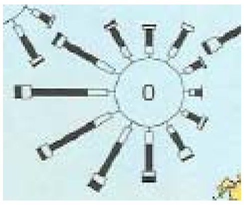
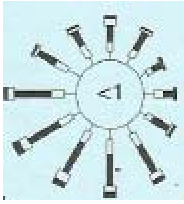
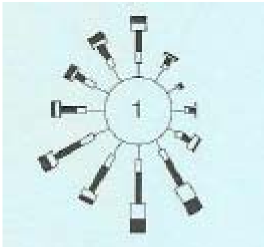
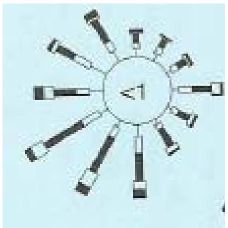
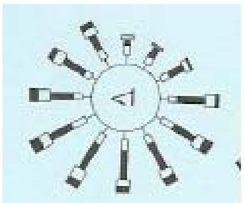
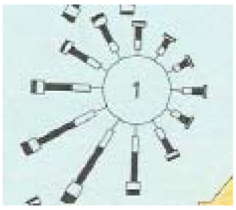
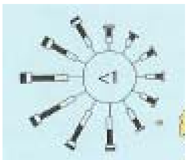
An overall description of the meteorology is given in (MUMM, 2015a).

The project area has been divided into a number of meteorological units within which the wind conditions are assumed to be uniform. The physical scale of the meteorological areas depends on the availability of data as well as on the shape and size of oceanographic units (such as a bay or open water area).

The Admiralty Pilot publications for the North Sea (Admiralty, 2010) are highly valuable for the selection of meteorological areas. These publications contain seasonal wind roses at selected locations, which are based on many years of wind data. The wind roses show the statistical distribution of wind speed and directions. For the present project wind roses from different locations and seasons have been compared and it has been assessed to which degree they show the same statistical features.

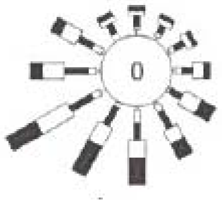
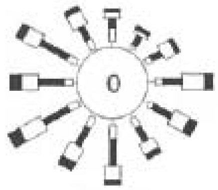
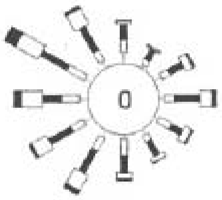
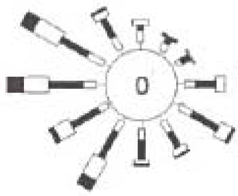
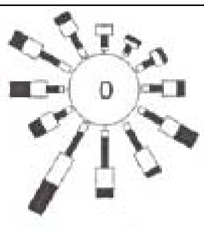
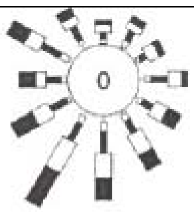
Examples of spatial variation of the wind climate in the different areas of the North Sea Pilots the wind roses for November are shown in Table 3-3. The table includes the detailed wind roses from (Admiralty, 2011), and, for comparison, the modelled wind speeds from UK met office global meteorological forecast model. These wind data have been prepared by RBINS-MUMM before being interpolated to fit the sectors and wind classes required in the present BE-AWARE project.

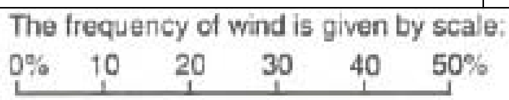
Table 3-3 Spatial variation of wind climate. Wind roses in November for different locations in the Bonn Agreement area (Admiralty, 2011).

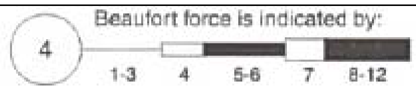
Wind location A: Wind rose for Irish West Coast, November	
Wind location B: Wind rose for West Coast Scotland, November	
Wind location C: Wind rose for West Coast Norway, November	
Wind location D: Wind rose for Western North Sea, November	
Wind location E: Wind rose for Eastern North Sea, November	
Wind location F: Wind rose for Southern North Sea, November	
Wind location G: Wind rose for Western Channel, October (since no November wind rose is shown)	

The seasonal variability in the eastern part of the North Sea (Island of Helgoland) is illustrated in Table 3-4.

Table 3-4 Seasonal variation of wind climate
Wind roses for Island of Helgoland in 6 different periods (Admiralty, 2011).

Period	Wind rose
January - February	
March - April	
May - June	
July - August	
September - October	
November - December	





Wind flow is towards the circle. The figure in the circle gives the precentage of calms.

For the selection of meteorological areas, a general judgement has been made of the features that change the meteorological conditions. This judgement is based on experience from marine projects throughout the globe. Each area has to be quasi- homogeneous within itself and it must be different from its neighbour area.

By combining the information from the Pilot Books and the general experience, a map of meteorological areas has been made. This map is seen in Figure 3-2.

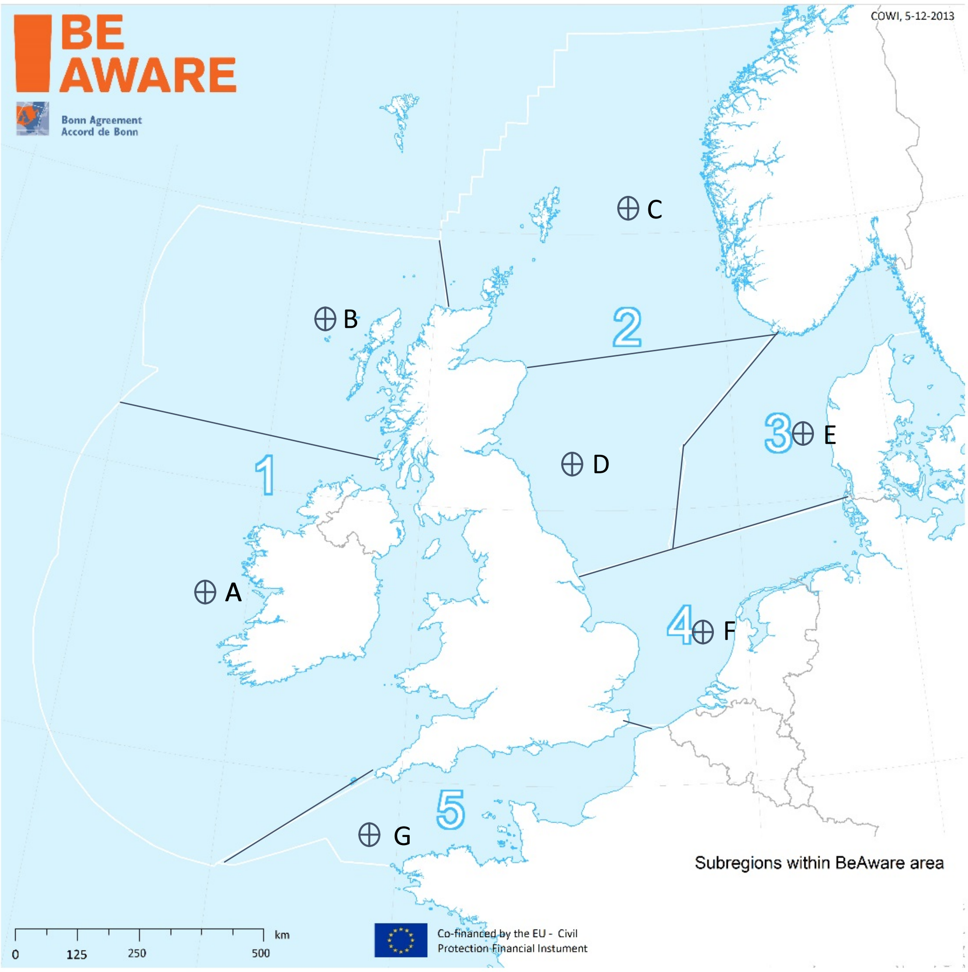


Figure 3-2 **Identification of the 7 meteorological sub-regions (black boundaries) and location of 7 locations A to G representing the wind conditions of each corresponding meteorological sub-region.**

The wind roses representing the sub-regions A to G are shown in Table 3.3.

The above figures are shown in order to illustrate the differences and the similarities between the wind statistics of the different meteorological sub-areas. Although the entire region is dominated by passages of the same low pressures coming from west and moving towards the east, some difference are observed, particularly in the far north, whereas the regions from the western English Channel through the Dover Strait and towards the southern North Sea are relatively similar.

It is seen from the map that altogether 7 meteorological areas are defined within the project area.

3.2.3 Division of hydrographical areas

An overall description of the oceanography is given in (MUMM, 2015a).

The project area has been divided into a number of hydrographical areas. A hydrographical area is defined as a smaller unit of the water area in which the hydrographical conditions, such as wind patterns and currents can be assumed uniform. Thus oil spilt anywhere in a hydrographical area will, in principle, traverse the same direction and speed. The selection of the hydrographical areas is made on basis of experience and knowledge of the hydrographical conditions within the North Sea. Further, the selection is made so that the hydrographical areas fit within the borders of the meteorological areas.

In total, 11 hydrographical areas result from this analysis. The hydrographical areas are shown in Figure 3-3.

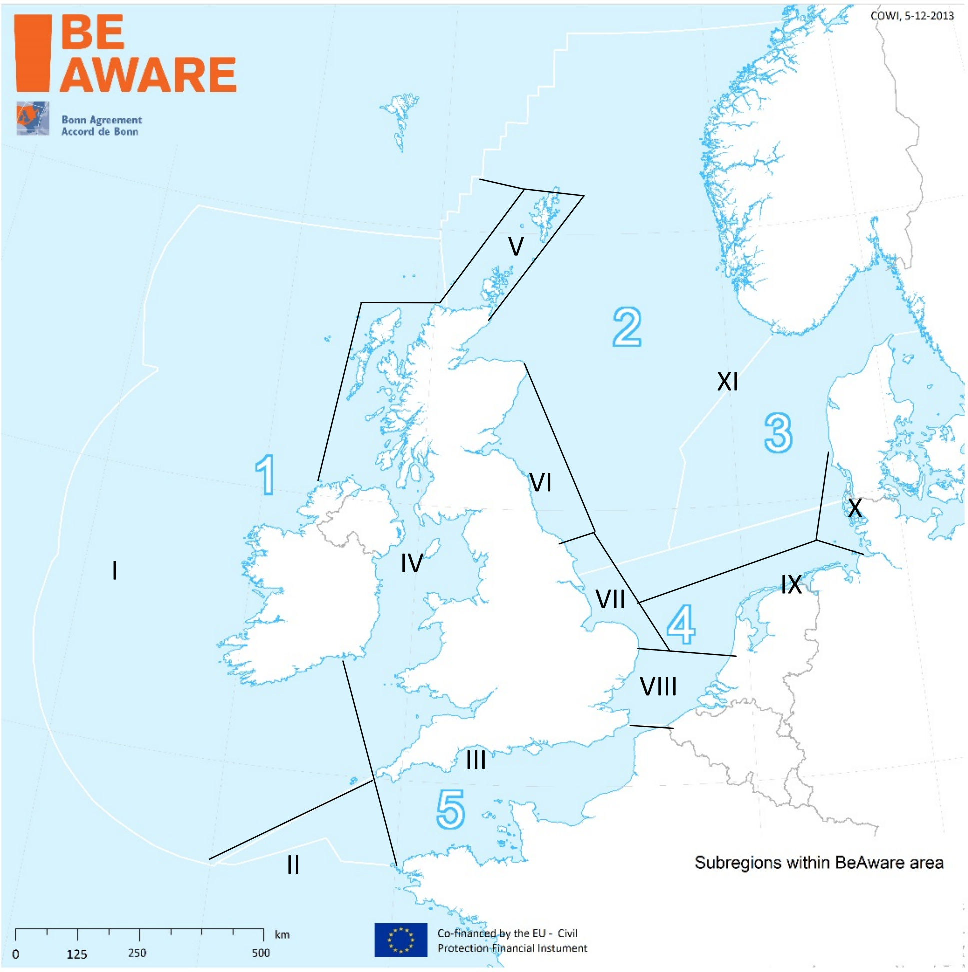


Figure 3-3: Definition of Tidal sub-regions (Roman numbering).

3.2.4 Defining wind classes

The wind classes for the oil spill scenarios are determined based on the experience from (BRISK, 2012). Time, wind speed and direction characteristics have been extracted from the UK Met Office global meteorological forecast (UK Met, 2014) by RBINS-MUMM at each of the meteorological locations, cf. Figure 3-2. Since the model simulations is representing 3 wind speed classes, 12 wind directions (30º sectors) and 4 seasons (Winter, Spring, Summer, Autumn), altogether 124 combinations exist for combined wind-direction classes. The wind speed classes are given in Table 3-5.

Table 3-5 Definition of the wind speed classes

	Wind speed class 1	Wind speed class 2	Wind speed class 3
Speed interval (m/s)	0.2 - 5	5 - 11	>11
Representative wind speed (m/s)	3.5	7	14

The direction classes are 30 degrees interval centralised around the main compass directions. This means that the first direction class is in the interval from 345 °N to 15 °N, the next interval ranging from 15 °N to 45 °N, etc.

3.3 Drift and spreading of oil

3.3.1 Introduction

In this section, the term 'oil' is used generally to describe all oil types. The detailed processes of transport, dispersion and weathering of various oil types on the ocean is parameterised and simplified in such manner that key features of the behaviour are maintained and a simple generic model be established. The advantage of the simple model is that it is able to calculate a large number of calculations. In this regard, the modelling is different from traditional oil spill simulations in which advanced process models are applied to describe the effects of a particular oil spill with high accuracy.

Thus, the modelling includes a description of the spreading of the oil on the water surface, the drift by current and wind, as well as the weathering of the oil. For light oil types, the weathering is simplified to describe only the evaporation while for heavy oils the weathering is simplified to describe emulsification and natural removal from the surface.

3.3.2 Principles for measurement of impact

The impact of oil pollution is calculated on basis of the generalised descriptions of transport, spreading and weathering of oil during the entire spill event. As a result, the following is found:

- The amount of oil in each calculation cell in the ocean as a function of time
- The total amount of oil hitting the shoreline

Offshore

Given that an oil spill had occurred, the offshore impact is area specific and consists of the amount of pollution (mass) and the duration (time) of the pollution in the area considered. The term 'impact' in the present context is solely defined on basis of the occurrence of pollutants and time, thus omitting environmental parameters, which will be included at a later stage.

The justification for including the amount of pollutant in the impact concept is the simple assumption that larger amounts of pollutant results in larger impact as compared to smaller amounts of pollutants. Therefore, two areas equal in size, which receive a large and a small amount of pollutant, will be impacted to a large and a small extent respectively.

The duration of a pollutant within a water body is likewise a natural part of the 'impact' concept. The basic assumption is that the longer the duration the larger the impact will be. Thus, two areas of equal size, which are exposed to a long and a short period of pollution with similar amount of oil, will be impacted to a large and small degree respectively.

For oil on open waters the result of the impact calculation will be given in the unit 'amount times time per area unit' (e.g. tonnes*hours/km2).

A certain amount of oil will over time be dissolved or entrained into the water column as micro-particles. This oil is not on the surface and it is not possible to recover it anymore. Therefore, it is treated as naturally dispersed, and together with the evaporated amount of oil and the amount recovered by response vessels it will from the amount of oil that is not on the sea surface anymore.

Onshore

For oil onshore the result will be given as amount of oil that hits the shoreline in the course of a spill event.

3.3.3 Modelling of spreading and natural dispersion

The goal is to calculate the occurrence of oil under a large number of combinations of conditions. The basic problem is that detailed modelling of each spill events is too costly in terms of computer power. On the other hand, a strategic analysis of the risk of oil spills requires a large number of combinations of conditions to be simulated. To overcome this problem, the following method is applied:

Detailed models are applied for simulation of a few selected scenarios. From these results a simple model is established, which can calculate a large number of scenarios in a short time in a similar way.

Drift, spreading and natural dispersion and other key processes are first calculated for selected key scenarios with complex and detailed models (analytical models) for a number of oil types, wind and temperature conditions, spill locations and quantities etc.

The drift of oil in a tidal flow regime is somewhat more complex than in a pure wind driven sea area. Drift is determined as the velocity (speed and direction) of the centre of gravity of the oil slick. The spreading is described as the increase of the slick radius. Each of the processes is described in more detail below.

Drift

The spill is drifting with time as a result of the impact from wind friction as well as from the residual current in a specific area.

Drift due to wind action

Even in situations with low wind (calm), residual currents in different North Sea areas will transport oil slicks. The wind drift describes the drift of the centre of gravity of an oil slick that is floating on the water surface. The drift velocity is described as a fraction of the wind speed and the direction is described relative to the wind direction.

Drift due to residual currents

The modelled annual mean current at 30 m depth is selected to describe the net residual currents that will transport oil slicks independently of wind. This drift will act on floating oil at the water surface as well as on dispersed oil slicks in the water surface. In case of calm (no wind), this will be the only transport mechanisms.

A schematic illustration of the addition of wind driven and residual drift is given in Figure 3-4.

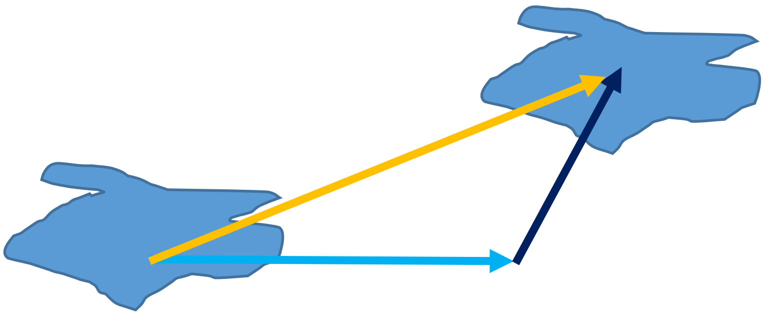


Figure 3-4 Schematic illustration of the resulting drift velocity (yellow) as a superposition of wind drift (light blue) and residual current drift (dark blue).

Spreading:
Although a slick can have many different shapes, such as circular, ellipsoidal or irregular, it is modelled as circular in the present modelling. In reality, spills are elongated in the downwind edge. However, including an ellipsoid in the modelling would double the required computing time and this would not add significantly to the accuracy of the model as the total swept area, and not just the final position of the spill, would remain the same in the model. The actual shape of the oil spill is of secondary importance in a strategic modelling approach as long as the area of the spill as well as the remaining mass of the spill is modelled through the history of each spill. The diameter of the spill increases with time and the thickness reduces correspondingly. Oil recovery activity will decrease the thickness of the spill, not the area.

The development of the slick radius is a result of the gravity spreading and the spreading by tide:

Rres = Rgrav + Rtide

Rgrav: Spreading by gravity:
An instant release of oil will give rise to spreading resulting from to opposite forcing:
a) Gravity, forcing towards a fats spreading, and
b) Viscosity, forcing the spreading to be slower for higher viscosity.

Rtide: Spreading by tide:
The tide will move any floating particle in so-called tidal ellipsoidal movements. Such tidal movements imply that any particle (slick) will move according to the site-specific tidal ellipsoid and hence affect and area that is larger than the area that is affected if only the wind drift is taken into account.

Rres is considered a typical scale of a radius that describes the area likely to be affected over a tidal cycle rather than the instant area of oil. This implies that the area for Rres will be larger, and, consequently, the average thickness will become smaller. This is considered a smaller error compared to the benefit of describing the affected area.

3.3.4 Tidal drift velocity and direction

Within a tidal cycle, the water level is performing a sinusoidal vertical movement. On the horizontal, however, the water particles are typically performing an ellipsoidal movement. This is illustrated in Figure 3-5 below. The reason for performing ellipsoidal movements at all is the Coriolis force. The shape of tidal ellipses are a function of local bathymetry (coastlines and depth contours). Typically, flat tidal ellipses are found close to the shoreline, where the cross-shore component of the current is relatively small. This situation corresponds to the theory of the Kelvin wave. “Circular” tidal ellipsis, on the other hand, are usually found offshore, where the tide is less influenced by bathymetric features, and the tides hence can be viewed at as an inertia-gravity wave (or Poincarré wave).

