Guidance on environmental risk analyses using ERA Acute

Version 01, February 2020

FOREWORD

The ERA Acute model was developed by a consortium of industry partners with varying participation in different phases, but with Equinor and Total as leading partners throughout the process. In the final phase, 2017-19, the consortium consisted of Equinor, Total, OMV, Lundin, Aker BP, ConocoPhillips, Wintershall DEA and the Norwegian Oil and Gas Association, with financial support from the Research Council of Norway. Experts in environmental risk analysis (Acona, Akvaplan-niva, DNV GL and Sintef) were engaged for method development, and Geodata was responsible for software development.

Norwegian Oil and Gas engaged DNV GL with support from Acona and Akvaplan-niva to prepare this guidance for using ERA Acute in environmental risk analysis.

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CONTENTS

Abbreviations and definitions

Acute discharge – an accidental discharge to the natural environment of hydrocarbons or chemicals hazardous to the environment or to human health as the result of an undesirable incident.
Alarp – as low as reasonably practicable. This principle states that risk must be reduced as far as is possible in practical and financial terms. In other words, risk-reducing measures must be identified and implemented to the extent that their cost is not significantly disproportionate to their benefit.
Analysis area – the geographical area of the natural environment being analysed. It can be larger than the area of influence.
Area of influence – an area which, with some degree of probability, could be affected by a spill scenario. Each environmental compartment has its area of influence.
Barrier – technical, operational and organisational elements which are intended individually or collectively to reduce the possibility of a specific error, hazard or accident occurring, or which limit its harm/disadvantages.
BCF – bioconcentration factor.
Biological resource – defined in this guidance as a biological population or a habitat.
BSAF – biota-to sediment accumulation factor.
CBR – critical body residue.
DSHA – defined situation of hazard and accident. Used in the ERA as the incidents to be addressed by the analysis.
Environmental damage – direct reduction in one or more resources and accompanying recovery time resulting from an acute discharge. Expressed by the resource damage factor. In practice, environmental damage categories such as insignificant, minor, moderate, major and severe/serious are used.
ESI – environmental sensitivity index.
ERA – environmental risk analysis.
eRAC – environmental risk acceptance criteria.
Field – a collection of installations for drilling on/producing from one or more reservoirs, or within a naturally delimited geological area.
Habitat – a delimited area where a number of species live and interact, such as a shoreline or seabed area.
HSE – health, safety and the environment.
Impact – the population or habitat loss from an oil spill.
Insignificant damage – negative effects which do not cause environmental damage to identified resources in the analysis. This means that the impact is low and not quantifiable by the current method.
Installation – a permanent offshore facility which can be used for drilling and/or production, such as an integrated production platform, a free-standing subsea template or a pipeline.
Neba – net environmental benefit analysis.
NCS – Norwegian continental shelf.
Operation – a single job of limited duration which could lead to an acute discharge. An example is drilling an exploration well, which includes all activities from the arrival of the rig on the drilling site until it departs. An operation can also be other individual hazardous actions. Where acceptance criteria are concerned, the term "operation" is not used for activities conducted on an installation.

Population – a set of individuals of a species which is reproductively isolated within a specific geographical area.
Population-biology properties – properties of a population which will collectively determine its restoration ability. Includes factors such as the initial age of sexual maturity, age-specific fertility and mortality, density-dependent responses and maximum life span.
ppb – parts per billion.
ppm – parts per million.
QSAR – quantitative structure-activity relationship.
RDF – resource damage factor, representing the integral of impact and recovery time. It should be understood as lost population years for seabird and marine mammals and lost habitat years for shoreline flora and fauna.
Restoration time (duration) – restoration has been achieved when the original fauna and flora in the affected community are restored to virtually the same level as before the discharge (when natural variation is taken into account), and biological processes are functioning as normal. Populations are considered to be restored when they have reached 99 per cent of their pre-incident level. Restoration time is the period from the occurrence of an oil spill until restoration has been achieved.
Risk – risk is defined as the consequences of an activity with the associated uncertainty.
Risk acceptance criteria – criteria for determining whether a risk is acceptable or unacceptable.
Risk-reducing measures – measures which reduce the probability for or consequences of an undesirable incident. Pursuant to the regulations, measures to reduce probability should take priority over action to limit consequences.
Sima – spill impact mitigation assessment.
THC – total hydrocarbon concentration.
TOC – total organic carbon.
UTM – universal transverse Mercator.
VEC – valued ecosystem component, a standardised method for selecting particularly important environmental resources. A VEC is defined as a resource or an environmental property which

- is important (not only economically) for local people
- is of national or international interest
- if altered from its present condition, will be significant for the way the environmental impact of measures is assessed and for which mitigating actions are chosen.

Vulnerability – the vulnerability of all potentially affected resources to acute oil pollution, classified on the basis of recognised models for classifying vulnerability.

1 INTRODUCTION

1.1 Purpose of environmental risk assessments

Risk management is an integral part of finding good solutions for protecting people, the environment and assets. Conflicting objectives may exist between these aspects, and risk management will help finding a rational balance between them. Ensuring that operations do not pose an unacceptable level of risk for society and the industry is extremely important. Oil and gas companies therefore analyse many different risk aspects, including environmental risk, as part of managing their operations.

Quantitative environmental risk assessments (ERAs) for acute oil spills have been in use on the Norwegian continental shelf (NCS) for several decades as part of the risk management system at operators. They conduct ERAs to manage environmental risk, both as input to planning emergency preparedness for acute pollution and as part of their application for a licence to operate. Norway's HSE regulations also require the establishment of acceptance criteria for environmental risk, and of goals for protecting vulnerable resources. In addition, ERAs form the basis for documentation to the government and society at large that the business is taking adequate account of the environment, and that analyses required by the regulations have been conducted.

Unfortunately, no technologically advanced activity can be pursued without some degree of risk. A certain amount of uncertainty will always exist about the potential consequences of an enterprise's activities. Analysing and increasing knowledge of the risks associated with these activities reduces this uncertainty when business decisions are taken.

Proper risk management includes being able to identify the need for risk-reducing measures and to quantify the effect of implementing such measures. On that basis, cost-effective steps can be taken to achieve the desired risk reduction. Such measures could include reducing the probability of an incident occurring (in other words, technological or organisational barriers) or reducing the consequences of an incident if it occurs (through such measures as oil-spill response and clean-up of polluted shores).

1.2 Purpose and structure of this guidance

This guidance document has been created to support implementation of the newly developed **ERA Acute risk assessment methodology** for acute discharges of oil and condensate.

It is based on the following definition: "risk is defined as the consequences of an activity with the associated uncertainty". The guidance is divided into two main sections:

1) a description of the ERA Acute method
2) the methodological elements in an environmental risk analysis using ERA Acute.

The descriptive section builds on comprehensive work finalised in 2015 on detailing the impact and recovery algorithms for four different environmental compartments.

- *ERA Acute Phase 3 – Surface compartment*. Acona report to Statoil and Total. Report no 37571. v 04. Oslo, 22 May 2015.
- *Development of Shoreline Compartment Algorithms*. DNV GL report. 1ILBNGC-9. 43 pp. 2015.
- J*oint Report – Impact and Restitution Model – Water Column*. Sintef and DNV GL report. Sintef F26517/DNV GL 1IL8NGC-13. 81 pp. 2015.
- *ERA Acute – Development of Seafloor Compartment Algorithms – Biological Modelling.* Akvaplan-niva report 5425.02. 126 pp. 2015.

The target audience for this guidance is administrators and decision-makers at companies working with ERAs and oil-spill contingency analyses, and specialists carrying out such studies. It is also intended to serve as a useful methodological document for government bodies and affected parties who are asked to participate in consultation processes or to take decisions based on such analyses. The guidance describes the methodological elements in ERA Acute and how to apply them in carrying out an ERA with its aid.

In addition to this guidance, the following guidance documents have been established for use with ERA Acute:

- best-practice document for setting up oil-spill modelling for ERA Acute, to be maintained by Norwegian Oil and Gas
- best-practice documents (user manual and technical documentation) for the use of ERA Acute software, to be maintained by Epim
- best-practice document for setting up valued ecosystem component (VEC) data for ERA Acute, to be maintained by Norwegian Oil and Gas

All documents, including the guidance and best practice, are available at the Norwegian Oil and Gas website: www.norog.no.

2 DESCRIPTION OF THE ERA ACUTE METHOD

2.1 General introduction

The ERA Acute methodology uses input from the oil-spill trajectory model and the distribution of VECs to calculate the impact in each grid cell and for each simulation. This is done for each VEC in four environmental compartments:

- sea surface (SS)
- water column (WC)
- shoreline (SH)
- seafloor (SF).

For all compartments, impact modelling in ERA Acute uses the same overall framework of calculation elements – probability of exposure, probability of lethal effect given exposure, and presence of vulnerable resources for calculating impacts – whilst reflecting differences between the VECs in the four compartments with regard to damage mechanisms from acute oil spills .

The generic formula for the impact in a grid cell is:

$$Imp = P_{exp}\ x\ P_{let} x\ N$$

where

- P_{exp} = probability that the exposure will occur
- P_{let} = probability of lethal effect given the exposure
- N = resource (VEC) unit in the grid cell. Population fraction (sea surface and water column) per kilometre coastline (shoreline types) or square kilometre (seafloor habitats).

ERA Acute can use different levels of detail in the impact calculations, depending on the availability of data on VEC occurrence and distribution. The screening levels allow for the absence or limited availability of data on VECs. If no VEC data on the presence of environmental resources are available, oil drift simulations alone will determine exposure and potential mortality – assuming that the most sensitive VECs are present in all grid cells (level A1). This approach is suitable for identifying areas at risk in a screening or early-phase project decision, or for data gap identification.