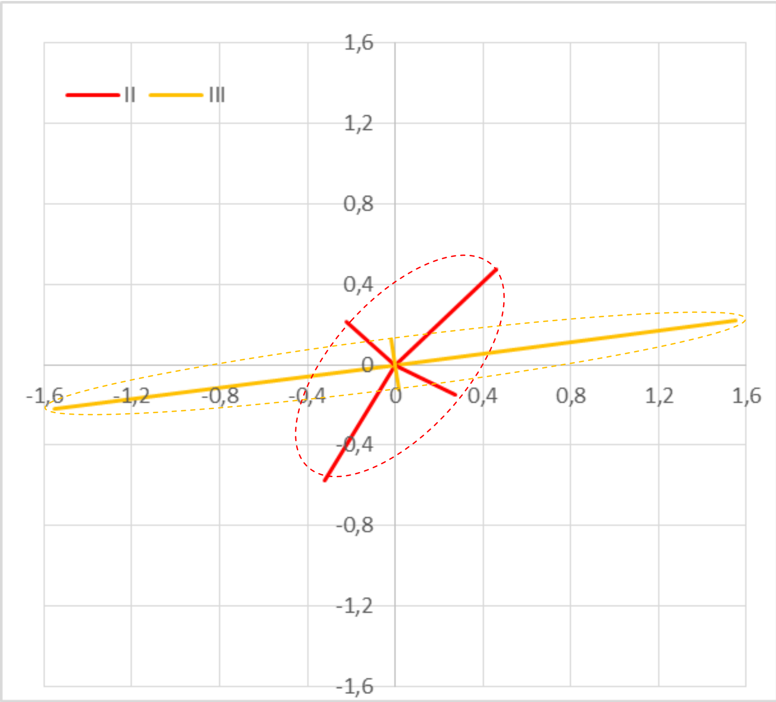


Figure 3-5 **Illustration of different tidal ellipsoids:**
II (red): Off Brest
III (yellow): Central English Channel
The horizontal and the vertical axes represent the magnitude (in m/s) of the eastward and the northward tidal current component, respectively. The tidal ellipsis area is a measure of the tidal energy at the considered location.
Data were prepared by RBINS-MUMM from the FES2012 tidal atlas.

When the drift of the slick is added, the ellipsoidal character of the tidal movement will imply a two dimensional “curly” movement of the slick, implying that an even larger area will be swept by the slick. An example of such a movement is given in Figure 3-6, which illustrates the affected area after several tidal cycles.

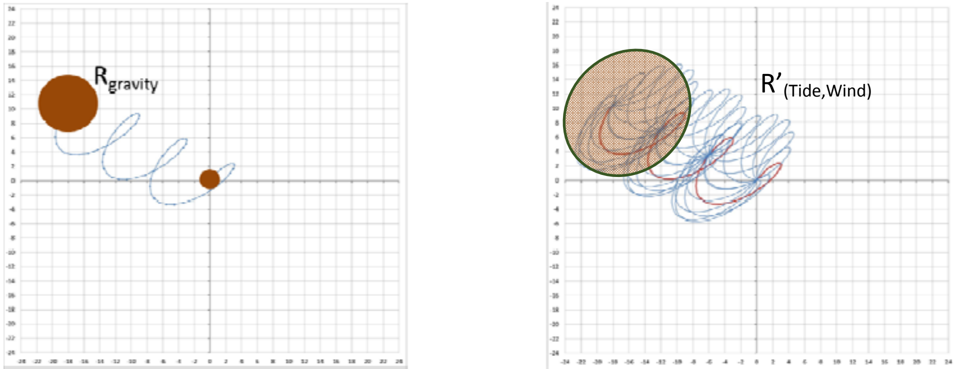


Figure 3-6 Schematic illustration of the area of the oil slick (left) and the area likely to be affected by oil (right) in the situation with tide and superimposed wind drift.
Left panel: Slick area (described by $R_{gravity}$) and track of centre of gravity after 3 tidal cycles
Right panel: Area likely to be affected (described by R') and tracks of centre of gravity after 3 cycles.
This example: Wind is 7 m/s from 120º, Tide from Brest with major axis 0,7 m/s, 45ºN, and minor axis 0,3 m/s, 315ºN.

It is seen from Figure 3-6 that the slick will cover a larger area when the ellipsoidal movement due to the tidal ellipsoid released at different times within a tidal circle is taken into account.

Development of oil on water surface over time:
The amount of oil remaining on the water surface is subject to several processes that are highly complicated and inter-correlated. In order to achieve an operational and consistent description the resulting process is modelled as a change in the mass of the spill as a function of time. The basic relations are given in (ITOPF, 2006) and illustrated in Figure 3-12.

The development of an oil slick is illustrated schematically in Figure 3-7 below. The figure includes a heavy oil type for which emulsification takes place resulting in a larger mass. The figure further shows the modelling of dispersed oil where the plume of dispersed oil spread and propagates at a reduced speed in the water column. Under such conditions, weathering takes place at different speed and remediation is not possible any longer. Finally, the figure shows the effect of changed drift direction once the oil slick enters a new hydrographical area with different characteristics.

Submerged oil is not included in the present analysis, since submerging oil requires the density of oil is equal to the density of water. In the North Sea, where the seawater density is close to 1028 kg/m^3, this is not very likely to occur to a degree that is relevant for the present strategic study,

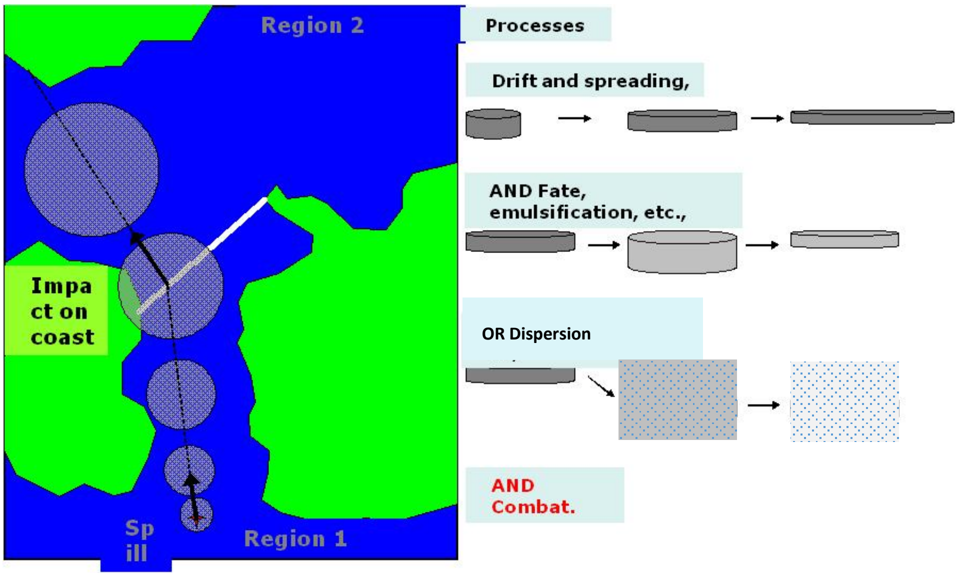


Figure 3-7 Principle of the calculation of the development of an oil slick in the model

3.3.5 Wind drift velocity and direction

The main usage of the results from the oil spill simulations is to derive drift velocity and drift direction for each of the hydrographical areas. Based on experience the drift velocity of the oil slick is a linear function of the wind velocity in open waters. Likewise, the drift direction in open waters of an oil slick is a linear function of the wind direction.

From the literature and the BRISK project (BRISK, 2012) it is noted that the drift velocity is either a linear function of the wind velocity or a constant value. The constant value appears to be a better representation in water bodies, which primarily serves as a conveyance of flow, such as in Straits and channels.

The following general expressions are therefore derived:

$$V_{Drift} = V\_coef \cdot V_{Wind}$$

Based on a comprehensive study in (BRISK, 2012) the median value (50% percentile) for coefficient for the wind drift V coef is found to be 2.3%. It is found that the values modelled for in 21 sea areas only varies with a standard deviation of about 30%, which is considered to be very small and the median value hence to be considered robust value. In standard oil spill models the wind drift coefficient is usually between 2% and 4% (OSERIT uses 3.15%), which confirms the found value.

The drift direction is generally found to vary linearly with the wind direction according to

$$Direction_{Drift} = D\_coef \cdot Direction_{Wind} + D\_K1$$

For the drift-direction modelled by SEATRCK Web in (BRISK, 2012) it is found that the resulting drift direction virtually is equal to the wind direction and hence that the direction coefficient D coef is one and the offset D_K1 is zero. It is the experience from e.g. OSERIT-modelling, that the offset crosswind deviation (expressed by the offset D-K1) is of minor importance when the wind speed is higher than 5 m/s, i.e. in the present wind class 2 and 3. Therefore, an offset of zero can be applied in the present model context.

The drift speed Vdrift and the drift direction Ddrift are determined as follows:

V-coeff = 0,023	=> Vdrift	= 0,023 · W,	W: Wind speed (m/s)
D-coeff = 1	=> Ddrift	= D,	D: Wind direction (deg)

3.3.6 Residual drift velocity and direction

The long-term average drift is determined based on the modelled average currents in 30 m water depth. This current represents the residual current that dominates in calm weather, as well as the drift of oil that is dispersed into the water column, and that therefore not is exposed to wind drag. The modelling is carried out by (MUMM, 2014). The modelled average flow field is represented in Figure 3-8.

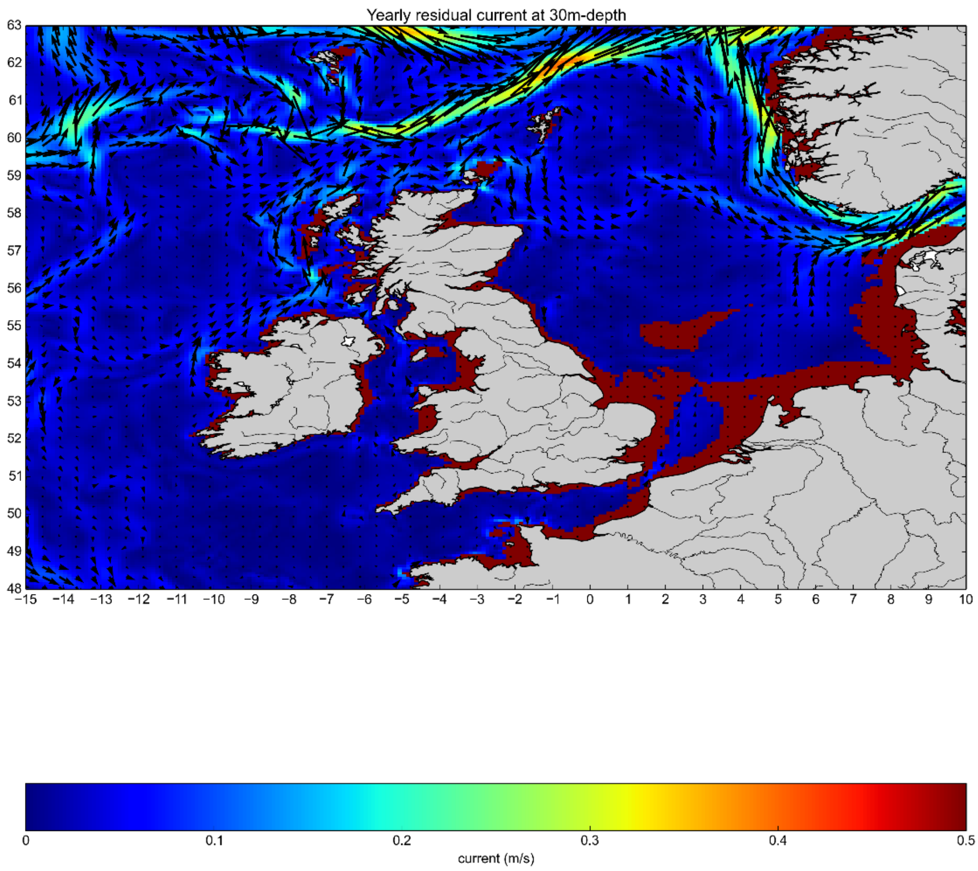


Figure 3-8 Average flow filed based on one year model results in 30 m water depth, (MUMM, 2014). Brown areas indicate areas shallower than 30 m.

The residual flow speed and direction that characterises each meteorological area are assessed based on

- extraction of average velocities (speed and direction) at specific points
- average consideration for each meteorological area.

Flow on areas shallower than 30 m is considered to follow the flow in the adjacent deeper areas.

It is found that the residual currents on average for a meteorological area are of an order of magnitude smaller than the average wind driven currents. Further, it is found that some meteorological areas include residual currents with different or even opposite current directions. Average considerations have to be taken in such cases, resulting in minor residual currents, like in the Skagerrak. Finally, some meteorological areas include no clear residual currents, but currents that are mainly depending on the present wind conditions. This is the case in the Southern North Sea as well as in the English Channel. In these areas, the residual current is set to be equal to 50% of the wind-induced surface current. The corresponding flow direction is projected on the main channel direction, i.e, on 30ºN in the area F (southern North Sea) and on 60ºN in the area G (English Channel).

The resulting residual drift velocities are given for each meteorological area in Table 3-6. A map of the meteorological areas A to G is given in Figure 3-2.

Table 3-6 Residual drift velocities and direction for each meteorological area.

Meteorological area	Description	Residual drift speed (m/s)	Direction of drift (ºN)
A	West of Ireland	0,05	45
B	NW of Scotland	0,07	45
C	West of Norway	0,1	45
D	East of UK	0,02	150
E	West of Denmark	0,07	45
F	Southern North Sea	0,01W, projected	30, 210
G	English Channel	0,01W, projected	60, 240

3.4 Spreading of oil on the sea surface

Spreading of an oil spill on the sea surface is calculated based on the effects of gravity and viscosity in the first hours of a spill. Afterwards the hydraulic and oceanographic conditions determine the spreading process through differences in the surface currents.

The initial spreading due to gravity and viscosity is determined based on the analytical methods, usually applied in the spill models. The applied formulae are also applied in SINTEFS oil weathering manual (Reed, 2004). The formulae assume that the oil spill is circular, which is a simplification, particularly for spills that are followed over longer periods. Changing current and wind conditions will stretch the spill. However, the ratio between the length and the width of a spill will within the first days of a spill most often be the same order of magnitude. The radius of the spill is determined as

$$\frac{d}{dt}X^{4/3} = 1.75\left(h^2 \rho g'\right)^{\frac{2}{3}} \left(\rho_w \mu_w\right)^{-\frac{1}{3}}$$

X : Radius (m)
t : Time (s)
h : Thickness (m)
ρ : Density of oil (kg/m^3)
g' : Reduced and normalised gravity ($(\rho_w-\rho)/\rho_w$)
ρ_w : Density of water (kg/m^3)
μ_w : dynamic viscosity of water (kg/(ms))

The kinematic viscosity ν equals the dynamic viscosity μ divided by the density ρ.

The oil volume is included indirectly in the formula above as it operates with both, the radius (X) and the spill thickness (h).

The development over time of the spill radius is illustrated for a 3,000 ton spill of crude (μ = 1.8·10-3 kg/(ms)). The development is in principle depending on several processes, however, only the most important shall be included in the present strategic model. An example of the radius development is shown in Figure 3-9 below.

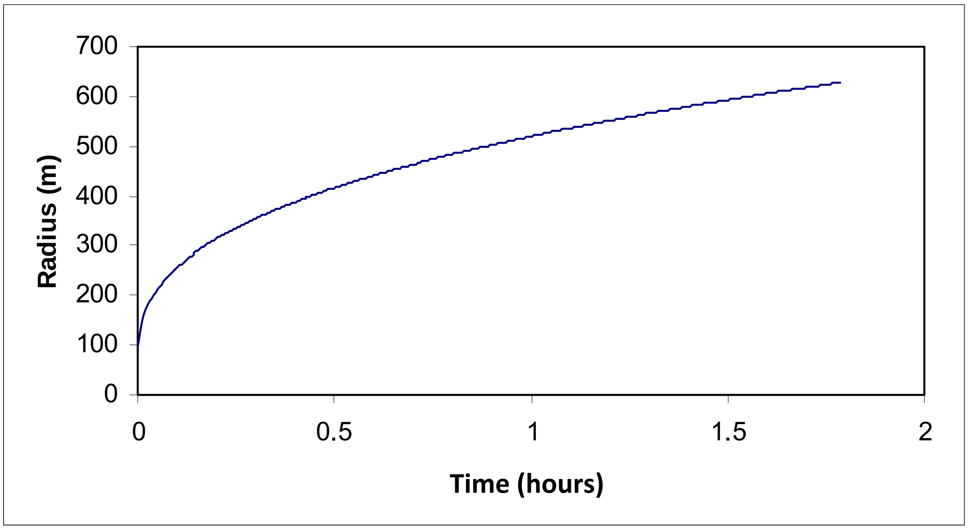


Figure 3-9 Example of the initial phase of the development of the spill radius for a 3,000 t crude oil spill, calculated after (Reed, 2004).

It is seen from the graph above that the radius in the initial phase increases logarithmic and becomes almost linear in the later phase. The linear relation of the spill radius is evaluated based on several simulations of different spill sizes and results in a final assumption as illustrated in Figure 3-10 below.

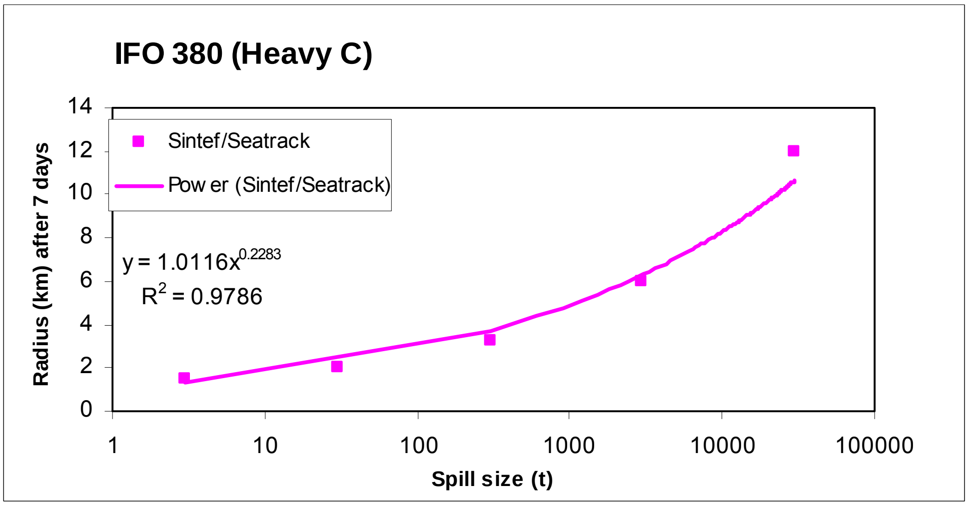


Figure 3-10 Example of the effect on the spill radius of a heavy oil spill after 7 days

The effect of different viscosities (oil types) on the radial spreading of the spill is illustrated in Figure 3-11below, where the increase of spill radius for a heavy bunker oil (kinematic viscosity v = 50.000 cSt) is shown together with the increase of the spill radius of a light oil (v = 50 cSt).

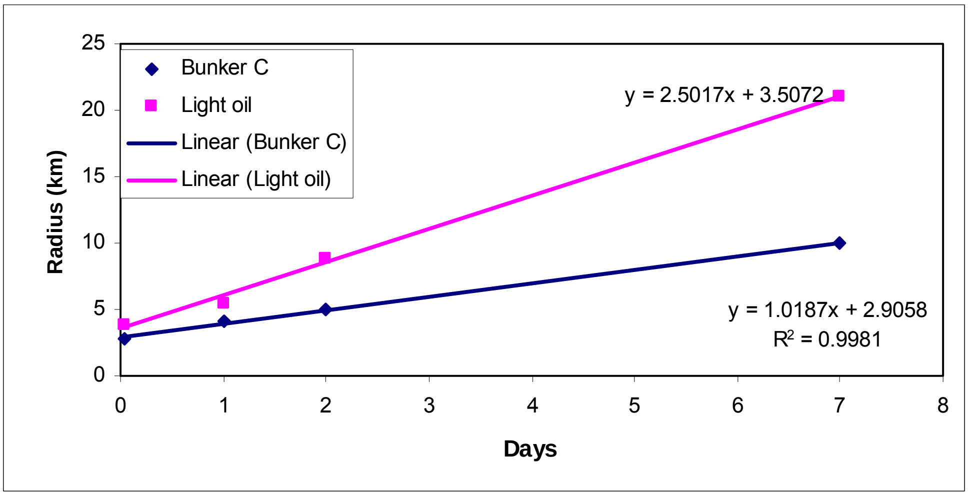


Figure 3-11 Development of spill radius as function of oil type (viscosity) for a 30,000 t spill

The linear relationship between time and spill radius is described with the expression below. In order to describe the large range of the viscosities (3 decades) a logarithmic expression is chosen. This also has the advantage (compared to Reeds expression) of resulting in an explicit description, avoiding time consuming solutions of differential equations. The resulting expression for spill radius is hence:

$R(t,M,v)= 0.113 \cdot M^{(0.22)} \cdot [\{0.13-0.02\log(v)\} \cdot t+\{3.8-0.2\log(v)\}]$,

R : Radius of oil spill (km)
t : Time (Timer)
M : Mass of spilt oil (t)
v : Kinematic viscosity (cSt) at the given temperature
log : 10- logarithm (Briggs)

The viscosity in the above expression is given by the user based on the specific oil type and the specific temperature.