Levels A2 and A3 use resource data to identify specifically where impacts and risks to resources are highest. A2, the second screening level, utilises data on whether the most sensitive VEC is present in the cell, thereby excluding cells with no sensitive VEC present. At the most detailed level (A3), data on VEC abundance distributions are used together with population growth parameters, providing a more accurate measure of potentially impacted fractions of the VEC (population loss, impacted coastline length or seafloor area) and corresponding restoration to pre-spill conditions. This is suitable for more detailed studies, such as in sensitive areas, detailed decision-making, regulatory purposes and so forth, and is used for full damage and risk calculations in the next step, level B.

For a full damage assessment, the duration of the impact is calculated as three time factors for each VEC: the impact time (time until full impact is seen), lag time before restoration can commence, and the time it takes for the resource to recover (restoration time). The sum of impact, lag and restoration times gives total recovery time. The environmental damage to a VEC is described by the resource damage factor (RDF), calculated as the integral of the curve describing the extent of impact and duration of damage (see Figure 1).

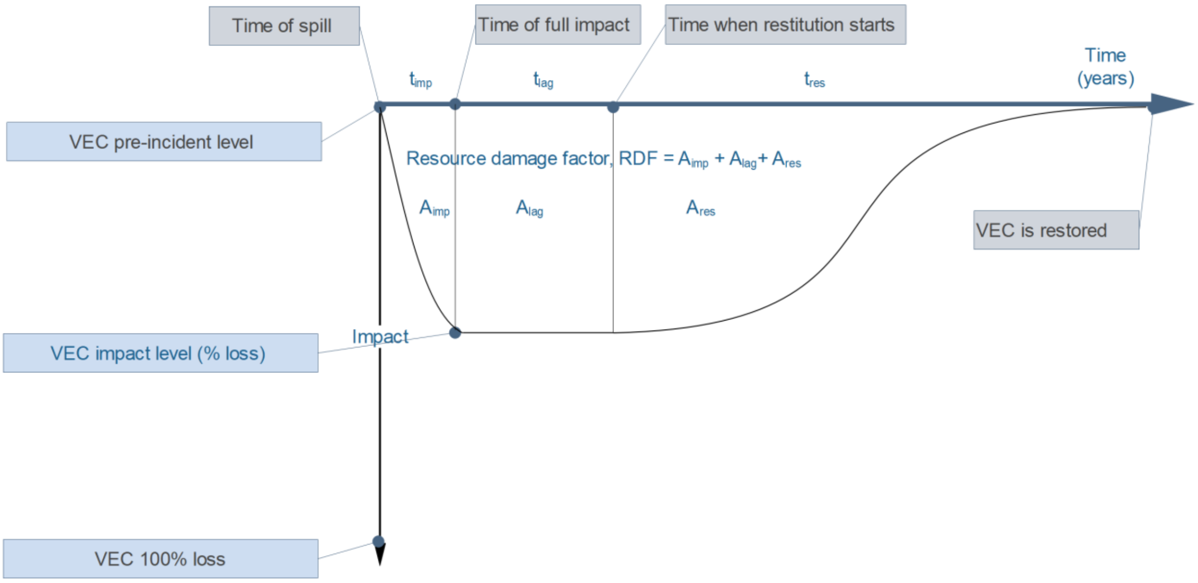


Figure 1 Basic illustration of the use of impact as resource (VEC) loss and time factors to calculate the RDF as the geometric area representing the combination of impact extent (y axis) and duration of impact (x axis).

2.2 Input data

Several input data are needed as input to impact, damage and risk calculations:

- the results of stochastic oil drift simulations from spill scenarios
- distribution of sensitive resources (VEC data) in relevant compartments
- resource- and compartment-specific parameters (sensitivity, restoration parameters and so forth).

The preparation of input data can be time-consuming, imposes important limitations and opportunities for the further assessment and evaluation, and should not be underestimated. A general overview of input data is given in table 1.

Table 1 Overview of input data needed for different levels of ERA Acute assessments.

ERA Acute level	Resource data	Data parameters
A1 – screening	None	None
A2 – screening	VEC presence/absence	None
B – full risk assessment	ESI ranking (shoreline) VEC distributions (sea surface and water column)	ESI vulnerability classification and tidal range Individual vulnerability factors Population specific restoration parameters/growth rates

2.3 End points for damage and risk calculations

As shown in Figure 1, ERA Acute has several endpoints which can be used to describe the environmental consequences and risk of a spill.

For a full damage assessment (level B), impact is given as a total population loss (in per cent) for seabirds and marine mammals and as larval loss for fish larvae. The population loss is summarised for all loss contributions from all affected grid cells in a simulation. Impact is given as the total impacted shoreline in kilometres for the shoreline and as the area of impacted seafloor habitats in square kilometres for the seafloor.

Impact time is specified in years and so are lag and restitution time, all adding up to a total recovery time. Since the RDF value is the integral of the extent and duration of impact until recovery, RDF is given as population loss-years for seabirds, marine mammals and fish populations. The value for shoreline is kilometres impacted shoreline-years, and for seafloor is then impact area in square-kilometre-years. It is meaningful to think of the RDF as a factor describing the total damage (extent and duration) caused to a population or habitat by an oil spill.

Since each oil-spill simulation, representing a specific historical weather condition, will give one impact, recovery time and RDF value for a VEC, applying many spill simulations will result in probabilities for different outcomes/consequences. As such, the ERA Acute approach is all about quantifying the probabilities for different outcomes in terms of how an oil spill will damage a VEC.

A detailed description of the ERA Acute algorithms in each environmental compartment is given in the following sections, describing how the impact and recovery calculations are performed and how the RDF is estimated.

2.4 Sea surface compartment

In the sea surface compartment, ERA Acute uses the coverage of harmful oil above a threshold of two µm for seabirds and 10 µm for marine mammals to calculate impact (mortality). The acute mortality in a grid cell *i* is given by:

$$N_{let-2} = \sum_{i=1}^{n} N_i - \left(1 - p_{beh} \times Cov_{iT} \times p_{phyT}\right)^{T_{expiT}} \times N_i$$

where $N_{let\text{-}2}$ is the acute mortality, p_{beh} is the probability of encountering the sea surface, and p_{phy} is the conditional probability of mortality given an encounter with oil above a specified oil film thickness (T). *Cov* is the coverage of the grid cell *i* with harmful oil (in other words, the fraction of the cell covered with oil above T) and T_{exp} is the exposure time to harmful oil in the grid cell.

A simplified equation which does not take account of the exposure time of harmful oil in the grid cell is also included:

$$N_{let-1} = \sum_{i=1}^{n} p_{beh} \times Cov_{iT} \times p_{phyT} \times N_i$$

A generic look-up table for 13 surface VEC groups has been constructed on the basis of species-specific values for the individual vulnerability factors (p_{beh} and p_{phy}). See Acona (2014). See also appendix A.

Table 2 Pbeh and Pphy values derived in this study for different surface VEC groups. LO = lowest estimate, BG = best guess, HI = highest estimate.

NO	VEC group	P_{beh}			P_{phy}			$P_{beh} \times P_{phy}$		
		LO	BG	HI	LO	BG	HI	LO	BG	HI
1	Pelagic diving seabirds	79%	79%	89%	80%	90%	100%	63%	71%	89%
2	Pelagic surface foraging seabirds	45%	45%	51%	80%	90%	100%	36%	41%	51%
3	Coastal diving seabirds	67%	67%	76%	80%	90%	100%	54%	61%	76%
4	Coastal surface feeding seabirds	31%	33%	44%	69%	78%	87%	21%	24%	33%
5	Wetland surface feeding seabirds	48%	48%	54%	80%	90%	100%	38%	43%	54%
6	Wading seabirds	35%	35%	35%	80%	90%	100%	28%	32%	35%
7	Baleen whales	35%	53%	88%	0.4%	0.4%	0.4%	0.2%	0.2%	0.4%
8	Toothed whales	40%	60%	100%	0.8%	0.8%	0.8%	0.3%	0.5%	0.8%
9	True seals, walruses and sea lions	83%	90%	96%	0.4%	2.8%	5.8%	0.4%	2.6%	5.7%
10	Fur seals	63%	78%	93%	50%	72%	93%	33%	57%	87%
11	Sea cows	95%	98%	100%	0.8%	4.3%	8.3%	0.8%	4.2%	8.3%
12	Aquatic mammals	79%	88%	97%	50%	72%	93%	40%	63%	90%
13	Sea turtles	95%	99%	100%	3.0%	3.0%	3.0%	2.9%	2.9%	3.0%

Lag time (t_{lag}) for seabirds and marine mammals is given by the lag time of shoreline cells (see the shoreline compartment description) and a resource-specific sensitivity factor, and is obtained with the following equation:

$$t_{lag,su} = \sum_{i=1}^{n} N_{hab_i} \times t_{lag,sh_i} \times SF_r$$

The restoration time (t_{res}) is estimated by using a discrete logistic population model:

$$N_{t+1} = \frac{N_t R}{1 + (aN_t)^b}$$

where R is the fundamental net reproductive rate, a is $(R\text{-}1)/K$, where K is the carrying capacity of the population and b is a factor determining the strength of the density dependency in the population. N_t is the population size at time t and is calculated by the impact equations. Standard values are given for the parameters in the model and a generic look-up table for fundamental population growth rate (R) was developed for seven surface VEC groups (Table 3).

Table 3 Surface VEC groups with generic population growth rates.