Spreading of oil that is chemically dispersed in the water column is described in chapter 3.10.

3.5 Density and viscosity

Four different oil types are investigated in the present study. Their respective densities and viscosities at different temperatures are given below.

3.5.1 Gasoil (Diesel)

Table 3-7 Density and viscosity for diesel at 4 temperatures. For water temperatures close to freezing point the relations are extrapolated (Environment Canada, 2006)

	4 °C	7 °C	11 °C	16 °C
Density (kg/m^3)	837	834	828	827
Viscosity (cSt)	3	3	3	2

Taking the temperatures in the different subareas (see Table 3-21) into account, the following Table 3-8 and Table 3-9 are derived for density and viscosity, respectively:

Table 3-8 Gasoil density for each tidal area and season.

Density (kg/m3)		Season			
		Dec, Jan, Feb	Mar, Apr, May	Jun, Jul, Aug	Sep, Oct, Nov
Nr	Tidal area	Winter	Spring	Summer	Autumn
1	Atlantic (IR)	828	828	827	828
2	Atlantic (FR)	828	828	827	827
3	Channel	833	828	827	828
4	Irish Sea	833	828	827	828
5	Shetland	834	831	828	828
6	UK, North-East	835	831	827	828
7	UK, East	835	831	827	828
8	UK- South-East	835	830	827	828
9	NL-GE	836	828	827	828
10	DE-DK	838	828	827	828
11	North Sea	835	831	827	828

Table 3-9 Gasoil viscosity for each tidal area and season.

Viscosity (cSt)		Season			
		Dec, Jan, Feb	Mar, Apr, May	Jun, Jul, Aug	Sep, Oct, Nov
Nr	Tidal area	Winter	Spring	Summer	Autumn
1	Atlantic (IR)	3,0	2,8	2,0	2,8
2	Atlantic (FR)	3,0	2,6	1,6	2,4
3	Channel	3,0	3,0	1,8	2,6
4	Irish Sea	3,0	3,0	2,2	2,8
5	Shetland	3,0	3,0	2,6	3,2
6	UK, North-East	3,0	3,0	2,4	3,0
7	UK, East	3,0	3,0	2,2	3,0
8	UK- South-East	3,0	3,0	1,8	2,8
9	NL-GE	3,0	3,0	1,6	3,0
10	DE-DK	3,0	3,0	1,6	3,4
11	North Sea	3,0	3,0	2,0	3,2

3.5.2 Crude oil

Table 3-10 Density and viscosity for Russian Komineft crude at 4 temperatures. This oil is transported in large quantities through the North Sea from Skaw to Rotterdam. For water temperatures close to freezing point the relations are extrapolated (Environment Canada, 2006)

	4 °C	7 °C	11 °C	16 °C
Density (kg/m^3)	852	849	845	840
Viscosity (cSt)	46	37	25	10

Taking the temperatures in the different subareas (see Table 3-21) into account, the following Table 3-11 and Table 3-12 are derived for density and viscosity, respectively:

Table 3-11 Crude oil density for each tidal area and season.

Density (kg/m3)		Season			
		Dec, Jan, Feb	Mar, Apr, May	Jun, Jul, Aug	Sep, Oct, Nov
Nr	Tidal area	Winter	Spring	Summer	Autumn
1	Atlantic (IR)	845	844	840	844
2	Atlantic (FR)	845	843	838	842
3	Channel	848	845	839	843
4	Irish Sea	848	845	841	844
5	Shetland	849	847	843	846
6	UK, North-East	850	847	842	845
7	UK, East	850	847	841	845
8	UK- South-East	850	846	839	844
9	NL-GE	851	845	838	845
10	DE-DK	853	845	838	847
11	North Sea	850	847	840	846

Table 3-12 Crude oil viscosity for each tidal area and season.

Viscosity (cSt)		Season			
		Dec, Jan, Feb	Mar, Apr, May	Jun, Jul, Aug	Sep, Oct, Nov
Nr	Tidal area	Winter	Spring	Summer	Autumn
1	Atlantic (IR)	25	22	10	22
2	Atlantic (FR)	25	19	4	16
3	Channel	34	25	7	19
4	Irish Sea	34	25	13	22
5	Shetland	37	31	19	28
6	UK, North-East	40	31	16	25
7	UK, East	40	31	13	25
8	UK- South-East	40	28	7	22
9	NL-GE	43	25	4	25

10	DE-DK	49	25	4	31
11	North Sea	40	31	10	28

3.5.3 Fuel oil (Bunker)

Table 3-13 Density and viscosity for bunker oil at 4 temperatures. For water temperatures close to freezing point the relations are extrapolated (Environment Canada, 2006)

	4 ºC	7 ºC	11 ºC	16 ºC
Density (kg/m^3)	998	996	992	988
Viscosity (cSt)	54.000	34.000	18.500	8.600

Taking the temperatures in the different subareas (see Table 3-21) into account, the following Table 3-14 and Table 3-15 are derived for density and viscosity, respectively:

Table 3-14 Fuel oil density for each tidal area and season.

Density (kg/m3)		Season			
		Dec, Jan, Feb	Mar, Apr, May	Jun, Jul, Aug	Sep, Oct, Nov
Nr	Tidal area	Winter	Spring	Summer	Autumn
1	Atlantic (IR)	992	991	988	991
2	Atlantic (FR)	992	990	986	990
3	Channel	995	992	987	990
4	Irish Sea	995	992	989	991
5	Shetland	996	994	990	993
6	UK, North-East	997	994	990	992
7	UK, East	997	994	989	992
8	UK- South-East	997	993	987	991
9	NL-GE	997	992	986	992
10	DE-DK	999	992	986	994
11	North Sea	997	994	988	993

Table 3-15 Fuel oil viscosity for each tidal area and season.

Viscosity (cSt)		Season			
		Dec, Jan, Feb	Mar, Apr, May	Jun, Jul, Aug	Sep, Oct, Nov
Nr	Tidal area	Winter	Spring	Summer	Autumn
1	Atlantic (IR)	18500	16520	8600	16520
2	Atlantic (FR)	18500	14540	4640	12560
3	Channel	30125	18500	6620	14540
4	Irish Sea	30125	18500	10580	16520
5	Shetland	34000	26250	14540	20480
6	UK, North-East	40667	26250	12560	18500

7	UK, East	40667	26250	10580	18500
8	UK- South-East	40667	22375	6620	16520
9	NL-GE	47333	18500	4640	18500
10	DE-DK	60667	18500	4640	22460
11	North Sea	40667	26250	8600	20480

3.5.4 Gasoline (Benzin)

Table 3-16 Density and viscosity for gasoline (Casinghead, Leaded) at 4 temperatures. For water temperatures close to freezing point the relations are extrapolated (Environment Canada, 2006)

	4 °C	7 °C	11 °C	16 °C
Density (kg/m^3)	712	709	705	700
Viscosity (cSt)	0,61	0,58	0,54	0,49

Taking the temperatures in the different subareas (see Table 3-21) into account, the following Table 3-17 and Table 3-18 are derived for density and viscosity, respectively:

Table 3-17 Gasoline density for each tidal area and season.

Density (kg/m3)		Season			
		Dec, Jan, Feb	Mar, Apr, May	Jun, Jul, Aug	Sep, Oct, Nov
Nr	Tidal area	Winter	Spring	Summer	Autumn
1	Atlantic (IR)	705	704	700	704
2	Atlantic (FR)	705	703	698	702
3	Channel	708	705	699	703
4	Irish Sea	708	705	701	704
5	Shetland	709	707	703	706
6	UK, North-East	710	707	702	705
7	UK, East	710	707	701	705
8	UK- South-East	710	706	699	704
9	NL-GE	711	705	698	705
10	DE-DK	713	705	698	707
11	North Sea	710	707	700	706

Table 3-18 Gasoline viscosity for each tidal area and season.

Viscosity (cSt)		Season			
		Dec, Jan, Feb	Mar, Apr, May	Jun, Jul, Aug	Sep, Oct, Nov
Nr	Tidal area	Winter	Spring	Summer	Autumn
1	Atlantic (IR)	0,54	0,53	0,49	0,53
2	Atlantic (FR)	0,54	0,52	0,47	0,51
3	Channel	0,57	0,54	0,48	0,52
4	Irish Sea	0,57	0,54	0,50	0,53

5	Shetland	0,58	0,56	0,52	0,55
6	UK, North-East	0,59	0,56	0,51	0,54
7	UK, East	0,59	0,56	0,50	0,54
8	UK- South-East	0,59	0,55	0,48	0,53
9	NL-GE	0,60	0,54	0,47	0,54
10	DE-DK	0,62	0,54	0,47	0,56
11	North Sea	0,59	0,56	0,49	0,55

3.6 Weathering and natural dispersion

Weathering processes are highly complex and subject to vary comprehensive research and modelling work. In order to keep the present model effort within limits the explicit and simplified description by ITOPF below applied.

Weathering processes are highly complex and subject to vary comprehensive research and modelling work. In order to keep the present model effort within limits the explicit and simplified description by ITOPF below applied.

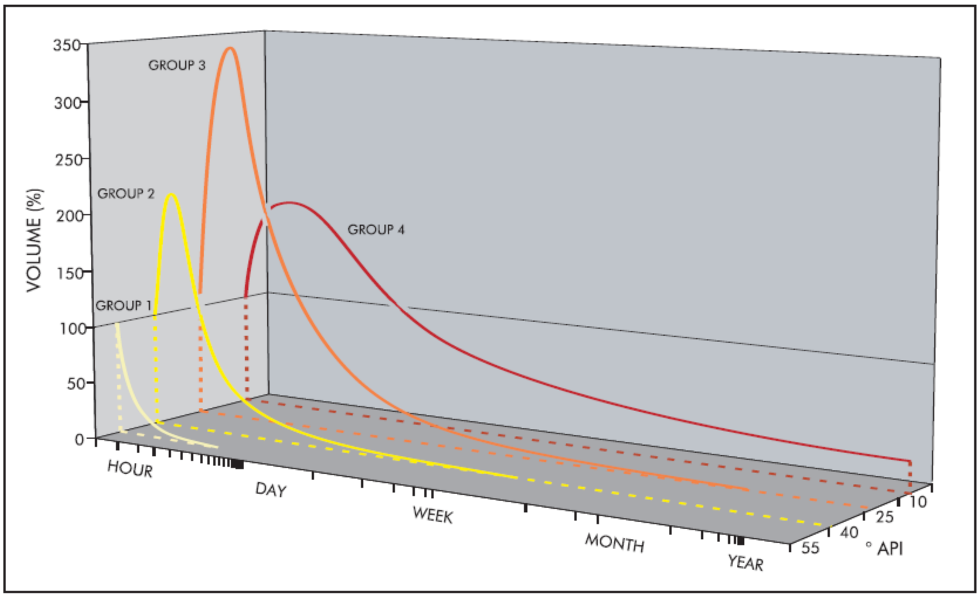


Figure 3-12 **Volume of oil and water in oil emulsion on the sea surface. The curves represent average weathering of different oil types (ITOPF, 2006). Group 4 represents bunker oil, group 2 and 3 light and heavy crude oil, resp. Group 1 represents diesel.**

The above volumes of oil and oil-in-water emulsions are expressed in simplified terms and illustrated below. The processes of evaporation as well as emulsification are integrated in the description.

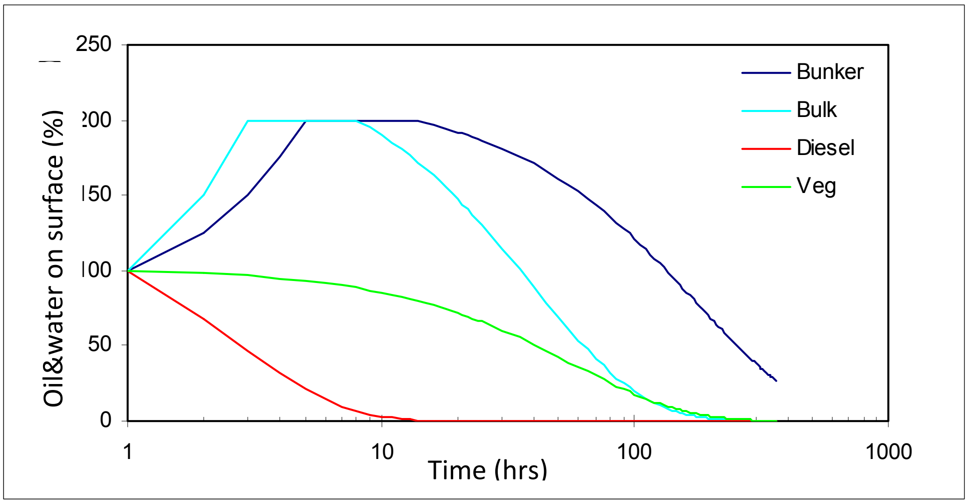


Figure 3-13 Simplified remaining mass of oil and oil- water emulsion on the sea surface, after ITOPF 2006.

The light oils and chemicals (diesel and vegetable oils) do not readily emulsify. The floating chemicals are volatile and will evaporate with similar time scales as for diesel. The mass of light oil Mlight on the sea surface is determined using the following approximation:

$M_{light}(t) = 100 \cdot \exp[-t/(3{,}3 \cdot v^{0{,}4})]$ %,

t : time (hours), (>=0)
v : Viscosity (cSt) given for the resp. season (v_{min}=10cSt)
ln : Logarithm function based on (e)

The heavy oil (crude and bunker) do emulsify. This complicated process is described in simple terms as a function of viscosity. The algorithms for the mass of heavy oils Mheavy on the surface are given below:

For $0 < t/\ln(v) < 1$ => $M_{heavy}(t) = 100 \cdot t/\ln(v) + 100$ (%)

For $1 < t/\ln(v) < 3$ => $M_{heavy}(t) = 200$ (%)

For $3 < t/\ln(v)$ => $M_{heavy}(t) = 200 \cdot \exp[-\{t - 3 \cdot \ln(v)\}/(3{,}4 \cdot v^{0{,}4})]$ (%)

The terms are explained above for the light oils.

3.7 Modelling stop criteria

In order to limit the modelling time it is necessary to specify criteria when the modelling of a single spill has to be stopped. In general, it is decided to stop the simulation when 5% of the oil is left on the sea surface. The rest of the oil is either

- Weathered
- Floated in shore
- Floated towards the open boundary towards the North Atlantic
- Removed by response action

3.8 Response capacity

3.8.1 Response calculation

The emergency response applies a wide range of different equipment including ships, barges, pumps, skimmers, booms and barriers as well as different hardware such as radar for the detection of oil, etc. In order to describe the effect of the emergency response to the oil spills in a practical manner in the model complex, the response methods are reduced to include only the capacity of pumps and skimmers, as well as the equipment applied to convey the spill to the skimmers, e.g. booms attached to tow boats. The time lag for mobilising and transport from homeport to spill position is included in the model.

The effect of the emergency response is modelled as a reduction of the amount of oil in the circular oil slick. The diameter hereof is unchanged, while the thickness reduces.

In order to calculate the effect of the emergency response it is chosen to define an artificial model response that replicates a possible and realistic emergency response, by a model of the actual emergency response.

It is assumed that the response capacity increases with time, as more ships will reach the scene.

The capacity for oil removal is calculated on basis of the total number of ships on scene, oil skimmers and pumps, as well as the total length of booms that is available. The nominal capacity of the pumps is used for the present study, well knowing that the capacity in many practical cases may be less. In order to have a comparable capacity for all pumps and taken into account the capacity reducing parameters listed in Table 3-19, it is considered an operational characterisation of the maximum pumping capacity.

In addition, the modelling contains a number of conditions, which may reduce the effectiveness of the emergency response, such as visibility, darkness, limiting significant wave height etc.

Table 3-19 shows the tentative parameters for the emergency response description and their values.

Table 3-19 Overview of input parameters for description of the emergency response (The values are for illustration only)

Parameter	Dimension	Model-response	Comments
Accumulated capacity of pump-skimmer system at time Tn	m3/h	Cap1: 0 Cap2: 50 Cap_n 100	To be set for each representative point
Accumulated length of booms at time Tn	m	L1: 300 L2: 600 L_n: 1200	To be set for each representative point
Alarm combat time T1, T2 … Tn	hours	T1: 1 T2: 2 T_n: 6	The time intervals applied is 0.25 hours the first 12 hours after the spill, 0.50 hours 12-24 hours after the spill and 24 hours after the response will be calculated on an hourly basis.
Tow speed	knots	V: 1	To be set for each vessel
Visibility coefficient (ratio of the time where combat is not possible due to fog and haze)	Non-dimensional	Spring: 0.02 Summer: 0.01 Autumn: 0.02 Winter: 0.04	To be set for each meteorological area
Darkness coefficient (ratio of the time where combat is not possible due to too little daylight)	Non-dimensional	Spring: 0.4 Summer: 0.2 Autumn: 0.4 Winter: 0.6	To be set for each meteorological area
Maximum significant wave height	m	1.5*)	To be set for each hydrographical area

*) Decided at Project Team Meeting No. 2, 2. June 2014

The capacities of pumps and skimmers, after applying the above reduction factors still depends on the storage capacity on board the oil collecting vessel. Since separated water can be discharged into the sea in most cases, and since procedures are on the way to make this possible, where this at presently not possible, the discharge provides additional time before the tank capacity is reached. In case this capacity is filled up, the collection activity has to be stopped and the oil-water mixture on board the vessel has to be emptied either to land storage or to another vessel / barge / storage device. In the model it is assumed, that sufficient storage capacity will be provided within the period before the storage tanks are full and that the recovery process is not limited due to this factor. This is valid for all regions and all scenarios and it is therefore up to the responders to provide sufficient storage capacity as an integral part of the emergency response management.

3.9 Applied capacity for each representative spill point

The regional response to oil spills is based on the response capacities as they have been reported by the Project Partners. This information represents an update of the existing database stored at Bonn Agreement.

The database includes the names of each vessel, its dimensions, speed, homeport, mobilisation time, and its equipment in terms of pumps, skimmers and storage. Further, additional equipment that is stored on barges and in depots is included in the database.

The response is calculated for each representative spill point. The representative points are illustrated in Figure 3-14. The service levels are therefore different at each location and the expected service level is of course lowest far out in the Atlantic and highest from the English Channel to German Bight and along the Norwegian Coast near the majority of the response equipment. The route net applied in BE-AWARE I was applied to calculate the distances sailed from the vessel location to the spill point.

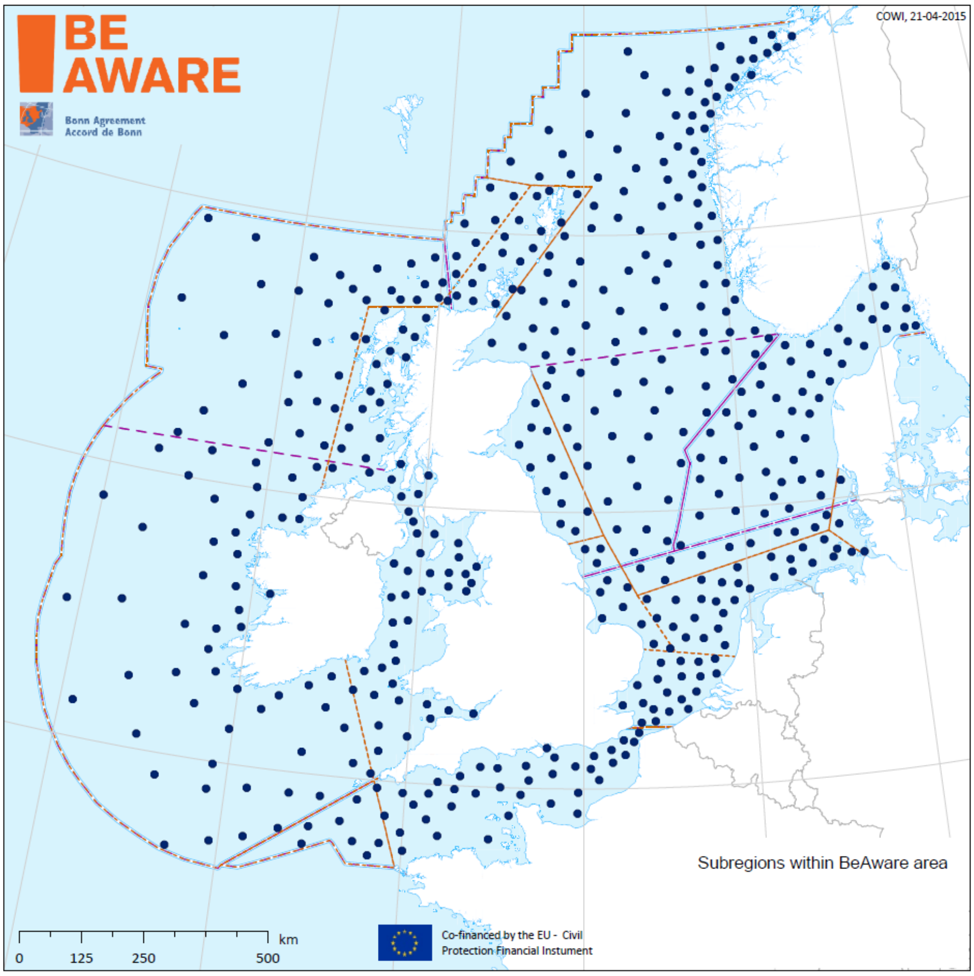


Figure 3-14 Illustration of the representative points where the specific response capability is calculated.