Surface VEC group	Typical species	Families	*R*	*r*
Albatross and skuas	Albatross (southern royal, Grey-headed Antipodean, northern royal), skua (brown, great, sub-Antarctic), northern fulmar	Diomedeidae, Stercorariidae, Procellariidae	1.05	4.9%
Auks, petrels and shearwaters,	Auks (razorbill, common guillemot, Atlantic puffin), petrels (black, white-chinned, Chatham), shearwaters (Bullers, flesh-footed), black-legged kittiwake	Alcidae, Procellariidae	1.10	9.5%
Gannets, penguins, gulls and terns	Gannets (northern, masked Australasian), penguins (snares crested, southern rockhopper, Fiordland crested), gulls (black-backed, lesser black-backed, little) and terns (common white, common, sandwich, Caspian)	Sulidae, Spheniscidae	1.15	14.0%
Cormorants, shags, divers, ducks and geese	Cormorant (great), shags (European, Campbell Island, spotted, Auckland Island), divers (red throated), ducks (common eider, common scooter) and geese (barnacle, snow, Bewicks swan)	Anatidae, Gaviidae,	1.20	18%
True seals, sea lions and fur seals, baleen whales	Grey seal, harbour seal, ringed seal, Antarctic fur seal, sub-Antarctic fur seal, blue, humpback and southern right whales	Balaenopteridae	1.13	12.2%
Walrus, aquatic mammals	Walrus, polar bear, Eurasia otter and sea otter	-	1.06	6.0%
Toothed whales, sea cows	Bottlenose dolphin, killer whale, harbour porpoise, Florida manatee	Delphinidae, Phocoenidae, Trichechidae, Dugongidae	1.03	3.0%

The total recovery time (t_{rec}) and the RDF are given by the following equations:

$$t_{rec} = t_{imp} + t_{lag} + t_{res}$$

and

$$RDF = 0.5 \times t_{imp}(1 - N_0) + t_{lag} \times (1 - N_0) + \int_{t_{lag}}^{t_{res}} 1 - N(t)dt$$

where the parameters are the times calculated in the impact, lag and restoration phases respectively. TLR is the threshold set for restoration.

2.5 Shoreline compartment

ERA Acute uses the ESI shoreline ranking as input data and calculates the possible impact for each ESI class (1-10) in addition to the total impacted coastline (ESI sum). Impact is determined on the basis of oil volume in the shoreline grid cell. The oil volume is redistributed to the ESI rankings in the cell on the basis of tidal range and the ESI oil-holding capacity (Table 6). ESI-specific threshold thicknesses for oil on shore are then evaluated to see if the coastal segment is impacted. An overview of the ESI shoreline rankings is provided in Table 4.

Table 4 ESI shoreline rankings. Source: http://response.restoration.noaa.gov/maps-and-spatial-data/shoreline-sensitivity-rankings-list.html

ESI rank	Estuarine	Lacustrine	Riverine
1A	Exposed rocky shores	Exposed rocky shores	Exposed rocky banks
1B	Exposed, solid human-made structures	Exposed, solid human-made structures	Exposed, solid human-made structures
1C	Exposed rocky cliffs with boulder talus base	Exposed rocky cliffs with boulder talus base	Exposed rocky cliffs with boulder talus base
2A	Exposed wave-cut platforms in bedrock, mud or clay	Shelving bedrock shores	Rocky shoals, bedrock ledges
2B	Exposed scarps and steep slopes in clay		
3A	Fine- to medium-grained sand beaches		
3B	Scarps and steep slopes in sand	Eroding scarps in unconsolidated sediment	Exposed, eroding banks in unconsolidated sediments
3C	Tundra cliffs		
4	Coarse-grained sand beaches	Sand beaches	Sandy bars and gently sloping banks
5	Mixed sand and gravel beaches	Mixed sand and gravel beaches	Mixed sand and gravel bars and gently sloping banks
6A	Gravel beaches Gravel beaches (granules and pebbles)	Gravel beaches	Gravel bars and gently sloping banks
6BC	Riprap Gravel beaches (cobbles and boulders)	Riprap	Riprap
7	Exposed tidal flats	Exposed tidal flats	
8A	Sheltered scarps in bedrock,	Sheltered scarps in	

	mud or clay Sheltered rocky shores (impermeable)*	bedrock, mud or clay	
8B	Sheltered, solid human-made structures Sheltered rocky shores (permeable)	Sheltered, solid human-made structures	Sheltered, solid human-made structures
8C	Sheltered riprap	Sheltered riprap	Sheltered riprap
8D	Sheltered rocky rubble shores		
8E	Peat shorelines		
8F			Vegetated, steeply-sloping bluffs
9A	Sheltered tidal flats	Sheltered sand/mud flats	
9B	Vegetated low banks	Vegetated low banks	Vegetated low banks
9	Hypersaline tidal flats		
10A	Salt- and brackish-water marshes		
10B	Freshwater marshes	Freshwater marshes	Freshwater marshes
10C	Swamps	Swamps	Swamps
10D	Scrub-shrub wetlands, mangroves	Scrub-shrub wetlands	Scrub-shrub wetlands

The shoreline impact will be calculated for each ESI ranking and can be summarised to an overall impact estimate. Information about ESI distribution and tidal range must be prepared as part of the habitat grid in the oil-spill model.

Shoreline lethal threshold values for invertebrate epifauna (ESI 1-10) are set to 0.1 millimetre, while the lethal threshold value for wetland vegetation (ESI 8-10) is set to one millimetre.

Information about oil thickness (T) on the shoreline is derived from the amount of oil stranded (V) in a grid cell divided by the length of the coastline (L) in the grid cell multiplied by the width of oiling (W_{imp}) on the shoreline:

$$T = \frac{V}{L * W_{imp}}$$

Given the slope (sl) associated with each ESI ranking (see Table 5), the tidal range (TR) and a fixed patchiness factor of 20 per cent, the width (W_{imp}) of oiling in each segment can be calculated by:

$$W_{imp} = \frac{TR}{\sin\left(\operatorname{atan}(sl)\right)} \times 0.2$$

Table 5 ESI shoreline slope values to be used in ERA Acute.

ESI ranking	Short description	Shoreline slope	Model value (degrees)
1	Exposed, impermeable vertical substrates	Generally 30 degrees or greater	35
2	Exposed, impermeable substrates, non-vertical	Usually less than 30 degrees, resulting in a wider intertidal zone; it can be less than five degrees and the intertidal zone can be up to hundreds of metres wide	10

3	Semi-permeable substrate, low potential for oil penetration and burial	Very low, less than five degrees	3
4	Medium permeability, moderate potential for oil penetration and burial	Intermediate, between five and 15 degrees	10
5	Medium-to-high permeability, high potential for oil penetration and burial	Intermediate, between eight and 15 degrees	12
6	High permeability, high potential for oil penetration and burial	Intermediate to steep, between 10 and 20 degrees	15
7	Exposed, flat, permeable substrate	Flat (less than three degrees)	1
8	Sheltered impermeable substrate, hard	Generally steep (greater than 15 degrees), resulting in a narrow intertidal zone.	20
9	Sheltered, flat, semi-permeable substrate, soft	Substrate flat (less than three degrees)	1
10	Vegetated emergent wetlands	Substrate flat	3

Table 6 Relative oil-holding capacities for each ESI ranking.

Shoreline type	**ESI ranking**	**Relative oil-holding capacity (m^3 oil/ m^2 sediment)**		
Rocky shore (exposed)	1,2	2.8	2.7	1.8
Sandy beaches	3	22.7	23.3	22.3
Mixed sand and gravel	4,5,6	11.9	12.4	13.5
Tidal flats (exposed and sheltered)	7,9	17.0	8.2	8.9
Rocky shore (sheltered), peat shorelines	8	5.7	6.8	8.9
Marshes, swamps, wetland	10	34.1	41.0	35.7

Based on the accumulated oil volume on the shoreline (V_{cell} from the oil-spill modelling) and oil viscosity, the distribution of oil in various ESI habitats in the grid cell can be estimated. This is done by weighting the various ESI segments by their length (L) and by applying the oil-holding capacity (OHC) factor related to each ESI ranking (r) for a given oil viscosity (see Table 6):

$$Weight_r = L_r \times OHC_r$$

The volume per ESI ranking is then:

$$V_r = V_{cell} \times \frac{Weight_r}{\sum_{r=1}^{10} Weight_r}$$

And furthermore, the oil film thickness (T) for each ESI ranking is given by:

$$T_r = \frac{V_r}{L_r * W_{imp,r}}$$

The thickness is then checked with the lethal threshold thickness in order to decide on effect or no effect for each ESI ranking in each grid cell. The total impact for each

ESI ranking (r) is given by the total length (L) for all grid cells where the thickness (T) is above the threshold value (TH).

$$Imp_r = \sum_{cell}(L_r | T_r \geq TH)$$

The overall impact for the shoreline compartment can be given as the sum of all ESI impacts or as ESI specific impact.

$$Imp = \sum_r Imp_r$$

The expression for the duration of the lag phase for shoreline habitats is based on the ESI status, hydrodynamic energy and oil types in accordance with a look-up table (Table 7).

Table 7 Look-up table for lag-phase (years) based on ESI shoreline ranking and oil type.

Shoreline energy status (ESI)	**Type 1** **Very light oils**	**Type 2** **Light oils**	**Type 3** **Medium oils**	**Type 4** **Heavy oils**
High energy (ESI 1-2)	0	0	0	0
Medium energy (3-7)	0	0	1	1
Low energy (8-10)	0	3	7	10

Differentiation of the oil types is suggested in accordance with http://response.restoration.noaa.gov/oil-and-chemical-spills/oil-spills/oil-types.html.

Assumed values for recovery (t_{rec}, the time to 99 per cent restoration) of vegetation or species important for the structure of a habitat are specific to habitat type and are based on experience from observations of natural restoration following disturbances (including spills) and from habitat creation projects. Values vary from three to 20 years. Restoration time for benthic invertebrates to 99 per cent of function/pre-spill condition is estimated at three-five years, based on a natural recovery cycle (Table 8).

Table 8 Recovery rates (years to 99 per cent restoration) for vegetation or other structural organisms, and for benthic invertebrates where habitat structure is not impacted.

Habitat (ESI shoreline classification)	**Vegetation or structure (years)**	**Benthic invertebrates (years)**
Rocky shore (1 and 8) Exposed rocky platforms (2) Fine-grained sand beaches (3) Coarse-grained sand beaches (4) Mixed sand and gravel beaches (5) Gravel beaches and riprap structures (6) Exposed tidal flats (7 and 9)	3	3
Wetland: emergent marsh (10A, 10B)	15	5
Wetland: swamp (10C, 10D)	20	5

The RDF for the shoreline is calculated by:

$$RDF = imp_{cell,r\,x} \times (0.5 \times t_{imp} + t_{lag} + 0.5 \times t_{rest})$$

and given in kilometre-years.

2.6 Water column compartment

The methodology for water column organisms is divided into two different approaches for the impact calculations concerning fish eggs and larvae. The larval loss is then translated into a possible loss of adult spawning stock population using a global fish population model.

The impact calculation can either use total hydrocarbon concentrations (THC) in the water column from the spill simulation (THC approach) or be based on pre-modelled mortalities in each grid cell from the oil-spill model using a critical body residue (CBR) approach. The latter is based on the time-dependent toxicity of dissolved oil fractions represented by pseudo-components.

Although fish eggs and larvae have been identified as the most sensitive and relevant water column resources, owing to their abundance across time and space, the impact can in theory be calculated for any water-column resource, and using both impact approaches, by adjusting the effect level and/or the dose-response curve. However, the developed restoration model is specific for fish.

The impact in each grid cell ($Imp_{r,cell}$) is calculated using the general formula with probability for exposure (P_{exp}) and for lethal effect given the exposure (P_{let})

$$Imp_{r,cell,sim,} = p_{exp,r,cell,sim} \times p_{let,r,cell,sim} \times N_{r,cell}$$

For water column organisms, P_{exp} is set to = 1.

The first approach (THC) computes the probability of lethal effect (P_{let}) from a dose-response curve with median value (LC50) = 193 parts per billion (ppb) THC, effect level (LC5) = 58 ppb THC and SD 0.32, using a cumulative distribution function:

$$F(x) = \frac{1}{2}[1 + \text{erf}(\frac{x-\mu}{SD\sqrt{2}})]$$

with μ representing the median value (193 ppb THC), and *erf* representing the non-elementary Gauss error function. This is in line with the suggestion by Nilsen *et al* (2006) during EIF Acute (Figure 2).

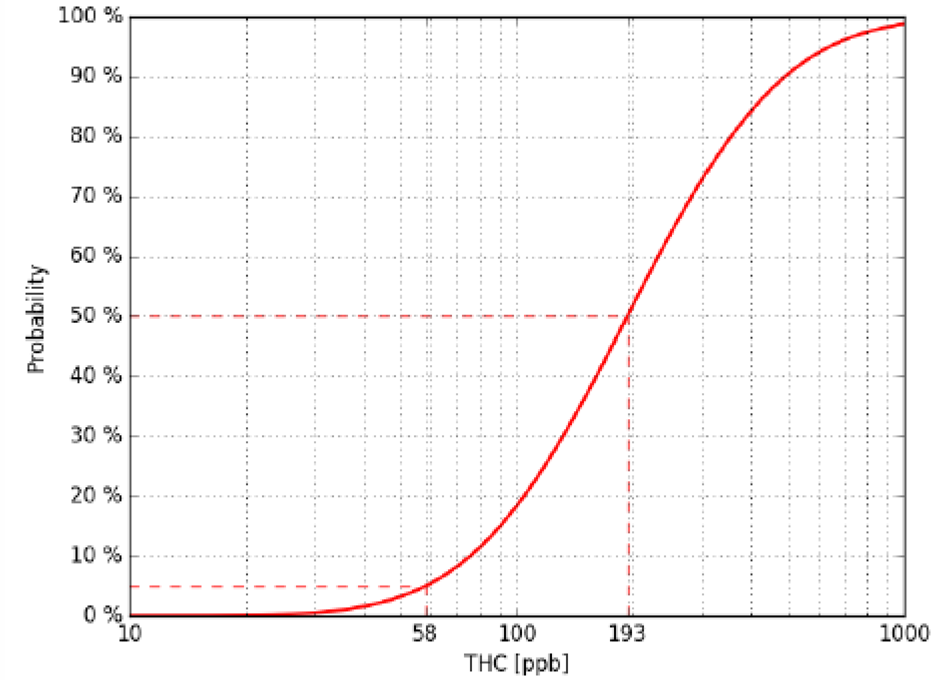


Figure 2 Species sensitivity curve used for impact calculations of THC.

The CBR approach computes time-dependent mortality of sensitive species (fish eggs and larvae, adult fish, corals and sponges) in the oil-spill model together with oil transport and fate via CBR and quantitative structure-activity relationships (QSARs). A dose-response curve analogue to approach one is used to compute potential mortality in each grid cell. The CBR method is typically implemented in the oil-spill model, since it uses time-dependent calculations.

It should be noted that the THC approach calculates mortalities using both the dissolved fraction (aromatic fraction) and dispersed oil droplets (alkane fraction). The CBR approach, on the other hand, only considers the dissolved oil fraction, accounting for a number of pseudo-components and their individual concentrations, with varying oil composition over time as a result of oil weathering.

No lag phase is considered for the water column compartment, since this is built into the restoration model.

Based on the calculated impact on fish eggs and larvae, ERA Acute uses a global fish restoration model to estimate the impact on the spawning population (see Sintef and DNV GL, 2015). As with other models, this relies on appropriate input data. Restoration modelling relies on expected natural survival from the egg stage and up to recruitment – the age at which fish start appearing in groups and reach a size where they represent a viable target for the commercial fishery. The recruitment age is typically two-four years for long-lived fish (three for Barents Sea cod), and one year for short-lived fish, including capelin.

A sub-routine for modelling natural variation in fish survival up to recruitment is built in, and based on historical records for Barents Sea cod and capelin. The restoration model reflects the real impact of oil spills by taking (extremely high) natural mortalities for early stages into account, and the impact of fishing can also be addressed.

Two runs of the global fish restoration model are made, with and without oil impact on eggs/larvae, using basic population biology parameters to calculate expected recruitment (E_{Recr}) with and without oil, relative to the average recruitment ($Recr_{Average}$).

The *critical density* parameter (default five per cent) expresses the threshold when a direct relationship is modelled between the size of the spawning stock and recruitment. If the analysed fish stock is above the critical density, recruitment is fully independent of the size of the spawning stock:

$$E_{recr} = Recr_{average}$$

If the analysed fish stock is below the critical density, the model calculates the expected recruitment relative to current spawning stock size ($SS_{current}$) and the long-term average spawning stock ($SS_{average}$):

$$E_{recr} = Recr_{average} \times \frac{SS_{current}}{0.05} \times SS_{average}.$$

The *critical oil mortality* parameter enables the user to choose the level of conservatism for impact modelling of acute oil spills. Critical oil mortality (in per cent) represents the threshold mortality of eggs and larvae for which a proportionate relationship between killed larvae and reduced recruitment is calculated.

- If the calculated impact is less than critical oil mortality, the model calculates the impact from a proportionate relationship between oil-induced mortality of larvae and reduced recruitment (one lost larva results in one lost recruit). If critical oil mortality is set to 30 per cent, for example, any oil-induced impact on eggs and larvae greater than 30 per cent will reduce recruitment by the same percentage.
- If the calculated impact is above critical oil mortality, the model calculates the impact using the “gate model” – in other words, modelled natural survival up to recruitment as a reference level for measuring oil impact on eggs and larvae against.

A full description of the global fish population model is provided in Sintef and DNV GL (2015).

RDF in the water column compartment is calculated as the summed-up reduction for years displaying a spawning stock reduction of at least one per cent (restoration level 99 per cent), and expressed as spawning stock reduction-years in per cent of an undisturbed stock:

$$RDF_{WC} = 100 \sum_i \frac{N_i}{N_{oil,\,i}}, \quad \forall_i \frac{N_i}{N_{oil,\,i}} > 0.01$$

where

- N_i is the spawning stock size without oil impact
- $N_{oil,i}$ is the spawning stock size where the population in the first year was impacted by oil-induced mortality.