At each representative point, where the oil spill is modelled, the response capability is calculated. The first 12 hours after the spill the average response capability is calculated every 15min. From 12h to 24h after the spill the response capability is calculated every 30min and after 24h the response capability is calculated in 1 hour intervals. At coastal spills close to a response vessel on standby the first vessel will be at the spill site very fast, and at spills far from the response vessels the time before the first vessel reach the spill site will be greater.

The response capacity is aggregated for each emergency area in order to provide an integrated value for applicable booms and skimmers.

The mobilised booms and skimmers can only collect oil and reduce environmental damage if they can be applied in the areas where spills will occur. If they are placed close to the hot spots, they will be able to collect a larger amount of oil compared to a situation where they are placed far away from the hot spots.

3.9.1 Visibility

The visibility coefficient is defined as the ratio of the time where response to oil spill is not possible due to fog, haze and snow. The estimations of the coefficient are based on description of the visibility in the North Sea Pilot (Admiralty, 2010).

Based on the verbal descriptions the following ratios for bad visibility are prepared:

Table 3-20 Visibility coefficient for the sub-regions and seasons. The coefficient describes the quotient of time where response operation is not possible due to fog (Admiralty, 2010)

Sub-region		Season			
		1	3	4	5
		Dec, Jan, Feb	Mar, Apr, May	Jun, Jul, Aug	Sep, Oct, Nov
Nr	Name	Winter	Spring	Summer	Autumn
1	Atlantic Ocean	*0,02*	*0,03*	*0,05*	*0,03*
2	Northern North Sea	*0,01*	*0,04*	*0,03*	*0,01*
3	Eastern North Sea	*0,04*	*0,04*	*0,01*	*0,01*
4	Southern North Sea	*0,04*	*0,03*	*0,01*	*0,01*
5	English Channel	*0,04*	*0,03*	*0,02*	*0,02*

A visualisation of the seasonal variation of the visibility coefficient is given in Figure 3-15 below.

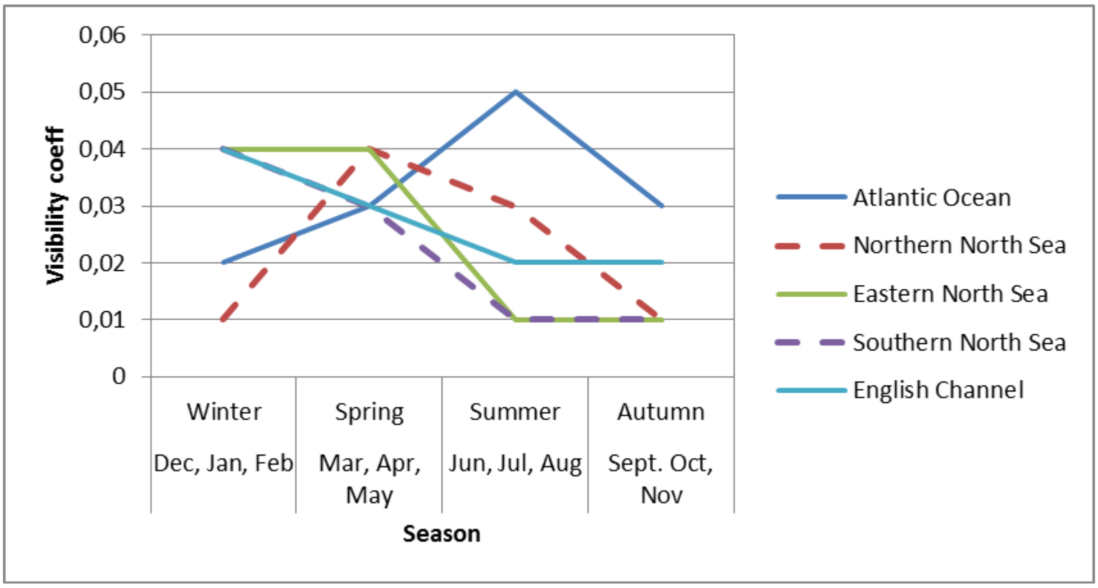


Figure 3-15 Seasonal variation of visibility coefficient.

3.9.2 Sea surface temperature

The sea surface temperature is important to determine the viscosity in the different seasons and different tidal areas. The temperatures are based on description on the information provided in the North Sea Pilot (Admiralty, 2010).

Based on the distribution maps the following temperatures are found:

Table 3-21 Sea surface temperatures the tidal areas and seasons. (Admiralty, 2010)

Sea surface temperature (ºC)		Season			
		1	3	4	5
		Dec, Jan, Feb	Mar, Apr, May	Jun, Jul, Aug	Sep, Oct, Nov
Nr	Tidal area	Winter	Spring	Summer	Autumn
1	Atalntic (IR)	*11*	*12*	*16*	*12*
2	Atlantic (FR)	*11*	*13*	*18*	*14*
3	Channel	*8*	*11*	*17*	*13*
4	Irish Sea	*8*	*11*	*15*	*12*
5	Shetland	*7*	*9*	*13*	*10*
6	UK, North-East	6	9	14	11
7	UK, East	6	9	15	11
8	UK- South-East	6	10	17	12
9	NL-GE	5	11	18	11
10	DE-DK	3	11	18	9
11	North Sea	6	9	16	10

3.9.3 Darkness

The darkness coefficient is defined as ratio of the time where response to oil spill is not possible due to too little daylight. The theory for calculating the length of the day is given by (Glamer, 2011).

The following image shows the tilted and shifted solar circle for the winter solstice at 45°N. The sun is only visible in part b of the whole circle; when continuing its path on the blue line it is night.

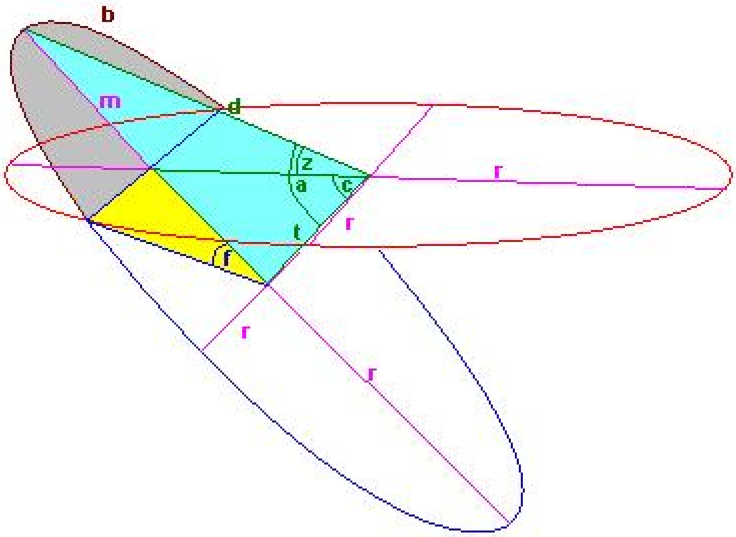


Figure 3-16 Solar circle for the winter solstice at 45°N (Glamer, 2011).

The period of darkness is defined as the full day period (24h) minus the length of the day and minus the time of the twilight. In this theory the length of the day is determined based on

- the latitude (lat) of the observer (0 deg at the equator, 90 deg at the poles)
- the obliquity (axis) of the ecliptic as the rotation of the earth is not perpendicular to its orbital plane, the equatorial plane is not parallel to the ecliptic plane, but makes an angle of 23,439 deg)
- the day of the year (day) (starting with the day of winter solstice)

In (Glamer, 2011) the theory can by simplified to the formula

Darkness = 1-(arccos(1-n)) /π, where

n = 1-tan(lat)tan(axis·cos(j·day))+h/cos(lat), where

j= 0,0172

h= tan(12deg).

The results for the different sub regions and the different seasons are determined and given below:

Table 3-22 Darkness coefficient for the sub-regions and seasons. The coefficient describes the quotient of time where it is dark and operation therefore is not possible.

			Season			
			1	3	4	5
Sub-region		Lat	Dec, Jan, Feb	Mar, Apr, May	Jun, Jul, Aug	Sep, Oct, Nov
Nr	Name	(deg N)	Winter	Spring	Summer	Autumn
1	Atlantic Ocean	53	0,55	0,36	0,24	0,50
2	Northern North Sea	58	0,57	0,34	0,18	0,52
3	Eastern North Sea	56	0,56	0,35	0,21	0,51
4	Southern North Sea	53	0,55	0,36	0,24	0,50
5	English Channel	50	0,54	0,37	0,26	0,50

A visualisation of the seasonal variation of the darkness coefficient is given in Figure 3-17 below:

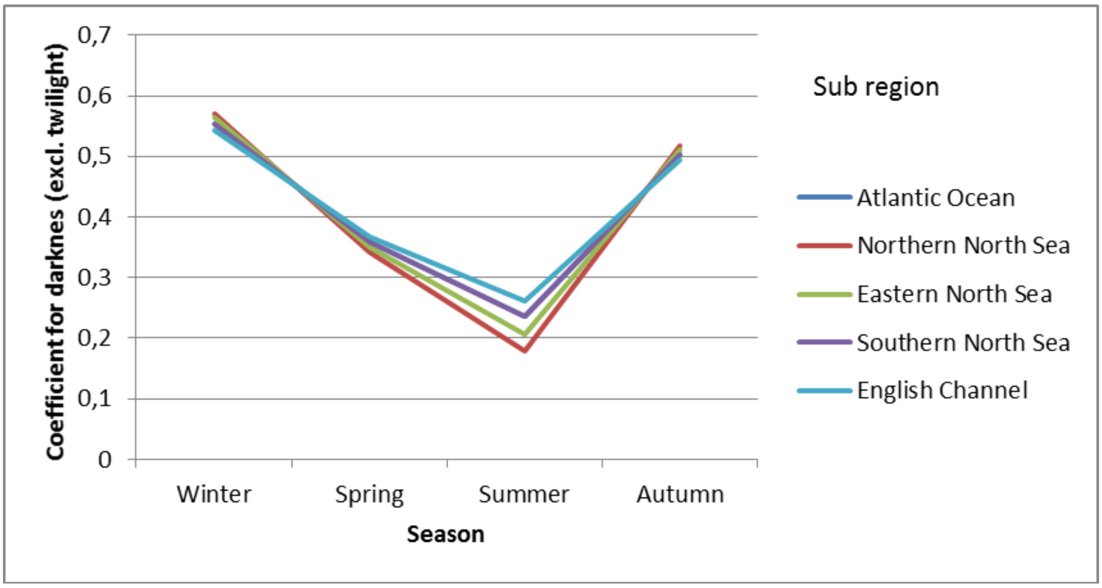


Figure 3-17 Seasonal variation of darkness coefficient.

3.9.4 Wave height

The wave height has a dominant effect on the recovery efficiency. This is included in the model with the introduction of a maximum significant wave height. As long as the wave height is smaller, recovery can continue without limitations. If the waves are high, the recovery stops.

The wave height is determined by the wind speed. Free fetch, water depth and duration of wind play minor roles for the Wider North Sea since the waters mostly are deep and the periods for oil spill response (few days) are long compared to the duration for establishment of a wave field (few hours) and the characteristic dimensions of the areas are large compared to the necessary free fetch. The steep wind generated wave will always cause the main limitations for the response action, whereas long swell waves not limit the operation.

It was decided by the Project Partner experts to apply a wave height of 1.5 m for wind waves, since it represents the limit for effective response.

The wind speeds required for given maximum wave height Hs of 1.5 m with an open fetch of minimum 200 km can be determined through the wave forecast tables in the Shore Protection Manual (US Army, 1977) and is found to be is approximately 8 m/s.

In agreement with the method applied in the BRISK project for the entire Baltic Sea as well as the method applied for the Danish Waters the probability for the different wind classes are determined as in the Table 3-23 below.

Table 3-23 Probabilities per wind class for wind less than 8 m/s (all sub areas)

Wind Speed Class	Probability (%)
Wind Speed Class 1 (< 5 m/s)	100
Wind Speed Class 2 (5-11 m/s)	50
Wind Speed Class 3 (> 11 m/s)	0

As mentioned above, the critical wind speed is 8 m/s. Since the Wind Class 1 only includes wind speed lower than 5 m/s, speeds from this class will always give rise to wave heights smaller than 1.5 m and hence not limit oil recovery due to wave height. Correspondingly, Wind Class 3 includes wind speeds higher than 11 m/s, which always will inhibit recovery activity. Since 8 m/s is placed in the centre of the interval of the Wind Class 2, half of the events for this wind class will allow recovery. Therefore, the probability that recovery is possible for winds speed for Wind Speed Class 2 is 50%.

3.9.5 Oil on shore

Oil on shore is summarised in the model for each sub-region. Once the oil touches a coastal cell in the model, the model will add this volume to the amount of oil on shore. Hence, this volume is removed from the oil on the free water surface.

3.10 Dispersants

A feature of oil spill response in the Bonn Agreement area is the possibility of combatting the oil spill with dispersants. The dispersants are typical applied from airplanes, although vessels also are able to be equipped with spray tools. In Norway, vessels are equally common as aeroplanes for dispersant spraying, and application by helicopter is part of the 2020 scenario for the Norwegian state response. Dispersants will loosen the surface tension of oil and it will be removed from the water surface and disperse within the water column.

The oil will hence not disappear but shift state and location. The impact on birds and on shore line will be smaller, but impact is expected to be larger on the pelagic biosphere (life between the water surface and the seafloor), in particular in case of shallow waters and/or water masses with low dilution potential (cf. typical 'trade-off' consideration in dispersant use decision-making. This is due to the fact, that the oil will have a much larger surface for chemical reaction and because the effect of the dispersant itself might be potentially harmful. The basic principles are illustrated in Figure 3-18 below:

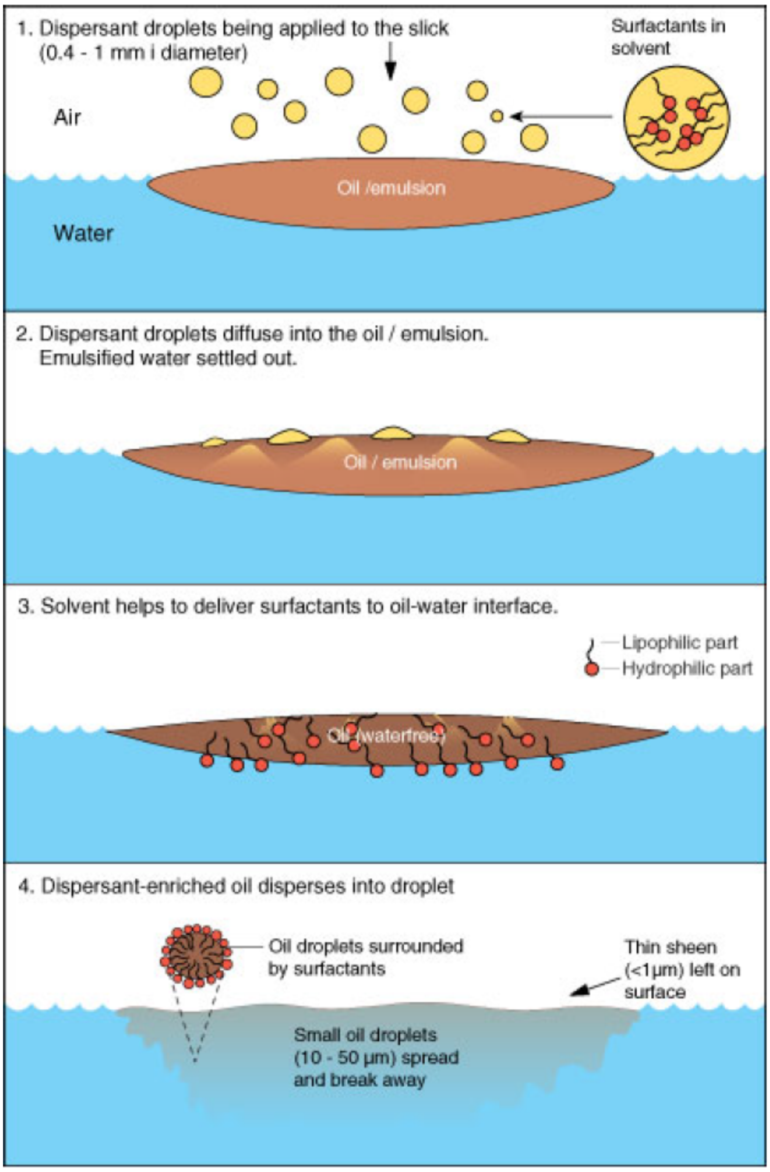


Figure 3-18 Basic principles for oil dispersion, from (EMSA, 2006)

The applicability of dispersants for the European waters is described in various publications, e.g. (EMSA, 2006). The modelling of the effect of dispersants is divided into two steps:

1. Identification of the window of dispersant applicability (when, where)
2. Modelling of drift, fate and impact once the oil is dispersed

3.10.1 Window of applicability

The conditions in which dispersant are assumed applicable are listed in the following.

Legality

Is it legal to apply dispersant in the territory of concern?

Only in the UK and FR waters, dispersants are applicable as a "potential first line of defence". In the UK “first line of Defence” applies only when strictly enforced criteria are followed. That is provided the oil is amenable, application is not in an area vulnerable to subsurface dispersed oil and dispersant use is considered to be an appropriate response strategy for that specific incident. The UK regulator has the final say. The necessary authorisation procedures are given in Table 3-24.

Table 3-24 Authorisation of dispersants use

Country	Authorisation required for dispersant use
Belgium	Allowed following official authorisation from the Management Unit of the North Sea Mathematical Model (MUMM), a scientific service of the Royal Belgian Institute of Natural Sciences (RBINS)
Denmark	Allowed following official authorisation from Environmental Protection Authority (EPA) under the Ministry of Environment
France	Allowed. The regional contact point for dispersant use is CEDRE
Germany	The application for dispersants is under consideration at the moment. In the EEZ it is an option but within the 12 nm zone there are strong restrictions due to the Wadden Sea World Heritage
Ireland	Allowed following prior official authorisation from the Irish Coast Guard
Norway	Allowed The industry's use of dispersants must be approved in emergency plans or in each case through a special approval by the Norwegian Coastal Administration. Certain operative conditions must be complied with in each case. Norwegian Coastal Administration is authorized for deciding upon the state's use of dispersants for combating oil pollution from ships.
Sweden	Allowed following prior official authorisation from response commander of the Swedish Coastguard
The Netherlands	Allowed under conditions since 2004. Approval by RWS based on the BONN AGREEMENT and EMSA studies
United Kingdom	Allowed Recent changes in UK legislation mean that operators must seek approval from the regulatory body to apply dispersants anywhere in the UK EEZ. * Authorisation to apply dispersants in the UK is from statutory licensing authorities (Marine Management Organisation for all incidents in English waters, Marine Scotland for Scottish waters; Natural Resources Wales for Welsh waters, Northern Ireland Environment Agency for Irish territorial waters. For incidents in Welsh waters outside of 12 nautical miles, Marine Management Organisation currently act in an advisory capacity to Natural Resources Wales [*Note: Formerly permissions were only required inside the 20m depth + 1 nautical mile zone.]