1.1 Seafloor compartment

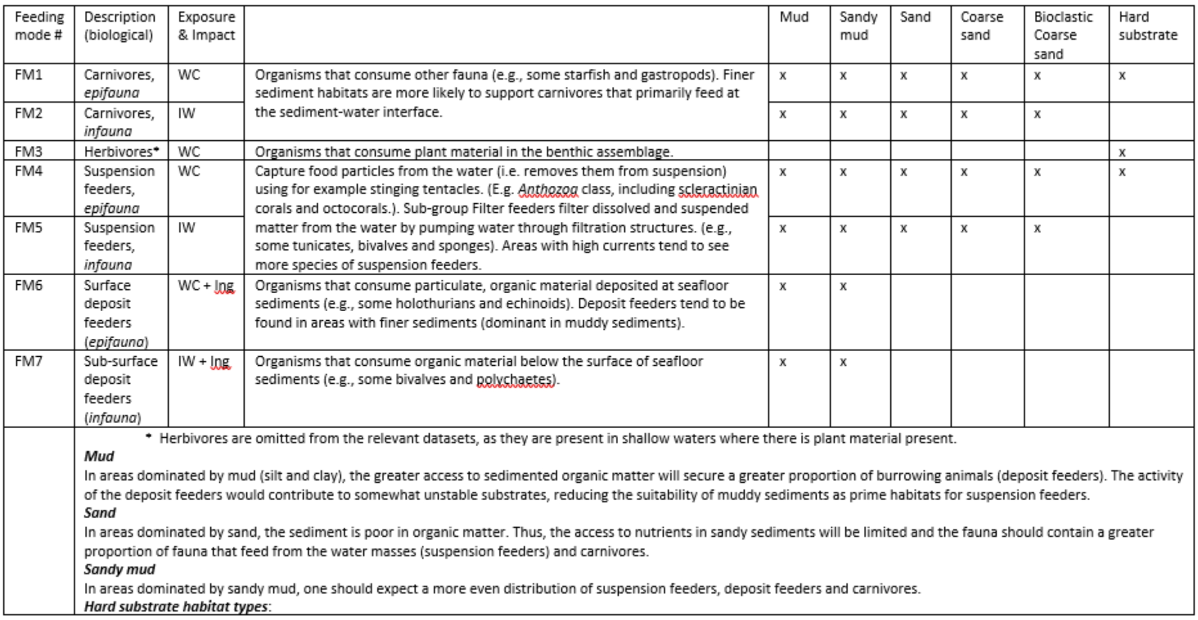
The seafloor is divided into two sub-compartments:

- hard-bottom epifaunal communities exposed through the water column
- soft-bottom infauna and epifauna communities exposed in sediments.

The main impact on sediment infauna is via exposure through interstitial water (IW) or ingestion (Ing), and on epifauna through the water column (WC). The equilibrium partitioning theory (EqP) is used to determine exposure to sediment-dwelling organisms. Seven feeding modes are identified on the basis of biological criteria.

An overview of expected dominant feeding modes per substrate type and primary route of exposure is provided in Table 9.

Table 9. Combination of impact functions based on primary route of exposure for different feeding modes (FM). Presence of expected dominant FMs per substrate habitat type. Organisms with other FMs may be present in substrates.



Feeding mode #	Description (biological)	Exposure & Impact		Mud	Sandy mud	Sand	Coarse sand	Bioclastic Coarse sand	Hard substrate
FM1	Carnivores, *epifauna*	WC	Organisms that consume other fauna (e.g., some starfish and gastropods). Finer sediment habitats are more likely to support carnivores that primarily feed at the sediment-water interface.	x	x	x	x	x	x
FM2	Carnivores, *infauna*	IW		x	x	x	x	x	
FM3	Herbivores*	WC	Organisms that consume plant material in the benthic assemblage.						x
FM4	Suspension feeders, *epifauna*	WC	Capture food particles from the water (i.e. removes them from suspension) using for example stinging tentacles. (E.g. *Anthozoa* class, including scleractinian corals and octocorals.). Sub-group Filter feeders filter dissolved and suspended matter from the water by pumping water through filtration structures. (e.g., some tunicates, bivalves and sponges). Areas with high currents tend to see more species of suspension feeders.	x	x	x	x	x	x
FM5	Suspension feeders, *infauna*	IW		x	x	x	x	x	
FM6	Surface deposit feeders (*epifauna*)	WC + Ing	Organisms that consume particulate, organic material deposited at seafloor sediments (e.g., some holothurians and echinoids). Deposit feeders tend to be found in areas with finer sediments (dominant in muddy sediments).	x	x				
FM7	Sub-surface deposit feeders (*infauna*)	IW + Ing	Organisms that consume organic material below the surface of seafloor sediments (e.g., some bivalves and polychaetes).	x	x				
	• Herbivores are omitted from the relevant datasets, as they are present in shallow waters where there is plant material present. ***Mud*** In areas dominated by mud (silt and clay), the greater access to sedimented organic matter will secure a greater proportion of burrowing animals (deposit feeders). The activity of the deposit feeders would contribute to somewhat unstable substrates, reducing the suitability of muddy sediments as prime habitats for suspension feeders. ***Sand*** In areas dominated by sand, the sediment is poor in organic matter. Thus, the access to nutrients in sandy sediments will be limited and the fauna should contain a greater proportion of fauna that feed from the water masses (suspension feeders) and carnivores. ***Sandy mud*** In areas dominated by sandy mud, one should expect a more even distribution of suspension feeders, deposit feeders and carnivores. ***Hard substrate habitat types***:								

Impact is calculated for each exposure route of the feeding mode, and the impact of the feeding mode (f_m) is the sum of the impacts of each exposure route (water column, interstitial water and ingestion):

$$Imp_{exposure\_route} = plet_{exposure\_route} \times N \times SF$$

$$Imp_{fm} = Imp_{wc} + Imp_{iw} + Imp_{ing}$$

Probability of exposure (P_{exp}) is set to = 1.

With the input of THC in the sediment expressed in kilograms per square metre, ERA Acute first calculates the concentration of THC in the sediment in ppb, using mixing depth, dry density and water content of the soft substrate type:

$$THC_{sed} = 1000.000.000 \times THC_{seafloor} \times \frac{1 - water\_content}{mixing\_depth \times dry\_density}$$

The partitioning of THC between sediment-bound (THC_{sed}) and bioavailable interstitial water (THC_{IW}) is then calculated using inputs of octanol-water coefficients (K_{OW}) and total organic carbon (TOC) to calculate the organic carbon/water partition (*koc*):

$$THC_{iw} = \frac{THC_{sed}}{koc \times toc}$$

The concentration in interstitial water determines exposure to infauna.

For deposit feeders which ingest sediment particles, partitioning between THC_{sed} and exposure in gut water (THC_{Ing}) is determined using calculated bioconcentration factors (BCF) to determine biota-to sediment accumulation factors (BSAF):

$$\log_{10} BSF = 0.85 \times \log_{10}(Kow) - 0.70$$

$$BSAF = \frac{BSF}{koc \times toc}$$

$$\log_{10} koc = 0.00028 + 0.983 \times \log_{10}(Kow)$$

$$THC_{ing} = BSAF \times THC_{iw}$$

A summary of recommended parameter values is presented in Table 10.

Table 10 Summary of recommended standard values for substrates, and VECs assigned to substrates, based on sensitivity testing of ERA Acute functions.

Substrate	**Dry density (kg/m³)**	**Water content (%)**	**TOC (%)**	**BDepth (m)**	**Sensitivity factor for restoration**	**Feeding modes**	**Restitution algorithm**
Bioclastic coarse sand	2650	25	0.4	0.05	0.4	FM1,2,4,5 (data sets for each)	SOFT
Coarse sand	2750	25	0.4	0.05	0.4	FM1,2,4,5 (data sets for each)	SOFT
Sand	2750	30	1	0.02	1	FM1,2,4,5 (data sets for each)	SOFT
Sandy mud	2100	50	1.2	0.01	1.2	FM1,2,4,5,6,7 (data sets for each)	SOFT
Mud	2100	65	2.4	0.005	2.4	FM1,2,4,5,6,7 (data sets for each)	SOFT
Hard substrate	NA	NA	NA	NA	NA	FM1,4 (data sets for each)	HARD
Umbellula	2100	50	1.2	0.01	1.2	FM4+FM5	SOFT
Burrowing (with Umbellula)	2100	50	1.2	0.01	1.2	FM7	SOFT

Sea pens	2100	50	1.2	0.01	1.2	FM4+FM5	SOFT
Burrowing (with sea pens)	2100	50	1.2	0.01	1.2	FM7	SOFT
Demospongia						FM4	HARD
Glass sponges						FM4	HARD
Soft-bottom coral garden	2100	50	1.2	0.01	1.2	FM4 + FM5	SOFT
Hard-bottom coral garden						FM4	HARD

The calculated exposure concentration, THC_{IW} or THC_{ing}, is entered in the same subsea dispersion (SSD) curve used in the water column compartment to determine $plet_{IW}$ and $plet_{ing}$.

For epifauna, such as corals or sponges, THC_{WC} is currently used directly, as in the water column compartment, to determine $plet_{WC}$. Species which ingest sediment particles are exposed both externally ($plet_{IW}$ or $plet_{WC}$) and with added lethality from $plet_{ing}$.

VEC data are prepared either as single-species data or a substrate-based data community with a feeding mode. VECs can be assigned with a combination of feeding modes in a community contributing to the calculation. However, this feature of the model can be used for species which are partially infauna, partially epifauna – such as sea pens. An additive effect of both water column and interstitial water exposure may be ascribed to these by using both modes to define exposure.

Time factors and restoration modelling

In the seafloor compartment, the time factors are included in the impact calculation for each cell and simulation before the results are summarised and statistics presented. Impact time, T_{imp}, is set by default to one year in order to cover an annual cycle. For soft substrates, the lag time, T_{lag}, is set to zero in the current soft substrate implementation, on the assumption that restoration begins in the next reproductive cycle.

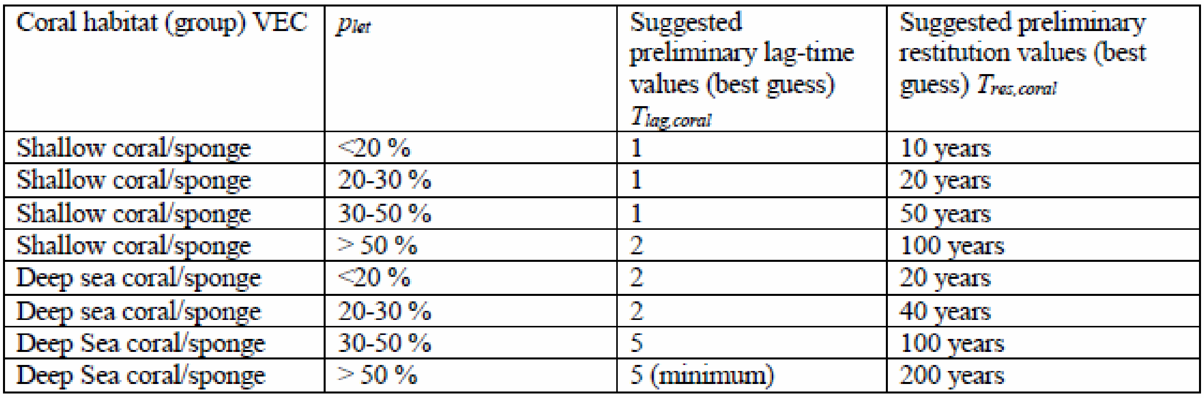
Restoration time, T_{res}, in soft substrates is calculated by a linear relationship implemented between the amount of oil in the sediment (THC_{sed}) above a threshold value ($THC_{threshold}$) of 50 parts per million (ppm) and the expected maximum concentration of THC resulting from sedimentation of oil from an accidental release ($THC_{benchmark\text{-}max}$) currently of 1 000 ppm:

$$t_{rest}[\text{years}] = SF \times 20[\text{years}] \times \frac{\frac{THC_{sed}}{1000}[\text{mg/kg}] - threshold[\text{mg/kg}]}{THC_{max}[\text{mg/kg}]}.$$

Where VECs (substrate communities) with different restoration times than the average value of 20 years found in a literature search are concerned, a restoration time-modifying sensitivity factor (SF) is added to the equation. The current proposal is to calculate the value of this factor as the ratio of the TOC content of the substrate relative to the TOC content of the sand substrate which was found to have a restoration time of 20 years (standard substrate).

With hard-bottom communities, such as corals, a significant number of years may pass before any regrowth is seen. A lag time before restoration commences (t_{lag}) and the restoration time (t_{res}) are given in the form of input tables as functions of the impact magnitude for the coral (Table 11).

Table 11 Lookup-table for lag and restoration times for corals and sponges, based on the lethality level in a cell.



Coral habitat (group) VEC	p_{let}	Suggested preliminary lag-time values (best guess) $T_{lag,coral}$	Suggested preliminary restitution values (best guess) $T_{res,coral}$
Shallow coral/sponge	<20 %	1	10 years
Shallow coral/sponge	20-30 %	1	20 years
Shallow coral/sponge	30-50 %	1	50 years
Shallow coral/sponge	> 50 %	2	100 years
Deep sea coral/sponge	<20 %	2	20 years
Deep sea coral/sponge	20-30 %	2	40 years
Deep Sea coral/sponge	30-50 %	5	100 years
Deep Sea coral/sponge	> 50 %	5 (minimum)	200 years

The RDF for the seafloor compartment is calculated as:

$$RDF = Impact\ x\ (0.5\ x\ t_{imp} + t_{lag} + 0.5\ x\ t_{rest})$$

3 GUIDANCE FOR ENVIRONMENTAL RISK ANALYSIS WITH THE ERA ACUTE METHODOLOGY

The main steps in a full environmental risk analysis with the ERA Acute approach are:

- establish environmental acceptance criteria for the activity
- establish an activity overview for the case to be analysed
- establish defined situations of hazard or accident (DSHAs) and spill scenarios
- decide on the analysis level and resolution
- perform stochastic oil-spill modelling on selected DSHAs and spill scenarios
- prepare VEC data for relevant environmental compartments
- perform ERA Acute calculations at the chosen level of detail
- evaluate the environmental risk against acceptance criteria.

Each of these steps is explained in more detail below.

3.1 Establish environmental acceptance criteria

The risk level should be measured against environmental risk acceptance criteria (eRAC) defined by the maximum likelihood of a certain consequence or damage which is tolerable for the operating company. If eRAC or other environmental decision criteria are used, these should be established before the ERA since they constitute a reference for evaluating the results of the risk assessment.

3.2 Establish an activity description for the case to be analysed

A clear understanding of what is to be analysed in the case must be obtained at an early stage in any risk analysis by establishing an activity description. All activities with a potential for accidental discharges should be identified and the DSHA should be characterised for each activity.

The hierarchy of ERA Acute cases is as follows:

- *Case*: the study to be performed for the activity. A case can consist of one or several DSHAs which the risk is to be included in.
- *DSHA*: can consist of one or several spill scenarios and has a specific definable frequency (such as a blowout, a pipeline leakage or a spill from a floating production, storage and offloading (FPSO) unit) which defines the expected likelihood that it will occur.
- *Scenario*: used in ERA Acute as a specific combination of spill rate and duration which oil drift simulations are carried out for. A scenario has a specific probability. The sum of all probabilities is one (100 per cent) (given that the DSHA occurs). A huge number of oil-spill simulations are run for each scenario.
- *Simulation*: a single run of the oil drift model which provides results for the spill scenario related to a specific start date. A huge number of simulations should be carried out to reflect the range of weather conditions (= stochastic spill modelling).

3.2.1 Installations and field development

Where installations and field developments are concerned, a realistic overview should be obtained of the planned or anticipated level of activity during the producing life of the installation or field. As a minimum, this must be secured for three to five years ahead. The overview must specify the number of different hazardous operations per year during the period. This also means that the ERA should be updated every three-five years in relation to the level of activity at the relevant time and if the level of activity changes (increases) from that which formed the basis for the analysis, as stipulated in the HSE regulations. Updating the ERA will also be relevant if new knowledge, model updates or significant newer data are available.

An activity plan for the installation specifies the distribution of activities over time, both for the year and for the producing life of the installation. In this context, it is important that operations conducted in connection with the operation of the installation, such as well workovers, wireline and so forth, are described specifically in terms of the period when the activity will take place. The ERA can then reflect seasonal variations in environmental risk, and possibly provide input on how the activity plan could be amended to reduce environmental risk. Environmental risk for installations can be analysed for the year with the highest level of activity. This assumes that an environmental risk considered acceptable at a high level of activity will also be so at a lower activity level.

3.2.2 All activities

Environmental risk is described and analysed per operation for exploration drilling and per year for production, drilling and well operations on producing oil fields. Acceptance criteria must be tailored to that. Defined categories of drilling and well activities in which a DSHA needs to be specified could be:

- exploration drilling
- development drilling
- well completions
- well workovers
- wireline operations
- coiled tubing operations
- snubbing operations
- oil production wells
- wells for gas production or gas/water injection (if potential for oil outflow).

The DSHAs could include:

- blowouts (topside and subsea)
- riser leaks
- process leaks

- pipeline leaks
- pipeline breaks
- leaks from storage tanks
- leaks from subsea templates
- leaks in connection with loading and discharging operations
- tanker accidents.

3.3 Establish DSHAs and spill scenarios

When all hazardous events have been identified, an assessment should be made to select those to be taken forward in the ERA and to define the oil-spill scenarios to be modelled. These scenarios are analysed through oil-spill modelling and determining potential consequences, which are combined with their likelihood to establish the risk.

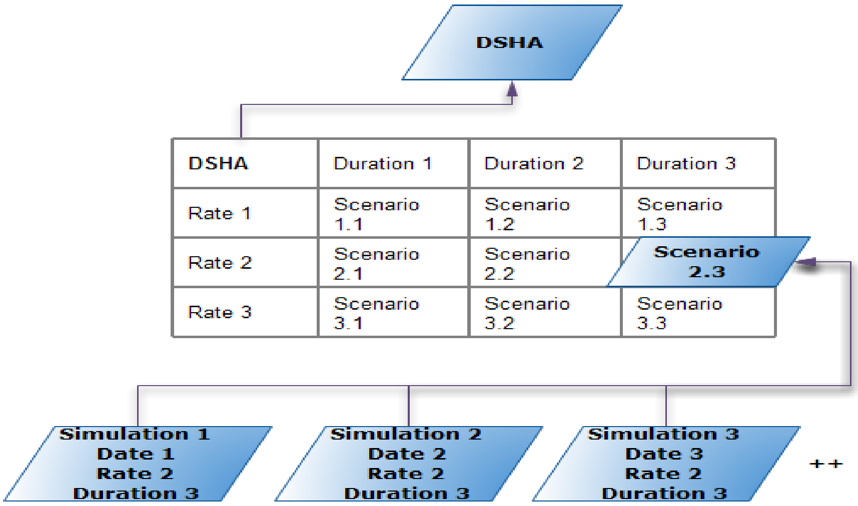
The identified hazardous events may be considered for further analysis and, as a minimum, all events which potentially represent a significant contribution to the risk should be considered (Figure 4). The likelihood of an event, and the potential quantity of discharged hydrocarbons, are two of the main parameters contributing to the risk of an event. Hazardous events with a higher likelihood and higher potential quantity of discharged hydrocarbons (in other words, combination of flow rate and duration) have a higher risk potential for the same release location and the same hydrocarbon type. Nevertheless, hazardous events which have a low likelihood but which may have a high consequence should also be selected.