Further to the description outlined above the following statement describes precisely the regulatory position in the UK for the use of dispersants:

"Under the Marine and Coastal Access Act 2009 the Marine Management Organisation (MMO) acts as the regulatory authority for the use of oil spill dispersant products in waters off England and Wales, though advice from Natural Resources Wales will be sought for the latter. In the waters off Northern Ireland, the regulator is the Department of Environment's Marine Division. For the waters off Scotland, Marine Scotland is the regulator in accordance with the Marine and Coastal Access Act 2009, and the Scottish Adjacent Waters Boundaries Order 1999 and the Marine Access (Scotland) Act 2010. However, the use of oil spill dispersant products in relation to offshore oil and gas exploration and production operations is specifically excluded from these legislative regimes and is regulated by DECC."

Water depth

Although national dispersant use regulations vary throughout the Bonn Agreement, as a general rule of thumb the use of dispersants is mainly considered (and in various countries only permitted) in areas where the water depth is more than 20 m plus a safety distance from shallower water of one nautical mile. This is often referred to as the "20 meter plus 1nm" rule.

Oil type

Not all oil types will actually disperse once dispersants are applied. In (Lewis, pers. comm.) the guidelines in Figure 3-19 are set:

Oil type	DISPERSE?	WHY?
Gasoline	NO	Dispersants would work, but would force toxic components of oil into water column
Kerosene (Jet fuel)	NO	
Marine Gas Oil	NO	
Marine Diesel Oil	NO	
Crude oil (paraffinic)	YES	Until the time "Window of opportunity" runs out
Crude oil (naphthenic)	YES	
Crude oil (asphaltic)	YES	
Crude oil (waxy)	MAYBE	Pour Point?
Hydraulic oil	NO	
Lube oil	NO	
IFO-30	YES	Until the time "Window of opportunity" runs out
IFO-80	YES	
IFO-180	YES	
IFO-380	MAYBE	Only at high sea temperature or rough sea
IFO-500	NO	Viscosity too high
IFO-700	NO	Viscosity too high

Figure 3-19 Guideline for what oil types are suited for dispersion (Lewis, pers comm). NOTE: Norway commented on this table and stated that dispersants possibly may be used on diesel.

The above table indicates that crudes and light IFO type oils are suited within the period before the oils emulsify or their viscosity is too high.

Weathering state

Dispersion is usually possible for viscosities up to approx. 5.000 centipoise (cP). For higher viscosities, the dispersing effect is reduced significantly. In (EMSA, 2006) the viscosity limits that define the dispersibility categories for weathered TROLL crude oil have been determined in the laboratory to be "easily dispersible" up to 3000 cP, "reduced dispersible" from 3000 cP to 7000 cP, and "poorly dispersible" above 7000 cP. The first limit of 3000 cP occurs after 2 hours in 15 m/s wind, but after nearly 2 days in 2 m/s wind, see Figure 3-20.

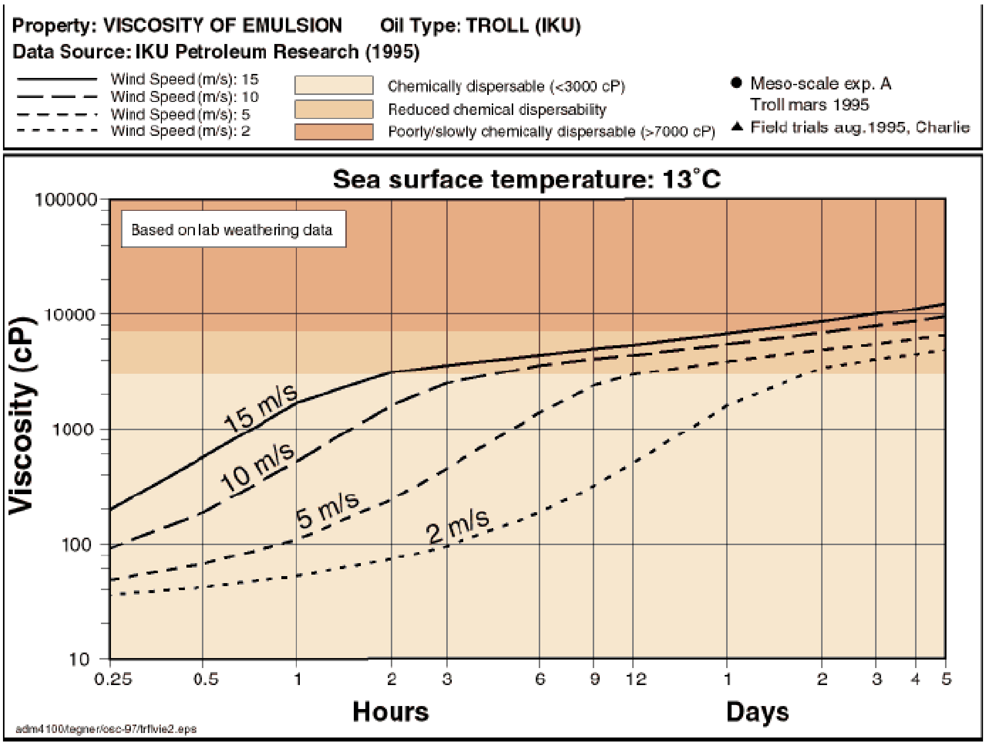


Figure 3-20 Evolution of emulsion viscosity and dispersibility category for Troll crude oil.

Based on the above, it is assumed to apply a time period where dispersion is possible of one day (24 hrs) for wind speed W in the class W < 5 m/s and a period of 6 hours for wind speed in the class 5 m/s < W < 11 m/s. For wind speed in the third speed class (above 11 m/s) it is assumed that application is not efficient. Although dispersion may have some effect in a broader time window, relative narrow intervals are applied here, in order to define periods where dispersion is highly efficient.

Sea state

For wind speed larger than 3,5 m/s dispersion will be effective. Dispersion will become less efficient at very high wind speeds due to inoperability, danger to airplane and to submersing oil in high waves. Such cut-off value is not given in literature, but since the model operates with a wind speed group of W>11 m/s, this is used as a relatively realistic upper limit speed for possible spraying operations.

Volume

Dispersants can be a primary response for oil spill response in the UK. For incidents where dispersants are judged to be the appropriate response: amenable oil and regulator backing on the environmental outcome. Dispersant response is frequently not considered since not all oils are dispersible, for example, some heavy fuel oils are too viscous for dispersants to penetrate the slick especially in low winter temperatures. Many oils may be dispersible when first entering the sea but as they "weather", they become emulsified with seawater and the viscosity increases to the point where the emulsion cannot be dispersed. The speed of that process quickens with increase in wind speed and sea energy. In a major on-going spill response when dispersants are no longer working, the MCA would engage with other pre-planned response strategies such as at sea recovery, dispersants being only one of a suite of UK response strategies.

The UK dispersant response contract is based on the ability to deliver 800 tonnes of dispersant in a 48 hour period. The contract also stipulates that the contractor must be able to deliver a full spray campaign for 30 days. The figure of 800 tonnes of dispersant equates to dispersing between 16,000 tonnes and 24,000 tonnes of oil at a dose ratio (dispersant to oil) of 1:20 and 1:30 respectively.

3.10.2 Modelling of chemically dispersed oil

The chemically dispersed oil is modelled as oil that changes identity from surface to water column. As for surface slicks, the chemically dispersed oil is modelled with regard to spreading, drift and degradation in principle. The involved mechanisms are however quite different.

An important characteristic of the dispersed oil is that it cannot be recovered by mechanical response means. Further, the dispersed oil will not reach the coastline but stay in the water column until it is biologically degraded.

Spreading

The spreading of chemically dispersed oil follows different mechanisms compared to oil spreading on the water surface. The spreading is divided in two phases before and after application of dispersants. As a time scale for dispersant application 18 hrs is selected. This time is selected as a typical mean application period after release, alarm, mobilisation and flight time (approx. 12 hours) and before spraying is not considered efficient anymore (24 hours).

Phase1: Before application of dispersants (t < 18 hrs)

Phase 2: After application of dispersants (t > 18 hrs)

In the first phase the oil-affected water mass is defined by the circle of the oil slick on the surface at the time of dispersant application. The radius of the oil slick at the time of dispersant application is calculated corresponding to 18 hours development of a surface slick (refer to chapter 3.4). The radius is determined (depending on oil volume, type of oil, temperature, etc.) and this radius determines the initial water mass affected by dispersed oil.

In the second phase, i.e. for the time of 18 hours after release, the spreading of chemically dispersed oil is determined by the turbulence level in the water mass. From observation sediment plumes during dredging operations it is found that the plumes increase their width by about 1/100 with downstream distance. This means that every time the chemically dispersed slick drifts 100 m the radius of the slick will increase by approx. 1m, the total width will increase by 2 m. The concentration of dispersed oil will decrease accordingly. The effect of tidal ellipsoid will be included in the considerations since the radius at 18 hrs already includes the effect of a full tidal cycle and hence the R'.

Drift

In the water column, the dispersed oil will only be subject to drifting due to the effect of the average drift of the water masses. The effect of tidal drifting of the centre of gravity of the spill will be averaged out after more than one tidal cycle. The effect of tidal currents on the radius will however be included. The effect of wind friction on the chemically dispersed patch that reaches down to the first density interface (20-40 m) is not taken into account. The long-term residual drift is described with respect to speed, direction and sub-areal division in chapter 3.3.6.

Biodegradation

The weathering of chemically dispersed oil by biodegradation is assessed to be larger than oil at the surface, because the effective surface area of dispersed oil is larger than for non-dispersed oil. (Prince, et.al., 2014) have shown that the halftime for crude oil biodegradation occurs with a halftime of about 11 days when the dispersant Corexit 9500 is applied on lightly weathered Alaska North Slope crude oil. The weathering rate can further be accelerated by addition of nitrogen and phosphorous (Harris, 2002). (Prince & Butler, 2013) concluded that a time scale for biodegradation between 1 week and 11 days is a central estimate for marine biodegradation. It also was noted that this timescale only is slightly affected by water temperature. A time scale of 9 days is hence chosen in the present study.

Environmental impact

The dispersed oil may have a toxic effect on plankton, larvae and other organisms in the pelagic system due to its bio-availability, the potential and extent of which will be very dependent on inter alia the dilution potential and natural energy present in the impacted area and the area's seasonal sensitivity.

The integrated impact of chemically dispersed oil will be compared to a sensitivity map for the water column, where habitats, protected areas and species are included that are sensitive to oil in water. This is contrary to most common sensitivity maps which refer to sensitivity on the sea surface. This means that toxic effect are included on plankton, larvae and other organisms in the pelagic system due to the dispersed oils increased bio-availability and the resulting long-term internal exposure. Smothering effects on birds and shoreline, however, are set to be zero in the model. The sensitivity map for the pelagic system is, as for the surface sensitivity, a two dimensional map, that measures the sensitivity in sensitivity/m^2. The impact of dispersed oil, measured in kg oil/m^3 water, shall also be transformed to a 2-dimensional map in order to be able to combine the two maps. The impact of dispersed oil will therefore be represented by 2-dimensional maps, indicating mass of dispersed oil per sea area times duration ($kg/m^2 \cdot s$). This map has the same dimensions as the corresponding map for surface slicks and it can hence be compared directly.

3.11 Deep-sea blowouts

Deep-sea blowouts are included in the present study in order to relate the risk for oil pollution from maritime traffic with the risk imposed by blowouts from deep-sea wells in the Bonn Agreement area. This analysis is not an integral part of the main analysis since deep-sea wells are not influenced by maritime traffic and since the scenarios for enhanced oil spill risk reduction from the maritime traffic and for increased oil spill combating capacities have little influence of blow out events and their damage. The public discussion about the “Macondo” event in the Mexican Gulf (Deep Water Horizon) made it advisable to include the risk from deep-sea blowouts in the North Sea. Since this task was an additional analysis, it should carried out with the aim to compare the orders of magnitude of risk from shipping with the risks from blowouts.

The high temperature and high-pressure wells in the North Sea are shown on the map in Figure 3-21.

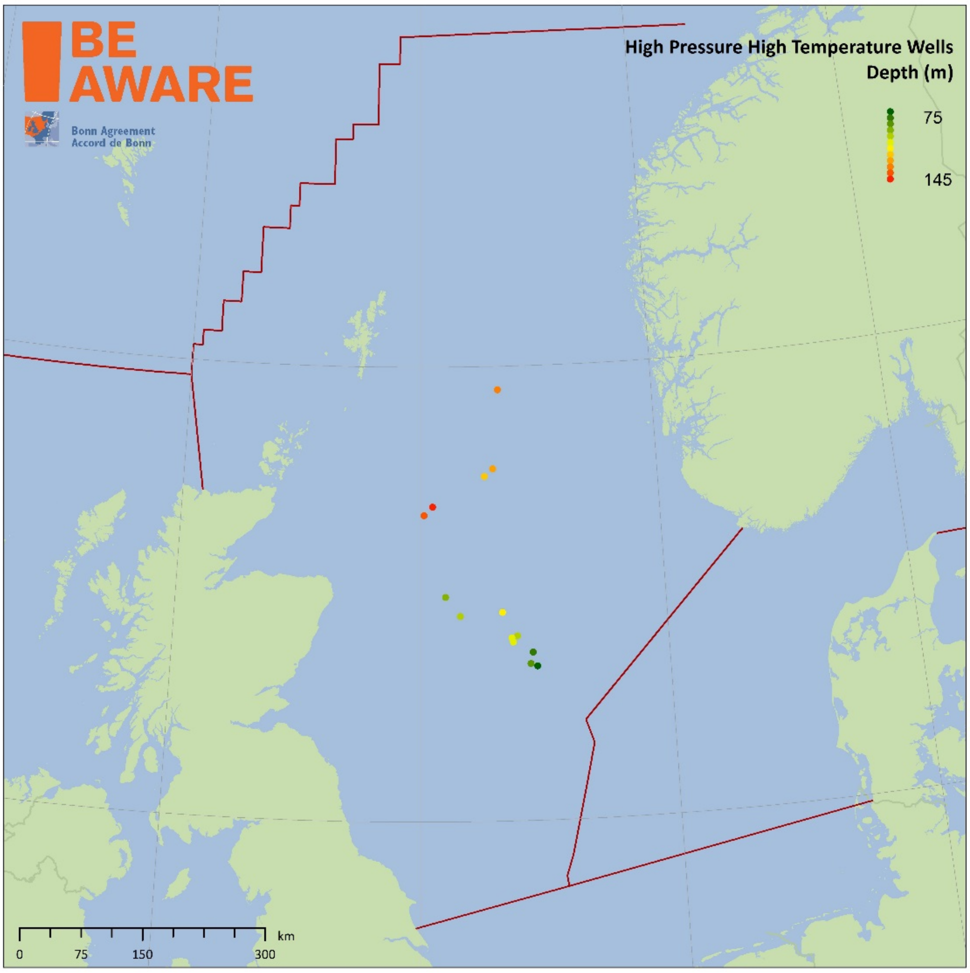


Figure 3-21 **Position and water depth of the High Pressure High Temperature Wells in the North Sea that represent a potential risk for well blowouts.**

The modelling of blowouts is illustrated in Figure 3-22.

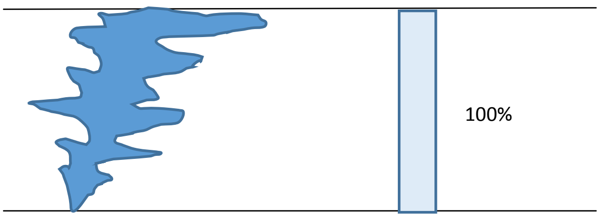


Figure 3-22 **illustration of blow out modelling.**
Left panel: Intuitive illustration of oil plume in the water column
Right panel: Modelling assumption about dispersed oil in the water column

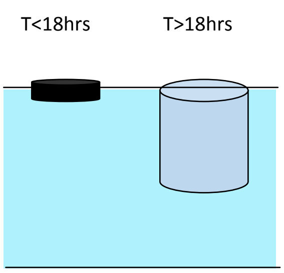
Due to the possible application of dispersant by deep-sea injection, surface oil cannot be recovered by booms and skimmers.

In the present analysis, a deep-sea blow-out is considered to be completely dispersed within the water column, either due to natural or chemical dispersion for modelling purpose. Even though, some oil may reach the surface and some of this oil may be recoverable by mechanical means. This may happen, but for the present analysis, it is not considered to have a significant impact of the environmental damage.

3.12 Discussion

The uncertainty on the assessment of the environmental impact is difficult to assess or measure. However, this is of minor importance in this case where relative changes are compared rather than calculating the absolute impact. Since the analysis determines differences between scenarios, any possible systematic uncertainty or error will be included similarly in both scenarios and will hence be subtracted.

The purpose of the analysis is to evaluate the integrated environmental impact considering various scenarios, different types of emergency response and of different risk reducing measures. The relative difference between the results will give a quantitative indication of whether the environmental risk will be reduced or increased. Hence, it will be possible to assess the relative effect on the environmental risk for different scenarios.



The left spill indicates the surface spill just before spraying of dispersants (all oil is on the surface).

The right spill indicates the dispersed spill, where all oil is dispersed in the upper mixing layer (all oil is in the water column).

Whereas the left oil spill will impact the surface sensitivity, the right oil plume will impact the water column sensitivity.

Figure 3-23 Illustration of spreading of chemically dispersed oil: Left: phase 1 (t<18 hrs), right: phase 2 (t>18 hrs)

This way, the impact of oil on the surface will be comparable with the impact of chemically dispersed oil in the water column. The sensitivity maps for surface sensitivity and water column sensitivity are comparable since they are based on the same concepts. Therefore, the combination of oil impact and sensitivity for surface and water column, respectively, will be of comparable character. The combination of impact and sensitivity is called environmental damage. It is decided by the project partners to prepare damage maps for environmental damage on the sea surface as for damage on the water column for four feature groups habitats, species, marine protected areas and socioeconomic features. Finally, all four damage maps will be combined based on an internal weighting between the groups.

The use of dispersants in UK waters is based on the following understanding:

Research carried out by Warren Spring Laboratory in the UK over a period of two decades and involving multiple real scale test slicks at sea has provided the confidence levels of our understanding of the fate of oil dispersed through use of dispersants. Key information derived from sea-trials included the well-documented and repeatable measurements of oil concentrations below dispersant treated slicks. In the majority of trials the measured concentration of dispersed oil rarely exceeded 10 ppm below 10metres and at 15 metres significantly less than 5 ppm. The typical measured droplet size of chemically dispersed oil was in a range of 3 to 40 microns, thereby presenting a vastly increased oil surface area for the microorganism community to biodegrade the hydrocarbon as a last stage of the process.

During dispersant application operations, which have been given the go ahead by the UK regulators (fisheries, nature conservation and environmental regulator), there will be a continuous discussion between the operators and the dispersant regulators. Therefore as the campaign moves on over time all variables are revisited and re-evaluated for any possibility of changing risk for the worse due to continuing dispersant operations.

Figure 3-24 illustrates the process of combining effects from surface slicks with the effects from chemically dispersed plumes.

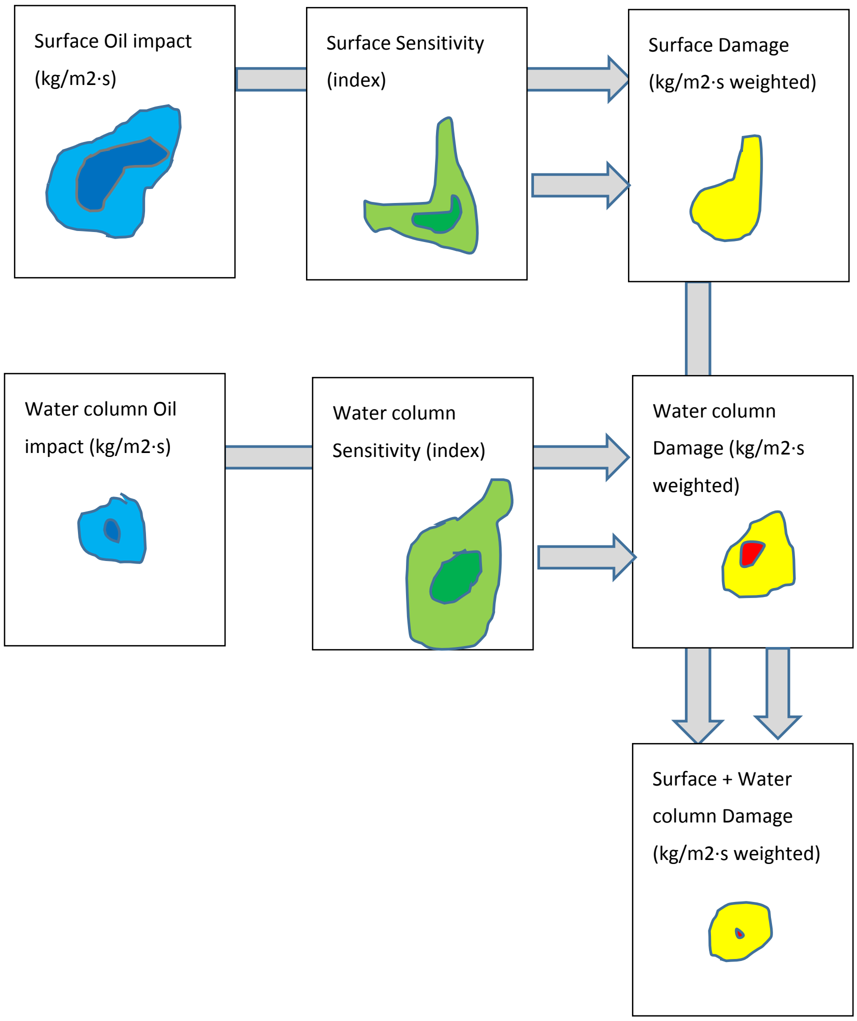


Figure 3-24 Flow diagram illustrating the development of combined surface and water column damage (the socio-economic feature damage will be added accordingly)

4. Mapping of vulnerability and classification of damage

4.1 Overall procedure

During BE-AWARE I it was agreed that the vulnerability ranking should be based on a modification of the BRISK methodology (Brisk 2012, Schallier et al 2013).

It is the overall objective of the present environmental and socio-economic vulnerability assessment (also often called sensitivity assessment) to describe the vulnerability on a regional scale. Further, it adds the effect of a series of different relevant environmental and socio-economic parameters that are mapped in a consistent and comparable way providing a basis for comparison across country borders. The study is based on existing knowledge and mappings and minor errors or inaccuracies are therefore to be accepted as long as they do not change the overall sensitivity distribution.

Accordingly, the ranking of the vulnerability of environmental and socioeconomic features to oil spills in the different regions of the BA area is carried out in the following distinct steps:

- **Step 1** the identification of environmental and socioeconomic features to be mapped and ranked according to vulnerability to surface oil spill and chemically dispersed oil spills

- **Step 2** the assessment and definition of rank scores to be allocated to each of the identified environmental and socioeconomic features during spring, summer autumn and winter for both surface oil spills and chemically dispersed spills.

- **Step 3** preparation of vulnerability maps based on maps on location of identified environmental and socioeconomic features the vulnerability rank scores for the features and a weighting matrix

4.2 Identification of environmental and socioeconomic parameters (step 1)

Ecological and socioeconomic features to be mapped and ranked according to vulnerability to oil spill were identified during BE-AWARE I (Schallier et al 2013) and adjusted during a BE-AWARE II workshop in Brussels 11-12 September 2014. The identified ecological features are listed in Table 4-1. The socioeconomic features are listed in Table 4-2.

Table 4-1 Sensitive environmental features identified to be mapped and ranked according to sensitivity to oil spill.

Sensitive Ecological features in the BA area	
Shoreline and Coastal Habitats	**Species Features**
› Exposed rocky shores and reefs (<20m;> 20m)	› Wintering areas for birds
› Sheltered rocky shores and reefs (<20m;> 20m)	› Staging areas for birds
› Littoral chalk communities	› Breeding areas for birds (incl. foraging areas)
› Sandy beaches	› Moulting areas for birds
› Shingle beaches	› Coastal feeding grounds for otters
› Tidal sand and mud flats	› Breeding, moulting and haul-out sites for seals
› Salt marshes	› Pelagic spawning areas for fish
› Estuaries	

› Large shallow inlets and bays › Coastal lagoons (open to the sea) › Underwater sandbanks (<20m;> 20m) › Biogenic reefs (<20m;> 20m) › Maerl beds › Eelgrass beds (*Zostera* sp. > 5%) › Kelp forests	› Demersal spawning areas for fish › Coastal nursery areas for fish
Open Sea Habitats	**Protected areas**
› Open water (<20m) › Deeper sea floor (>20m) › Deep sea water column (>20m) › Seamounts › Coral gardens and sponge aggregations › Carbonate mounds › *Lophelia pertusa* reefs › Sea-pen and burrowing megafauna	› Nature 2000 areas › RAMSAR areas › National areas › World heritage sites

Table 4-2 Sensitive socioeconomic features identified to be mapped and ranked according to sensitivity to oil spill.

Sensitive Industries and Socioeconomic features in the BA area	
Fisheries	**Aquaculture**
› Offshore fisheries › Coastal fisheries (incl. fishing harbours) › Shellfish/seaweed (algae) harvesting	› Fish farms › Shellfish cultures › Algae cultures
Tourism and recreation	**Other**
› Amenity beaches › Marinas › Tourism activities › Densely populated towns and communities › Surfing hot spots › Main recreational fishing locations › Cruise liner stops	› Heritage sites › Ports › Mineral extraction sites › Windfarm areas › Water intakes

4.3 Vulnerability ranking

4.3.1 Ranking scores and seasons

During BE-AWARE I it was agreed to rank the vulnerability to oil spill of each of the identified ecological and socioeconomic features using the scores and seasons applied in the BRISK project (BRISK, 2012). A full scientific documentation of the selection of the environmental parameters is given in the Result Report.

Table 4-3 Scores and seasons that will be applied in the vulnerability ranking

Scores	Seasons
Score 4 = Very high vulnerability	Winter: December, January and February
Score 3 = High vulnerability	Spring: March, April and May
Score 2 = Moderate/medium vulnerability	Summer: June, July and August
Score 1 = Low vulnerability	Fall: September, October and November.
Score 0 = Not affected	

During a workshop held in Brussels 11-12 September 2014 vulnerability scores for each of the identified environmental and socioeconomic features were assessed and determined for each of the four seasons (winter, spring, summer or autumn). Scores were defined for both a situation without combatting of oils spill using dispersants and one with dispersants application.

4.3.2 Criteria for ranking

Ecological features

The vulnerability scores for environmental features are based on the following criteria, which were decided on during BE-AWARE I:

- Fate of oil (exposure; chemical recovery). The fate of oil in terms of oil weathering, natural degradation and removal in the particular ecosystem/ environment, the main factors being:
    - Onshore: Wave and tidal exposure, shoreline slope, substrate type (~ ESI index)

Open water (3D): Natural energy (waves, currents, winds), depth

- Potential impact of oil/sensitivity of habitats and organisms and their recovery

Socioeconomic features

When oil impacts a sensitive socioeconomic feature, the extent will depend not only on the fate of the oil in the environment, but also on the oil-sensitivity of the human activity and the potential for recovery of the activity once most of the oil has been removed. In other words, the same three aforementioned 'vulnerability' factors (exposure, sensitivity, recovery) also apply to define socio-economic vulnerability. As a result, any additional socioeconomic ranking criterion should reflect one or more of these 3 vulnerability factors in its definition.

The BE-AWARE I project examined a set of additional socio-economic ranking criteria and agreed upon adding the following two additional criteria:

- Impacts in terms of length of interruption of an activity or service involve important factors such as the possibility (or not) of protecting an activity and the possibility (or not) of displacing an activity.

- Compensation in terms of whether a damaged feature can be economically compensated for or not. This is important when comparing economic vs. ecological vulnerability.

The criteria for environmental and socioeconomic features are described in more detail in the Result Report.

4.3.3 Ranking matrices

The results of the ranking exercise carried out during the workshop in Brussels 11-12 September 2014 are shown in Table 4-4 to Table 4-9.

The justification of these ranking scores is outlined in Technical Sub Report 2: Environmental and Socioeconomic Vulnerability.

In this technical sub report the vulnerability scores for each of the identified environmental and socioeconomic feature justified on the basis of:

- The discussions carried out during the workshop in Brussels 11-12 September 2014
- A literature review of scientific papers and reports. Especially papers and reports on surveys of the effects of particular oil spills on environmental and socioeconomic features in the North Sea and adjacent waters as well as laboratory studies on effects of oil and dispersants.

Ranking matrices. Habitats

Table 4-4 Habitats. Ranking matrix for surface oil spills

Habitats	Ranking scores surface oil spill			
	Spring	Summer	Fall	Winter
Shoreline habitats				
Exposed rocky shores and reefs (< 20m)	3	3	2	2
Exposed rocky shores and reefs (>20 m)	1	1	1	1
Sheltered rocky shores and reefs (<20m)	4	4	3	3
Sheltered rocky shores and reefs (>20m)	2	2	2	2
Littoral chalk communities	4	4	3	3
Sandy beaches	2	2	1	1
Shingle beaches	3	3	3	3
Tidal sand and mud flats	4	4	4	4
Salt marshes	4	4	4	4
Large shallow inlets and bays	3	3	3	3
Estuaries	4	4	4	4
Coastal lagoons	4	4	4	4
Underwater sandbanks (<20m)	3	3	2	2
Underwater sandbanks (>20m)	1	1	1	1
Biogenic reefs (<20m)	4	4	4	4
Biogenic reefs (>20m)	2	2	2	2
Maerl beds	4	4	3	3
Seagrass beds (*Zostera* sp coverage >5 %)	4	4	4	4
Open sea Habitats				
Open water column (< 20m)	2	2	1	1
Open water column (>20m)	1	1	1	1
Deeper sea floor (> 20 m)	1	1	1	1
Seamounts	1	1	1	1
Coral gardens and sponge aggregations	2	2	2	2
Carbonate mounds	2	2	2	2
Lophelia pertusa reefs	2	2	2	2
Sea-pens and burrowing megafauna	2	2	2	2
Protected areas				
Ramsar areas	4	4	4	4
Nature 200 areas	4	4	4	4
National protected areas	4	4	4	4
World heritage sites	4	4	4	4

Table 4-5 Habitats. Ranking matrix for chemical dispersed oil spills.

Habitats	Ranking scores chemical dispersed oil			
	Spring	Summer	Fall	Winter
Shoreline habitats				
Exposed rocky shores and reefs (< 20m)	3	3	2	2
Exposed rocky shores and reefs (>20 m)	2	2	2	2
Sheltered rocky shores and reefs (<20m)	4	4	4	4
Sheltered rocky shores and reefs (>20m)	4	4	4	4
Littoral chalk communities	4	4	3	3
Sandy beaches	2	2	1	1
Shingle beaches	3	3	3	3
Tidal sand and mud flats	4	4	4	4
Salt marshes	4	4	4	4
Large shallow inlets and bays	3	3	3	3
Estuaries	4	4	4	4
Coastal lagoons	4	4	4	4
Underwater sandbanks (<20m)	3	3	3	3
Underwater sandbanks (>20m)	2	2	2	2
Biogenic reefs (<20m)	4	4	4	4
Biogenic reefs (>20m)	4	4	4	4
Maerl beds	4	4	4	4
Seagrass beds (*Zostera* sp. coverage >5 %)	4	4	4	4
Open sea Habitats				
Open water column (< 20m)	2	2	2	2
Open water column (>20m)	2	2	2	2
Deeper sea floor (> 20 m)	2	2	2	2
Seamounts	2	2	2	2
Coral gardens and sponge aggregations	3	3	3	3
Carbonate mounds	3	3	3	3
Lophelia pertusa reefs	3	3	3	3
Sea-pens and burrowing megafauna	3	3	3	3
Protected areas				
Ramsar areas	4	4	4	4
Nature 200 areas	4	4	4	4
National protected areas	4	4	4	4
World heritage sites	4	4	4	4

Ranking matrices. Species

Table 4-6 Species features. Ranking matrix for surface oil spills

Species features	Ranking scores surface oil spill			
	Spring	Summer	Fall	Winter
Fish				
Pelagic spawning areas for fish (e.g. other than herring) Spring	2	1	0	0
Pelagic spawning areas for fish (e.g. other than herring) Summer	1	2	1	0
Pelagic spawning areas for fish (e.g. other than herring) Fall	0	1	2	0
Pelagic spawning areas for fish (e.g. other than herring) Winter	1	0	0	2
Demersal spawning areas (herring), Feb-Mar	4	3	3	4
Demersal spawning areas (herring), Aug	3	4	3	3
Demersal spawning areas (herring), Aug-Nov	3	4	4	3
Demersal spawning areas (e.g. herring), Nov-Jan	3	3	4	4
Birds				
Wintering areas for birds	3	1	3	4
Staging areas for birds	4	2	4	2
Breeding areas for birds	4	4	3	1
Moulting areas for birds	2	4	2	2

Table 4-7 Species features Ranking matrix for chemical dispersed oil spills

Species features	Ranking scores chemical dispersed oil			
	Spring	Summer	Fall	Winter
Fish				
Pelagic spawning areas for fish (e.g. other than herring) Spring	3	2	0	0
Pelagic spawning areas for fish (e.g. other than herring) Summer	2	3	2	0
Pelagic spawning areas for fish (e.g. other than herring) Fall	0	2	3	0
Pelagic spawning areas for fish (e.g. other than herring) Winter	2	0	0	3
Demersal spawning areas (herring), Feb-Mar	4	3	3	4
Demersal spawning areas (herring), Aug	3	4	3	3
Demersal spawning areas (herring), Aug-Nov	3	4	4	3
Demersal spawning areas (e.g. herring), Nov-Jan	3	3	4	4
Birds				
Wintering areas for birds	1	1	1	2
Staging areas for birds	2	1	2	1
Breeding areas for birds	3	3	2	1
Molting areas for birds	1	2	1	1

Ranking matrices Socioeconomic features

Table 4-8 Socioeconomic features. Ranking matrix for surface oil spills.

Socioeconomic feature	Ranking scores surface oil spill			
	Spring	Summer	Fall	Winter
Offshore fisheries	2	2	2	2
Coastal fisheries (incl. fishing harbours)	3	3	3	3
Fish farms	3	3	3	3
Shellfish cultures	3	3	3	3
Algae cultures	3	3	3	3
Amenity beaches	3	4	3	2
Marinas	2	3	3	1
Tourism activities	2	3	3	2
Densely populated towns and communities	2	2	2	2
Main recreational fishing locations	3	4	3	2
Cruiser liner stops	1	2	1	1
Heritage sites	4	4	4	4
Ports	2	2	2	2
Mineral extraction sites	1	1	1	1
Offshore windfarms	1	1	1	1
Water intakes	3	3	3	3

Table 4-9 Socioeconomic features. Ranking matrix for chemical dispersed oil spills.

Socioeconomic feature	Ranking scores chemical dispersed oil			
	Spring	Summer	Fall	Winter
Offshore fisheries	2	2	2	2
Coastal fisheries (incl. fishing harbours)	3	3	3	3
Fish farms	3	3	3	3
Shellfish cultures	3	3	3	3
Algae cultures	3	3	3	3
Amenity beaches	2	3	2	1
Marinas	1	1	1	1
Tourism activities	1	2	1	1
Densely populated towns and communities	1	2	1	1
Main recreational fishing locations	3	3	2	2
Cruiser liner stops	1	1	1	1
Heritage sites	2	2	2	2
Ports	1	1	1	1
Mineral extraction sites	1	1	1	1
Offshore windfarms	1	1	1	1
Water intakes	3	3	3	3

For the social economic parameters oil installations have been considered, as a shutdown may represent a major threat to the national energy supply. In order to assess the order of magnitude of risk for such an event, the Project Partners investigated briefly the history for such events, i.e. events where installations had to be evacuated and a total shut down hence would be necessary.

Following situations are recognised:

An internal situation, unwanted event, on board the installation. This falls outside the scoop of the project.

A collision between two vessels resulting in an outflow of oil in the vicinity of a platform. This is considered to cause limited effect. When the oil drifts towards the platform only the flashpoint of the oil could cause a problem. However, in the majority of incidents the flashpoint will quickly be above the 61° C considered to be the dangerous threshold. The effect will be limited, only a short temporarily problem. On the other hand, if one of the vessels would sink immediately after the collision and sink on top of a pipeline, this could then a shutdown of the pipeline and maybe of the production process.

A vessel in the vicinity of a platform loses propulsion due to engine failure, a so called Vessel Not Under Command (NUC). Studies by MARIN indicate the minimum force needed to have sufficient impact to the platform that this causes a total collapse. However if a large vessel drifts towards a platform the Coastguard may advice to evacuate a number of people, those that are above the minimum required operations level. The cost impact is minimal.

A vessel runs into a platform at full speed, due to navigation failure. There will hardly be time to evacuate the platform. On board the platform staff has to assess the situation, calculate the time required for a full shut down and other safety precautions and continue to warn the vessel.
This could then lead to a collision between the vessel and the platform and this could result in a total collapse of the platform and outflow of oil/gas.

Therefore the two incidents that have a potential socioeconomic impact on offshore oil and gas production are

- either the situation that a vessel sinks on top of a pipeline leading to shut down of the production process
- or a vessel runs with full speed into a platform.

Although in the past decade both on the UK shelf and the NL shelf platforms had to be decommissioned after being hit by relatively small vessels, no situations are known by the Project Partners that led to close down of production platforms. Therefore, this event is considered to be highly unlikely and therefore it was decided by the Project Partners not include it in this study.

4.4 Environmental vulnerability maps

4.4.1 Weighting of features

During the workshop there was a discussion on how to obtain a proper weighting of the feature scores in the future analyses. Several weighting ratios were discussed during the workshop. The Project Partners decided to use the four options shown in Table 4-10. Maps of total vulnerability were made using each of the four ratios to assess variations due to weighting.

Table 4-10 Proposed weighting ratios of feature groups.

Groups	Weighting ratios (%)			
	1	2	3	4
1 Habitats	25	35	15	50
2 Species	25	25	15	10
3 Protected areas	25	30	20	15
4 Socio-economy	25	10	50	25

For each of the 4 ratio combinations given in Table 4-10 maps ware prepared for each of the four season and for the two vulnerabilities, one for vulnerability towards oil on the sea surface and one for vulnerability towards oil that chemically dispersed is in the water column. Hence, in all 8 maps are prepared for each of the four combinations.

Based on these 8 maps, it was decided by the project partners, after thorough discussion and consultation with their national experts, to continue the analysis with the combination 1, representing equal weight to each of the four feature groups. The major reason for choosing this particular ratio combination was that

- all feature groups in principle are important,
- It was not possible for the group of Contracting Partners nor their respective external experts to provide a quantitative and objective argumentation why the concept of equality between the groups of feature should be derogated
- differences of major consequence were not found between the maps of the different ratio combinations. Therefore, areas with high vulnerability for one specific combination also had high vulnerability for the 3 other combinations; and visa-versa, areas with particularly low sensitivity for one combination also had low vulnerabilities in the maps for the 3 other combinations. In other word: "the highs are always the highs and the lows are always the lows". The relative vulnerabilities in the 4 different cases are found to be approximately uniform.

4.4.2 Normalised vulnerability maps

In the subsequent advanced analysis, where vulnerability is combined with oil impact in order to provide a measure for environmental damage, the applied data shall be transformed statistically in order to provide for equal influence.

It is the objective to avoid that a dataset that due its statistical characteristics will dominate the result. Hence, information held in the other data set will be neglected and lost. For instance, if the data set for oil impact includes values within a range of e.g. 7 decades and the values for vulnerability includes values within a range of half a decade; the resulting range (of 7½ decade) will be completely dominated by the data set for oil impact, whereas the information for vulnerability will vanish in the analysis. This under the assumption that the data for oil impact and the data for vulnerability shall be multiplied to provide a measure for damage.

In order to avoid this numerical domination of one dataset over the other, a normalising procedure has to be carried out. In applied statistics, this usually is carried out by normalising both data sets to the equal average and equal variance. This is possible for stochastic processes that are approximately follow a normal distribution. In our case, the vulnerability data are far from comparable to normal distributions. In order to follow the procedure applied in BRISK project and also to apply an operational normalisation process, it was decided to normalise the values for vulnerability with the max value in the dataset. This way all normalised values for the 4 groups of features will vary between zero and unity (0-1) and will hence contribute equally to the combined vulnerability map.

As illustrated above four feature groups are selected by the contracting parties and their external experts: Habitats, species, protected area and socio-economy. For each feature group eight different vulnerability maps are prepared, see Table 4-11.

Table 4-11 Schematic illustration of each feature group including scores for 4 seasons and 2 oil locations

Feature group x	Oil location surface	Oil location water column
Season 1	X	X
Season 2	X	X
Season 3	X	X
Season 4	X	X

The data set for each map will be normalised by division with the maximum value of the dataset. The entire process starting from mapping and scoring the individual features to the integrated set of 8 vulnerability maps (8 = 2 locations for the oil (surface and water column) x 4 seasons).