In order to establish blowout spill scenarios, information is required on reservoir, well design and drilling conditions. Available data on reservoir and well conditions will vary in relation to knowledge about the field and reservoir. Probability calculations for scenarios with potential environmental consequences are performed with the aid of experience databases and information about the relevant concept and activities to be included in the analysis. Note that information on the probability of incidents should be derived from the technical risk analysis, and that a close integration exists between the various risk analyses conducted. A number of data sources can be utilised for calculating frequencies. These include:

- the Sintef offshore blowout database (OBDB)
- Lloyd’s Register blowout and well release frequencies (based on the Sintef OBDB)
- DNV GL’s worldwide offshore accident databank (Woad).

The spill frequency must consider high pressure and temperature (HPHT) wells, type of liquid (oil, condensate) and so forth, and can be adjusted for local conditions on the basis of a well-specific risk assessment which takes account of rig and well control equipment, drilling-crew training and experience, geology and reservoir knowledge (permeability, pressure margins and number of reservoirs), and operational aspects such as well design and trips.

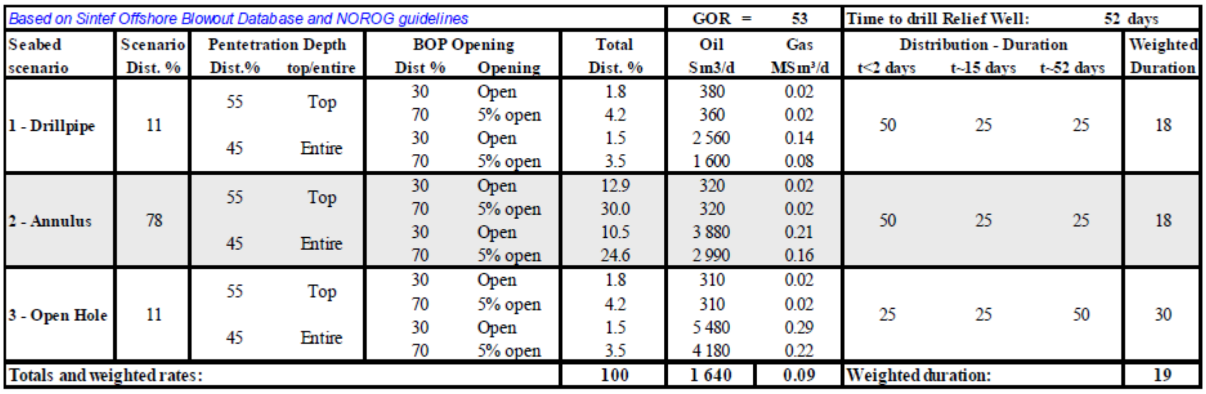
A DSHA will typically consist of many spill scenarios – in other words, many combinations of spill rate and duration – and the probability distribution between these must be specified in addition to the overall DSHA frequency. An illustration of a blowout DSHA is presented in Figure 3 with a total of nine spill scenarios (matrix of three different spill rates and three spill durations).



DSHA	Duration 1	Duration 2	Duration 3
Rate 1	Scenario 1.1	Scenario 1.2	Scenario 1.3
Rate 2	Scenario 2.1	Scenario 2.2	Scenario 2.3
Rate 3	Scenario 3.1	Scenario 3.2	Scenario 3.3

Figure 3 Illustration of a DSHA consisting of several spill scenarios, each represented by many spill simulations.

Table 12 shows an example of a subsea blowout DSHA with a rate/duration matrix featuring a probability distribution. An example of a case setup in the ERA Acute tool with different DSHAs is presented in Figure 4



Based on Sintef Offshore Blowout Database and NOROG guidelines							GOR =	53	Time to drill Relief Well:		52 days	
Seabed scenario	Scenario Dist. %	Pentetration Depth		BOP Opening		Total Dist. %	Oil	Gas	Distribution - Duration			Weighted Duration
		Dist.%	top/entire	Dist %	Opening		Sm3/d	MSm³/d	t<2 days	t~15 days	t~52 days	
1 - Drillpipe	11	55	Top	30	Open	1.8	380	0.02	50	25	25	18
				70	5% open	4.2	360	0.02				
		45	Entire	30	Open	1.5	2 560	0.14				
				70	5% open	3.5	1 600	0.08				
2 - Annulus	78	55	Top	30	Open	12.9	320	0.02	50	25	25	18
				70	5% open	30.0	320	0.02				
		45	Entire	30	Open	10.5	3 880	0.21				
				70	5% open	24.6	2 990	0.16				
3 - Open Hole	11	55	Top	30	Open	1.8	310	0.02	25	25	50	30
				70	5% open	4.2	310	0.02				
		45	Entire	30	Open	1.5	5 480	0.29				
				70	5% open	3.5	4 180	0.22				
Totals and weighted rates:						100	1 640	0.09	Weighted duration:			19

Table 12 Example of a DSHA matrix for a subsea blowout with 36 spill scenarios (12 spill rates and three spill durations), each with their individual probabilities adding up to 100 per cent.

DSHA	FREQUENCY	TOP/SUB	TOP/ SUB PROB.	RATE (vol.)	RATE PROB.	DURA TION DAYS	DURA TION PROB.
Production	5.89E-004	Topside	100%	3508	50%	5	18.7%
Production	5.89E-004	Topside	100%	1774	50%	15	17.3%
Production	5.89E-004	Topside	100%	3508	50%	15	17.3%
Production	5.89E-004	Topside	100%	1774	50%	35	6%
Production	5.89E-004	Topside	100%	3508	50%	35	6%
Production	5.89E-004	Topside	100%	1774	50%	52	6%
Production	5.89E-004	Topside	100%	3508	50%	52	6%
Process	3.40E-003	Topside	100%	25	100%	0.04	100%
Riser	4.90E-004	Topside	100%	119	100%	0.01	100%
Pipeline	4.08E-004	Subsea	100%	516	79%	0	100%
Pipeline	4.08E-004	Subsea	100%	1547	5%	0	100%
Pipeline	4.08E-004	Subsea	100%	5361	16%	0	100%

Figure 4 Example of a case setup in the ERA Acute software tool with different DSHAs (topside blowout scenarios from production in addition to a process leakage, a riser leakage and three different pipeline leakage scenarios).

3.4 Establish the analysis resolution

As part of the ERA Acute work, available open VEC data have been prepared for use at the highest level of detail (level B analysis). Even though such data are available for the NCS, the scope and objective of the analysis might mean that it is sufficient to perform the analysis at level A and present areas where the oil spill might have an effect in each compartment. Such results could also be used for high-level risk quantification in a risk matrix.

Given that the objective is to measure the risk against eRAC, a full level-B assessment should be carried out. This will give a quantification of damage at a species and habitat level, and will provide probabilities and frequencies for the various environmental damage categories.

3.5 Oil-spill modelling

ERA Acute uses oil-spill simulations for each scenario (rate and duration combination) separately.

A separate best-practice document for oil-spill modelling to be used with ERA Acute has been established by Norwegian Oil and Gas and should form the basis for oil-spill modelling if Oscar is used as the spill model. Stochastic oil-spill modelling must be performed with numerous spill simulations for each spill scenario (rate and duration combination) on the basis of historical wind and current data (typically 10 years). The following information is vital as input to the modelling of selected oil-spill scenarios:

- spill location (latitude/longitude) and topside or subsea (water depth)
- oil type and density (or closest reference oil for modelling purposes)
- spill frequency
- spill rates and durations (with probability) including time to drill relief well
- Gas-oil ratio (GOR) and spill diameter (open or restricted scenario) for subsea spill scenarios.

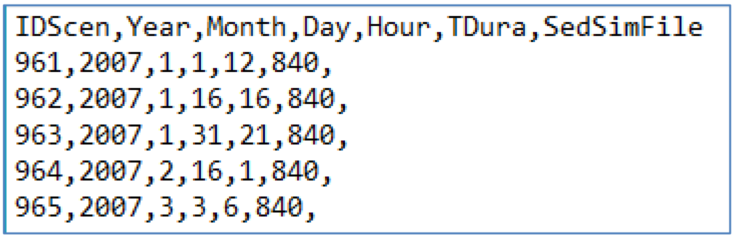
Results from the spill modelling must be reported in a standard universal transverse Mercator (UTM) grid in correspondence with the VEC distribution data (typically 10x10 kilometres, although ERA Acute allows for a higher resolution if the data permit and if this is appropriate for the study). As a rule of thumb, the oil drift model should be at a higher spatial resolution than the output from the model, which must match the grid used for VEC data.

The following oil drift result files must be available for further processing in ERA Acute.

1. Oil-spill simulation file

   The simulation file has columns IDScen, Year, Month, Day, Hour and TDura (scenario duration). In order to be used with the ERA Acute software, it needs to be extended with a further column (SedSimFile) which refers to the file with the sediment simulation results for the relevant simulation.