In all, 58 features are mapped. For each feature, a set of 4 sensitivity scores (each between 1 and 4) is selected indicating the 4 seasonal vulnerability towards oil on the sea surface. Another set of 4 seasonal scores is selected indicating vulnerability towards oil in the water column.

The 58 features are grouped into the 4 groups and the integrated score for each specific grid cell is determined by adding the scores of all features within the feature group. This is done 8 times (2 oil locations and 4 seasons). See and illustration of the process in Figure 4-1.

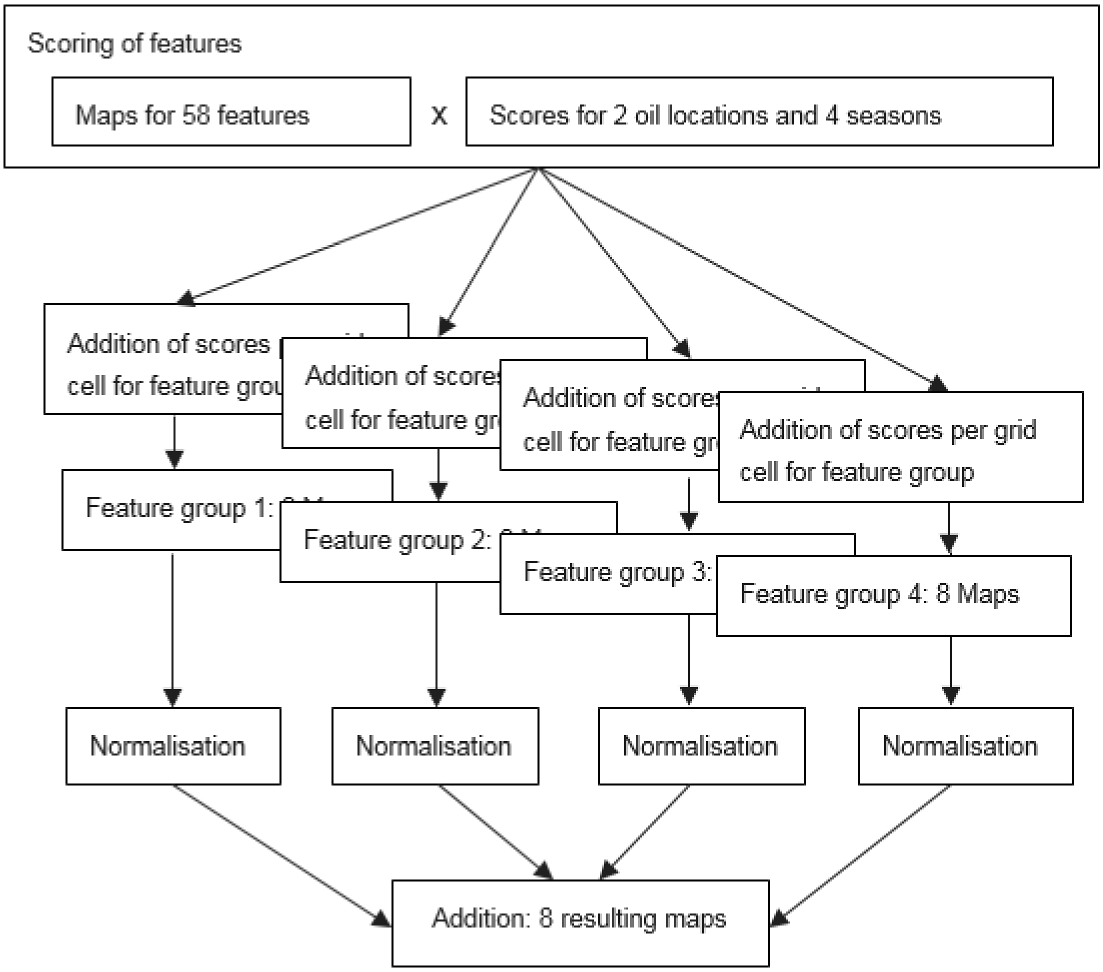


Figure 4-1 **Illustration of combining the normalised vulnerability maps to the final set of 8 maps (one map for each combination of 2 oil locations and 4 seasons).**

4.5 Environmental damage

The environmental damage represents the combination of environmental vulnerability and impact of oil. Once the 8 resulting vulnerability maps are prepared, the combination with the impact of oil has to be carried out.

The impact of oil is defined as the amount of oil that is on average will be in a certain square area is determined as follows:

1. Oil on shore will be used as the mass of oil per shoreline in a specific sub-region. This oil will not be combined with any vulnerability.

2. The impact of oil on the water surface is calculated as mass (oil) per area water surface. This impact will be combined with the vulnerability of the specific sea surface area.

3. For the impact of oil in the water column, the impact is determined equally, as mass (of oil) per area water column (horizontal area). This impact will be combined with the vulnerability of the specific water column.

Ad 1) It is relatively straightforward to keep the amount of oil on shore as parameter without any environmental weighting. The environmental weight of the near shore area will affect the damage caused by oil drifting ashore.

ad 2) The environmental damage of oil on the sea surface will be determined by combining the expected average mass of spilt oil on the surface per season (the impact) with the specific surface vulnerability per season (vulnerability)

Ad 3) Also here, the environmental damage will be determined as the expected average mass of spilt and chemically dispersed oil in the water column per season (the impact) with the specific water column vulnerability per season (vulnerability). This method holds the advantage, that the impact of oil that is in the water column directly can be compared with the impact of oil that is on the water surface. The same concept for comparing impact and vulnerability can be applied in order to provide a consistent comparison of vulnerability, impact, and damage whenever it relates to the surface or to the water column. On the other hand, the effect the water depth will be ignored in the calculations and hence the decreasing concentration with increasing mixing depth. This is assumed to be acceptable since the chemically dispersed oil mainly will stay in the upper mixed layer during the first 2 weeks of a spill. For the wider North Sea, the upper mixed layer will have a layer thickness of between 20 m and 60 m. The uncertainty of a concentration calculation is therefore within a factor of three, which is comparable with the remaining uncertainty of the other model system.

As for the vulnerability maps, the combination of vulnerability and impact shall be carried out on data sets that are of equal influence on the resulting damage data set. Therefore, one of the data sets has to be transformed in order that both data sets provide equal influence. Since the impact of oil is in specific physical dimensions (mass per area) and since the vulnerability already has been transformed and consists of sets of abstract indices, the vulnerability data sets is assumed to be most suited for transformation (as also done in BRISK project). The data transformation is carried out by transforming the vulnerability data by a logarithmic transformation so that the range of the impact data is equal to the range of the transformed vulnerability data. Again, this is carried out for all 8 cases (2 locations, 4 seasons), see Figure 4-2.

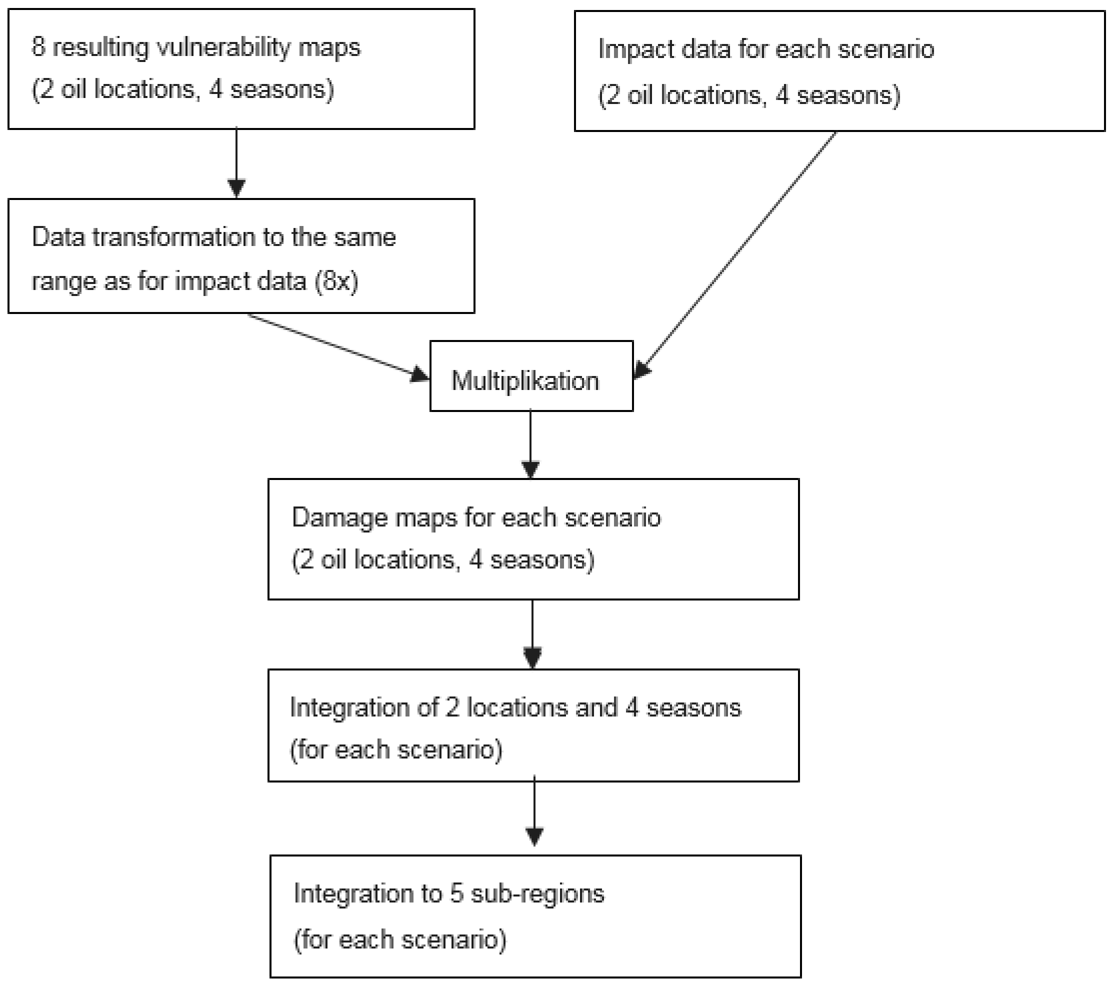


Figure 4-2 Schematic illustration of calculation of environmental damage

5. Risk Reducing Measures and Response Scenarios

At the BE-AWARE 2 Method seminar 8-9 of April 2014 in Southampton the process of selecting scenarios was initiated. All contracting parties were participating at the meeting where the initial ideas for scenarios were discussed and non-viable scenarios were discarded.

After the Method Seminar a wider process was initiated that included a long list of scenarios. This long list was condensed to the short list presented below. For a full description of potential scenarios considered reference is made to the Method Seminar Report (Bonn Agreement, 2014).

The different scenarios serve the purpose of identifying areas where improvements, e.g. implementation of safety measures or increase in recovery equipment, could lead to a decrease in the risk of having an oil spill or to limit the impact. In order to be able to measure the effectiveness the base scenario, i.e. the most likely current and future scenario also described in Be-Aware I, is used as a reference. Besides the reference scenario, the following scenarios have been decided.

Vessel Traffic Services (VTS)

The effect of adding a new and larger area with VTS coverage is investigated.

Traffic Separation Schemes (TSS)

The effect of implementing new suggested TSS schemed is investigated

AIS alarm (Wind turbines)

An evaluation of the effect of having an alarm system warning ships on a potential collision course with wind turbines will be carried out.

E-navigation

An evaluation of the effect of having generic risk reducing e-navigation technologies implemented.

New Emergency Towing Vessels (ETVs)

The effect of adding new ETVs is investigated on the regional scale.

Improved night detection capability

The effect of adding night recovery equipment to additional vessels is investigated.

Further use of dispersants

A regional wide use of dispersants only as response to oils spills is investigated.

50% increase in response equipment

The effect of increasing the response equipment by 50% and adding some additional vessels at locations with no or low service by response vessels.

As seen above there are five scenarios with risk reducing measures and three oil-spill response scenarios. The scenarios are listed in

Table 5-1.

Table 5-1 Listing of selected scenarios

Scenario No.	Scenario Name	Risk Reducing Measure	Response Measure
1	Reference: 2011-situation		
2	Reference: 2020-situation		
3	Vessel Traffic Services (VTS)	X	
4	Traffic Separation Schemes (TSS)	X	
5	AIS alarm (Wind turbines)	X	
6	E-navigation	X	
7	New Emergency Towing Vessels + Response Vessel	X	X
8	Improved night detection capability		X
9	Further use of dispersants		X
10	50% increase in response equipment		X

Factsheets describing the scenarios can be found in Annex 1: Scenario overview.

6. Evaluation of model scenario analyses

6.1 Comparison of scenarios

6.1.1 Introduction

The principle of the applied method is that all processes of relevance for the occurrence of spills and environmental damage are described and connected in a system of modules, so that the consequence of changed input parameters will result in a measurable change for oil impact and damage to the environment.

The result parameters are:

- oil on the water surface (oil on water),
- oil that is chemically dispersed in the water column (oil in water)
- spilt that is washed ashore (oil on coastline)

The parameters are modelled according to a commonly agreed methodology that has been partly developed by the Project Partners.

6.1.2 Scenarios

It is the objective to investigate the consequences of different potential scenarios in the future, i.e. the year 2020. These scenarios are described in terms of different new input parameters to the model. The project team has discussed and decided what scenarios shall be investigated and has developed corresponding input parameters for the model.

In all, 3 scenarios for different response capacities are defined. Further, 5 additional scenarios are selected describing alternative measures for avoiding accidents.

For reference and comparison, a scenario for the traffic in the year 2020 is defined that comprises the traffic for 2020 as given in a traffic prognosis. It also includes the response capacities on the same level as at present and it includes navigational aids for avoiding accidents that are decided upon and will be implemented before 2020. In order to describe the effect of the existing response capacity and the navigational aids two additional reference scenarios are defined.

Present situation scenarios

Reference scenarios describe the scenarios with existing traffic, existing response capacity and existing navigational aids.

The response capacities include "dedicated capacities" for all countries. Further, vessels under contract are included for countries that have no dedicated vessels. It is assumed that all ships that potentially can reach the pollution are alerted simultaneously. This includes cross-border assistance as well as assistance from other sub-regions.

Future scenario (reference)

This scenario includes the prognosis for the traffic and redistribution within goods categories for the year 2020. It also includes the navigational aids that are decided and response capacities to be implemented by the year 2020. This scenario is used to compare the effect of different future scenarios.

Navigational aids scenarios

These scenarios describe the impacts of introduction of different navigational aids to reduce the risk for accidents (risk reducing measures).

Response capacity scenarios

These scenarios describe the impacts of introduction of increased response capacities as well as extended application of dispersants.

6.2 Cost-benefit analyses of scenarios

Limited financial resources can be allocated to the response equipment/vessels and corresponding human resources. This depends on many conditions, including the length of the coastline and intensity of traffic in national waters and last not least, the political will to prioritise response capability.

The idea behind the cost-efficiency analysis, where the preparedness on an entire sub-region is assessed, is that there will be an adequate balance of resources among the neighbouring countries, providing an optimised and coordinated response capacity in the Bonn Agreement area. Therefore, specific and concrete programs, including a timetable for how to fulfil identified gaps in the capacities, shall be prepared for each sub-region.

The overall objective is each to ensure timely and well organised emergency response in such a way that environmental damage caused by accidents is minimised in a cost effective manner. The cost benefit analysis will prepare an analytical background for investments in emergency and response resources. The background is provided to the project partners (countries) so they can evaluate and select the scenarios that seem most viable for them, taking into account the country specific pre-conditions.

The cost benefit analyses for the scenarios investigating additional response resources options were carried out in cooperation between national experts and an external consultant specialised within this field.

The cost benefit analysis compares the:

- Effectiveness
  of each scenario compared to the reference scenario for year 2020 (also called "do nothing new" or "business as usual"). The effectiveness indicates how much the negative consequences are reduced in each scenario:
    - Reduction of spilt oil (in tons/sub-region) due to the introduced measures of each scenario.
    - Reduction of oil washed on shore and smothering the coastline (in tons/year/sub-region) for each scenario.
    - Reduction of environmental damage (in tons weighted/sub-region) for each scenario
- Cost Efficiency
  of each scenario compared to the reference scenario (2020). By taking the cost for each scenario

into account, the cost-efficiency provides the possibility to rank the scenarios with regards to how much benefit is gained per invested Euro:

  - Reduction of spilt oil per invested Euro (in tons/Euro/sub-region) due to the introduced measures of each scenario
  - Reduction of oil washed on shore per invested Euro (in tons/year/Euro/sub-region) for each scenario
  - Reduction of environmental damage per invested Euro (in tons weighted/Euro/sub-region) for each scenario

- Evaluation
  Based on the above analyses, the Project partners prepare an overall evaluations and summary of the results for each sub-region.

Regarding E-navigation scenario the costs per ship needed to be calculated for the region. Therefore the proportion of the sailed distance relating to short sea shipping and external trade needed to be calculated. The calculations were based upon the following assumption, supplied by the Norwegian Project Partner (Text is slightly adjusted for presentation in this report):

The ration of time, when vessels sail in the Bonn Agreement area, is determined for "Short Sea Shipping" and "External trade" in the Bonn Agreement Area. Based the unique IMO number in the Bonn Agreement Area and sailed distance in the same Area the ratio can be determined. Considering the uncertainty the following intervals are found:

Short Sea shipping: 60% - 70% of the sailed distance will be within the Bonn Agreement area

External trade: 40 % - 30% of the sailed distance will be within the Bonn Agreement area

It appears relatively certain that the above intervals reflect the reality in the Bonn Agreement Area. The calculation is done without fishing vessels. The biggest trawlers will be part of intelligent navigation systems I believe and I therefor recommend to use 70% - 30% (Short Sea Shipping - External trade) in our scenario.

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Annex 1: Scenario overview

An overview of the scenarios with variations to Risk Reducing Measures or Response Measures compared to the reference scenarios is given below:

Scenario number	Scenario name	Risk Reducing Measure	Response Measure
1	Present reference situation		
2	Future reference situation		
3	Vessel Traffic Services (VTS)	X	
4	Traffic Separation Schemes (TSS)	X	
5	AIS alarm (Wind turbines)	X	
6	E-navigation	X	
7	New Emergency Towing Vessels + Response Vessel	X	X
8	Improved night detection capability		X
9	Further use of dispersants		X
10	50% increase in response equipment		X

The scenarios are listed in the following

Scenario 1

Name:
Present situation scenarios

Description:
Reference present scenario describing the situation as it is in 2011 with existing traffic, existing response capacity and existing navigational aids

Purpose:
The response capacities include "dedicated capacities" for all countries. It describes the situations "as present" and serves for comparison with the prognostic situation for 2020 (Scenario 2). Further, vessels under contract are included for countries that have no dedicated vessels. It is assumed that all ships that potentially can reach the pollution are alerted simultaneously. This includes cross-border assistance as well as assistance from other sub-regions.

Scenario 2

Name:
Future situation scenario

Description:
Reference future scenario describing the scenario with prognostic traffic for 2020, including response capacities decided upon at present and existing navigational aids.

Purpose:
The scenario serves as reference for the additional future scenarios. The response capacities include "dedicated capacities" for all countries.

Further, vessels under contract are included for countries that have no dedicated vessels. It is assumed that all ships that potentially can reach the pollution are alerted simultaneously. This includes cross-border assistance as well as assistance from other sub-regions.

Scenario 3

Name:
Vessel Traffic Services (VTS)

Description:
Extension of the VTS coverage to areas beyond what is expected to be implemented by 2020.