   An example of a simulation file:

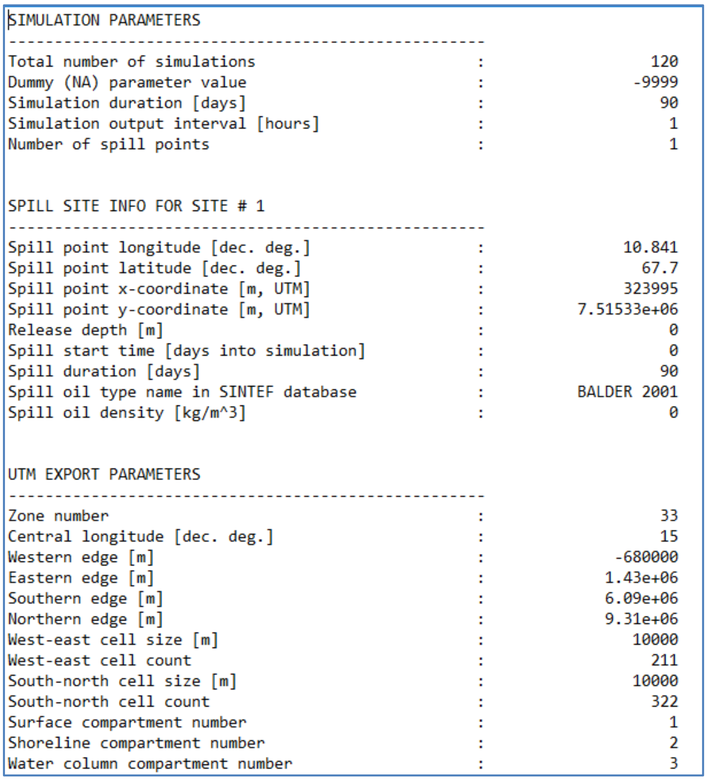


```
IDScen,Year,Month,Day,Hour,TDura,SedSimFile
961,2007,1,1,12,840,
962,2007,1,16,16,840,
963,2007,1,31,21,840,
964,2007,2,16,1,840,
965,2007,3,3,6,840,
```

2. UTM summary file

   The summary file contains information about the simulation parameters, spill site and UTM grid export parameters.

   An example of a UTM summary file:



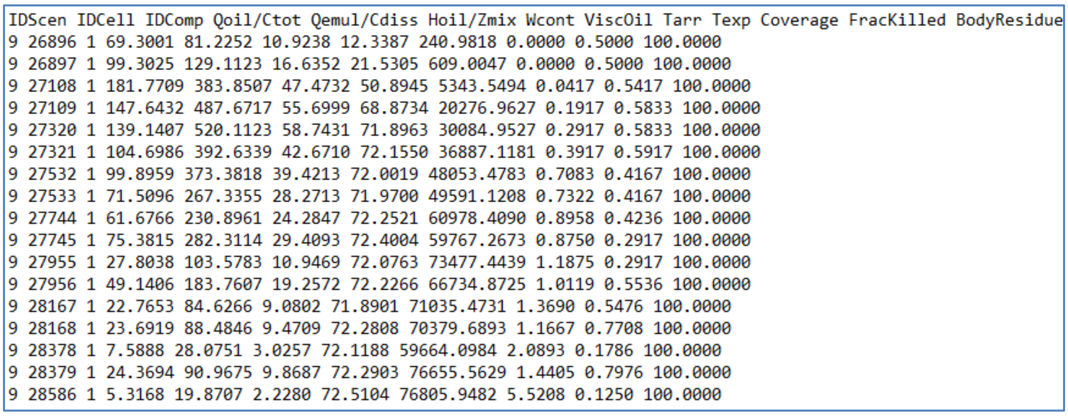
```
SIMULATION PARAMETERS
----------------------------------------------------
Total number of simulations                        :            120
Dummy (NA) parameter value                         :          -9999
Simulation duration [days]                         :             90
Simulation output interval [hours]                 :              1
Number of spill points                             :              1


SPILL SITE INFO FOR SITE # 1
----------------------------------------------------
Spill point longitude [dec. deg.]                  :         10.841
Spill point latitude [dec. deg.]                   :           67.7
Spill point x-coordinate [m, UTM]                  :         323995
Spill point y-coordinate [m, UTM]                  :    7.51533e+06
Release depth [m]                                  :              0
Spill start time [days into simulation]            :              0
Spill duration [days]                              :             90
Spill oil type name in SINTEF database             :    BALDER 2001
Spill oil density [kg/m^3]                         :              0


UTM EXPORT PARAMETERS
----------------------------------------------------
Zone number                                        :             33
Central longitude [dec. deg.]                      :             15
Western edge [m]                                   :        -680000
Eastern edge [m]                                   :       1.43e+06
Southern edge [m]                                  :       6.09e+06
Northern edge [m]                                  :       9.31e+06
West-east cell size [m]                            :          10000
West-east cell count                               :            211
South-north cell size [m]                          :          10000
South-north cell count                             :            322
Surface compartment number                         :              1
Shoreline compartment number                       :              2
Water column compartment number                    :              3
```

3. UTM grid file

The UTM grid file keeps all the results from all simulations and contains the following information:

Column	Description
IdScen	Simulation number
IdCell	Grid cell ID
IdComp	Compartment ID (1 = surface, 2 = shoreline, 3 = water column)
Qoil/Ctot	IDComp = 1 Qoil (time averaged oil in grid cell) IDComp = 2 Qoil (accumulated oil mass in shoreline grid cell) IDComp = 3 Ctot (max time averaged THC)
Qemul/CDiss	IDComp = 1 Qoil (time averaged oil emulsion in grid cell) IDComp = 2 Qoil (accumulated oil emulsion mass in shoreline grid cell) IDComp = 3 Ctot (max time averaged dissolved oil concentration)
Hoil/Zmix	IDComp = 1 Hoil (time-averaged average film thickness in grid cell) IDComp = 3 Zmix (average mixing depth)
Wcont	Water content in emulsion (%)
ViscOil	Viscosity in grid cell
Tarr	
Texp	IDComp = 1 (exposure time of oil above film thickness in grid cell) IDComp = 3 (exposure time of oil in water column)
Coverage	IDComp = 1 (percentage of grid cell covered by oil above thickness)
FracKilled	IDComp = 3 Oscar-specific (QSAR mortality in grid cell)
BodyResidue	IDComp = 3 Oscar-specific (body residue in grid cell)

An example of a UTM grid file:



```
IDScen IDCell IDComp Qoil/Ctot Qemul/Cdiss Hoil/Zmix Wcont ViscOil Tarr Texp Coverage FracKilled BodyResidue
9 26896 1 69.3001 81.2252 10.9238 12.3387 240.9818 0.0000 0.5000 100.0000
9 26897 1 99.3025 129.1123 16.6352 21.5305 609.0047 0.0000 0.5000 100.0000
9 27108 1 181.7709 383.8507 47.4732 50.8945 5343.5494 0.0417 0.5417 100.0000
9 27109 1 147.6432 487.6717 55.6999 68.8734 20276.9627 0.1917 0.5833 100.0000
9 27320 1 139.1407 520.1123 58.7431 71.8963 30084.9527 0.2917 0.5833 100.0000
9 27321 1 104.6986 392.6339 42.6710 72.1550 36887.1181 0.3917 0.5917 100.0000
9 27532 1 99.8959 373.3818 39.4213 72.0019 48053.4783 0.7083 0.4167 100.0000
9 27533 1 71.5096 267.3355 28.2713 71.9700 49591.1208 0.7322 0.4167 100.0000
9 27744 1 61.6766 230.8961 24.2847 72.2521 60978.4090 0.8958 0.4236 100.0000
9 27745 1 75.3815 282.3114 29.4093 72.4004 59767.2673 0.8750 0.2917 100.0000
9 27955 1 27.8038 103.5783 10.9469 72.0763 73477.4439 1.1875 0.2917 100.0000
9 27956 1 49.1406 183.7607 19.2572 72.2266 66734.8725 1.0119 0.5536 100.0000
9 28167 1 22.7653 84.6266 9.0802 71.8901 71035.4731 1.3690 0.5476 100.0000
9 28168 1 23.6919 88.4846 9.4709 72.2808 70379.6893 1.1667 0.7708 100.0000
9 28378 1 7.5888 28.0751 3.0257 72.1188 59664.0984 2.0893 0.1786 100.0000
9 28379 1 24.3694 90.9675 9.8687 72.2903 76655.5629 1.4405 0.7976 100.0000
9 28586 1 5.3168 19.8707 2.2280 72.5104 76805.9482 5.5208 0.1250 100.0000
```

3.6 VEC data preparation

Many natural resources can be present in an analysis area. Even with a relatively stringent choice of these in accordance with the selection criteria specified for VECs, a large number of such components may be identified. As a result, a limited number of the relevant VECs will be selected for analysis on the basis of a prioritisation. As a minimum, the resource(s) assumed to make the biggest contribution to environmental risk must be represented.

Based on the general definition of a VEC, a fixed set of prioritisation criteria is utilised in the risk assessment to limit the set of components used in the analysis:

- the VEC population must be present for a large part of the year or the relevant season
- the VEC must be vulnerable to oil pollution (year-round or in the relevant season)
- the VEC population must be abundant in the influence area
- the VEC habitat must have a high probability of exposure to oil pollution.

In addition to the species with the greatest likelihood of suffering the greatest impact in the calculations, red-list species found in the area of influence should be considered for inclusion as VECs, since it is important to address these.

Environmental resource data for the various VECs must be prepared on the same UTM grid as the output from the oil-spill modelling.

For risk-screening purposes (level A2, section 3.7), the VEC data should be prepared with presence/no presence {0,1} in each grid cell. For a full risk assessment (level A3, section 3.8), relevant VEC data should be prepared on the UTM grid with monthly values of N according to the specifications for each environmental compartment and VEC type, as follows:

- sea surface: resource distribution data (population share) in each grid cell {0,1}

- water column: fish egg/larvae distribution (pop share) in each grid cell {0,1}
- shoreline: kilometres of each ESI ranking in each grid cell plus tidal range (kilometres)
- seafloor: resource distribution data (pop share) in each grid cell/habitat boundary {0,1}.

ID	Wildlife_group	Species_name	Population_name	Sjan	Sfeb	Smar	Sapr	Smay	Sjun	Sjul	Saug	