Implementation in model:

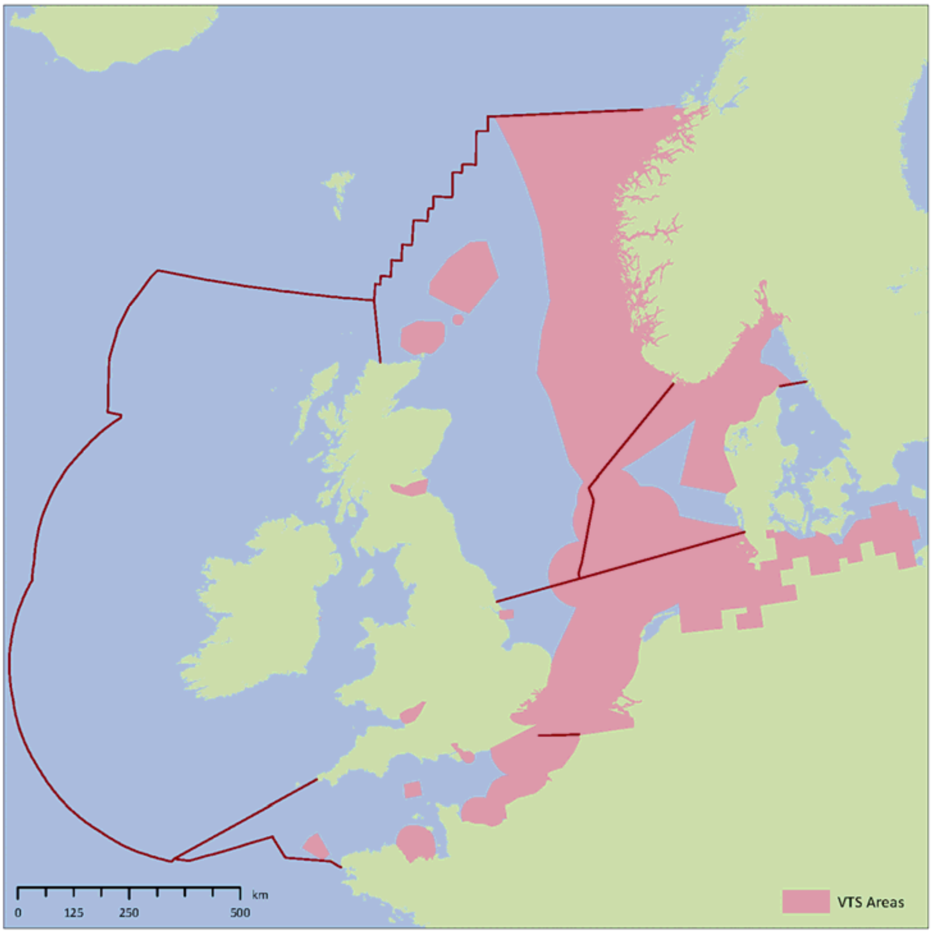
The risk reducing effect of having VTS is included in the model with the same efficiency parameters as the existing VTS centres modelled in the BE- AWARE I project. The factors on VTS affect the causation probability. Description is given in "Technical sub-report 5" on page 6.

Purpose of the scenario:

VTS centres are widely applied in areas with increased risks e.g. due to complex traffic etc. These centres are also used for ensuring that the rules are followed in areas with e.g. TSS. Vessels with a deviating course can be contacted and guidance can be given.

The purpose of the scenario is to investigate the effect of extending the VTS areas to hotspots identified in the BE-AWARE I project and to proposed new TSS routes in the current project.

Attachments:
Map of the total area where the effect of VTS is included in this scenario is given below:



Scenario 4

Name:
Traffic Separation Schemes (TSS)

Description:
Extension of the use of Traffic Separation Schemes beyond what is expected to be in place by 2020

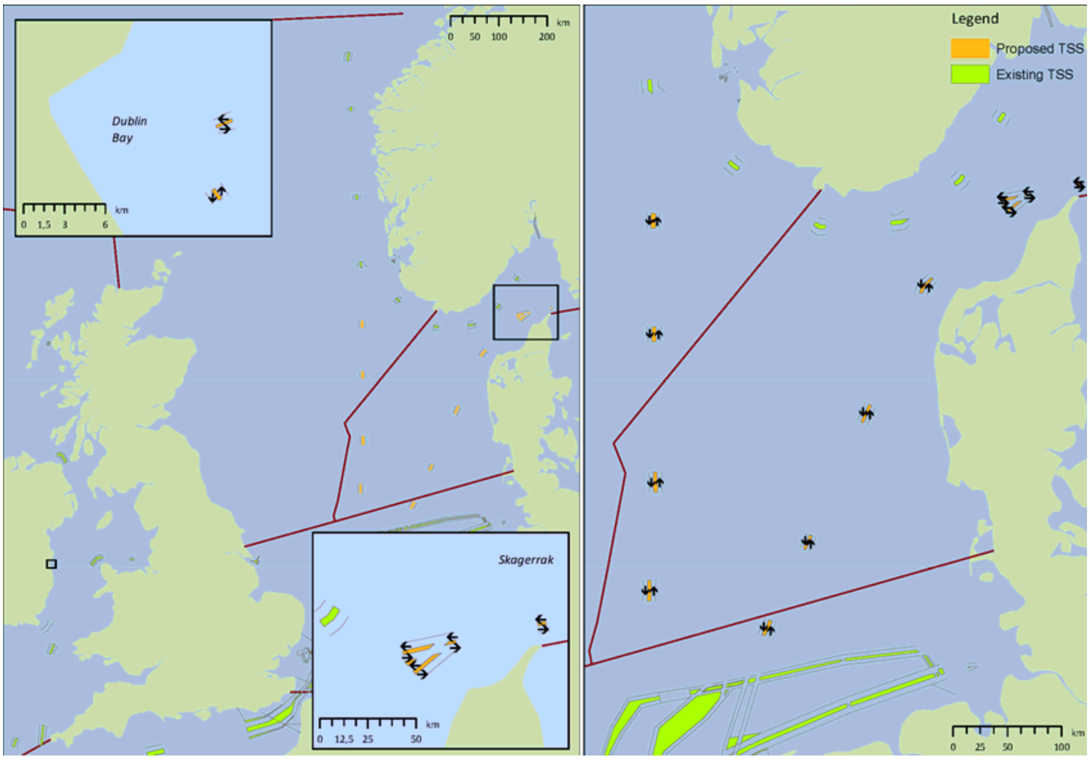
Implementation in model:

The risk reducing effect of having TSS is included in the model by assigning vessels on a selection of route legs to the new TSS route. The vessels that will follow these routes are limited to vessels that are currently following the typical transit routes, and not vessels crossing these routes, e.g. fishing vessels, offshore supply etc. TSS is not included by a factor on the current traffic but by manually moving the traffic on a route level according to the new TSS. Description is given in "Technical sub-report 5" in BE-AWARE I

Purpose of the scenario:

TSSs are used to separate bi-directional ship traffic and will lead to a decrease in the probability of head-on collisions. Areas to be included in this scenario include those where high en-route collisions were identified in BE-AWARE I. In open sea areas where there is a risk from head-on collisions is significant, this measure has been suggested. The purpose of the scenario is to investigate the effect implementing TSS in these areas.

Attachments:
An overview map of the areas where additional TSS`s are included in this scenario is given below. New TSS zones are marked with orange. In according with international regulations, TSS zones are only given as waypoints, but in reality it will affect the traffic pattern between these waypoints. The distance between the waypoints must be such that the effect between them is indisputable, like we see along the main route in the channel.



Scenario 5

Name:
AIS alarm (Wind turbines)

Description:
This scenario was initially setting up guard rings around wind parks, transmitting VTS centres a notification if a vessel does not follow the normal regulation. However due to the presence of narrow shipping lanes in-between wind parks this has been changed to AIS alarm – hence not limited to a guard ring but covering a wider range of AIS tools which can identify strange behaviour of vessels, such as sudden changes in course or speed.

Implementation in model:

The risk reducing effect is limited to that modelled under the VTS scenario. The risk reducing effect will be restricted to motorised vessels passing vessels that would otherwise have been on a collision course with a turbine, hence it has no effect for various maintenance vessels servicing the parks or drifting vessels in general. An estimation of the fraction of the risks coming from these vessels is necessary as only the resulting collision and spill frequencies and not the collision model are available from BE- AWARE I.

Purpose of the scenario:

The additional risk coming from the planned future wind parks gives a significant rise in the risk compared to the present situation. Therefore, this scenario was proposed as a means of obtaining a risk reduction in the same magnitude as a VTS centre whilst allowing VTS staff to actively focus on areas with higher density traffic.

Attachments:
The measure affects the frequency of ship-turbine collisions at all wind parks.

Scenario 6

Name:

E-navigation

Description:
The term E-Navigation covers a range of electronic systems which can improve the navigation and reduce the risk of accidents by providing additional information or alerting vessel crews to dangerous situations. A cost benefit analysis of E-navigation published by IMO May 2013 reviewed the various Risk Control Options including an evaluation of their risk reducing effect of various E-navigation by an expert group (table 10: in the annex 1, page 37). As they have also assessed risk distribution among accident causes (table 8: annex 1, page 18) the total risk reduction impact on maritime accident for the individual options can be assessed to be between 8-17%.

Implementation in model:

A generic risk reduction factor for all relevant types of maritime accidents can be developed based on the IMO paper. With an indicated risk reduction factor on all maritime accidents of between 8 and 17% for the individual e-navigation options in the paper, a combined reduction of 25% to illustrate the effect of E-navigation in general will be used. Based on the numbers in the report this is a conservative estimation.

This scenario will apply to the full model area.

Purpose of the scenario:

To investigate the risk reducing effect if the e-navigation systems currently being investigated by the ACCSEAS project were implemented on all shipping the Bonn Agreement area. The scenario will also highlight the collaboration between the ACCSEAS and BE-AWARE projects.

Attachments:
NAV 59-6 - Report of the Correspondence Group on e-navigation to NAV 59 (Norway)

Scenario 7

Name:
New Emergency Towing Vessels (ETVs)

Description:
This scenario models the effect of inserting three new ETVs

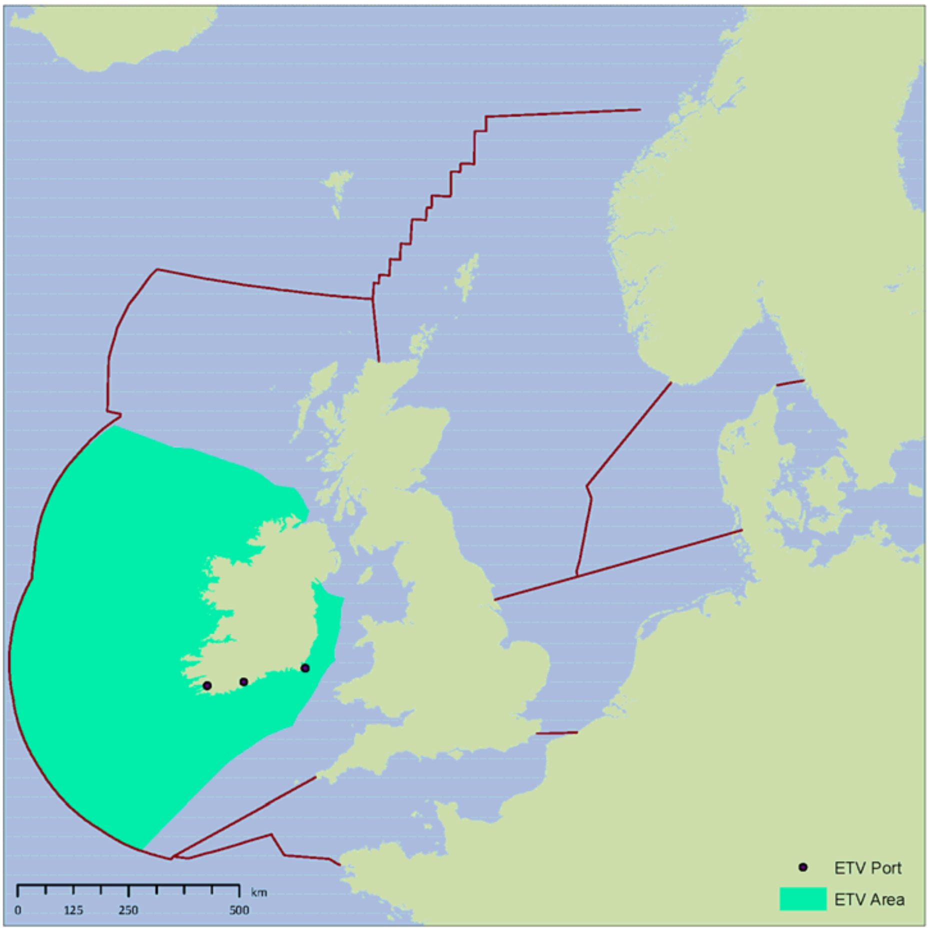
Implementation in model:

As in BE-AWARE I the effect of ETVs was assumed to reduce the oil spill by 30%. The description is given in "Technical sub-report 5" in BE-AWARE I.

Purpose of the scenario:

Measure the regional effect of inserting three new ETVs. It is underlined that the ETV’s actually are both, a response and risk reducing measure, as they can prevent accidents as well as being involved in the recovery of oil following a spill.

Attachments:
The location and coverage of the three new ETVs shown in the figure below:



Scenario 8

Name:
Improved night detection capability

Description:
The combination of dedicated oil detection radars and infrared cameras on oil response vessels increases the recovery capability of these vessels during the night and in bad weather. This scenario investigates the effect of implementing these systems to the vessel outlined below.

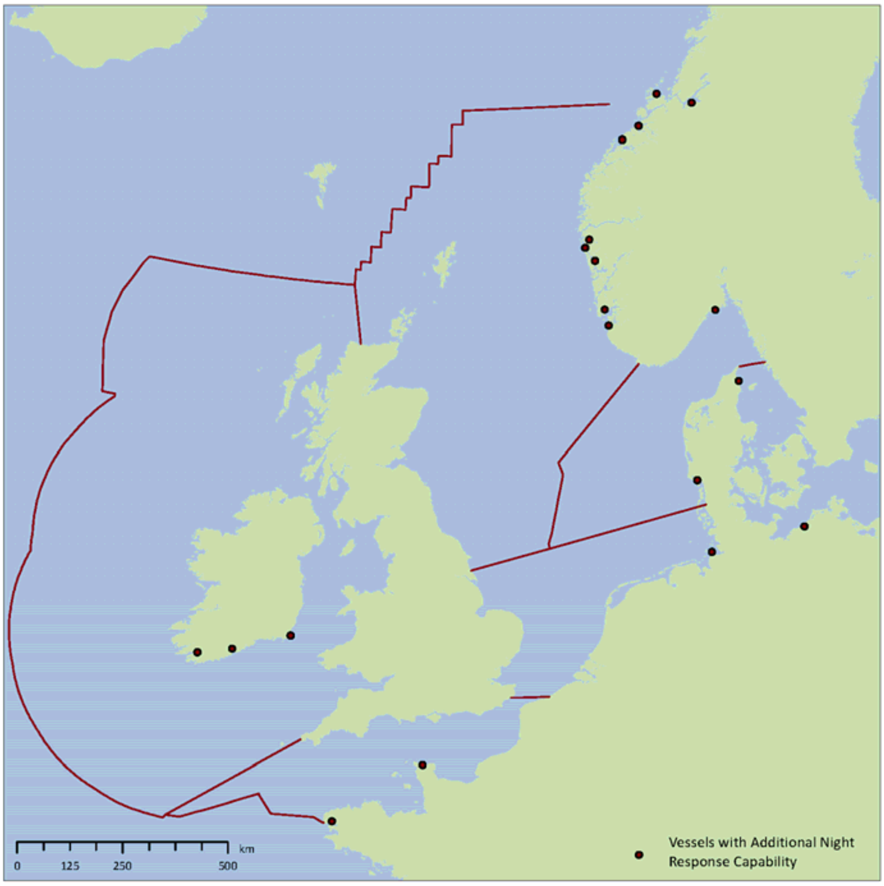
Implementation in model:

Down time due to night and bad visibility reduced according to the agreed factors. Based on the discussions at the eighth WebEx 14 October 2014 it is suggested to use the Norwegian efficiency factors for Radar and IR combined of 0.65 and Radar only of 0.5, compared to daylight/full visibility.

Purpose of the scenario:

Investigations of improved night detection in the BRISK project showed promising results and on this basis the scenario was also agreed relevant for the Bonn Agreement area.

Attachments:
The location of the vessels where improved night detection capacity will be modelled in this scenario is attached below:



Scenario 9

Name:
Dispersants only

Description:
This scenario investigates the effect of applying dispersants only in the full Bonn Agreement area.

The dispersant only scenario should be understood as exactly that, no other response strategies used in addition to dispersants. For the UK, the national contingency plan describes dispersants as a primary response technique but determining which strategy to adopt will be determined after consideration of all of the relevant factors concerning the incident response overall. It is likely in most incident scenarios that a range of response strategies will be employed and dispersants may be one unless the oil is non-dispersible or their application will cause more damage than not using them. That decision will be made on a case by case basis after consultation across the routine raft of UK stakeholders. While not impossible, a response to a major oil spill incident in the UK using dispersant only would be highly unlikely

Generally speaking it means that for scenarios where the oil is dispersible and operations are in over 20 m of water with no known sensitivities to dispersed oil such as aquaculture or fish spawning sites – it is highly unlikely that sensitive sea-bed resources will be damaged. Seawater column resources similarly will likely be exposed for relatively short periods and only in the top 10 metres.

Implementation in model:

The same dispersant response capability as currently used for UK waters is applied for all other areas as well, including spill size and response time limitations, etc. The principle is to apply dispersants in areas with a water depth greater than 20m plus 1nm.

In the UK sector:

No change on the response to spills, dispersants applied as in the base scenario.

In rest of the BA area:

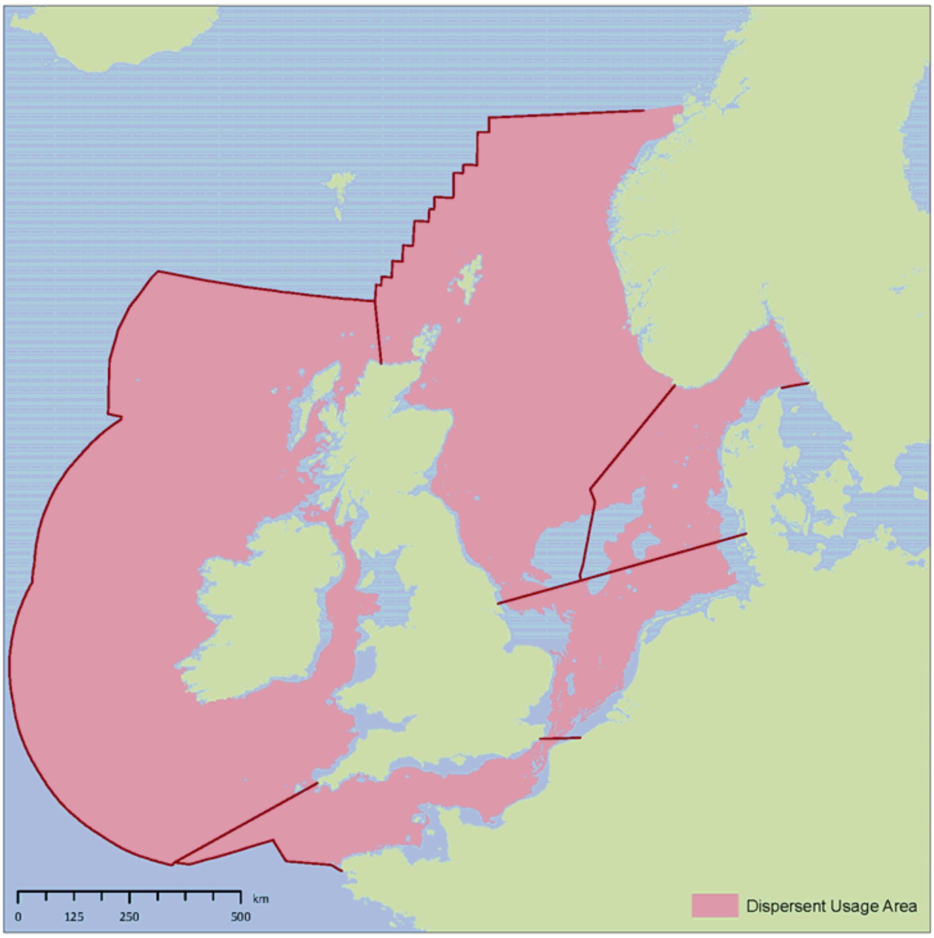
The dispersants only scenario dispersants are applied on all spills up to 15,000 tons in the area given below.

By applying this "dispersants only scenario", the mechanical recovery used in the base scenario is not used on spills below 15,000 tons in the area marked with red, see below.

Purpose of the scenario:

This scenario investigates the effect of applying dispersants in the full Bonn Agreement area.

Attachments:
The area where dispersants are applied in this scenario is shown below:



Scenario 10

Name:

50% increase in response equipment

Description:

The scenario includes a 50 % extension of the length of applied booms and 50% increase of applied pumping capacity within all CP`s, compared to the 2020 base scenario (This implies additional vessels to operate the additional equipment and also more trained personnel). Furthermore, one response-vessels is added on the west coast of Denmark.

Implementation in model:

Increase in length of applied booms and increase of applied pumping capacity + addition of 1 response vessel in Denmark.

Purpose of the scenario:

Show effect of additional equipment.

Attachments:

The 50 % increase is applied in the full Bonn Agreement project area. The locations of the additional recovery vessel in Denmark is seen in the figure below: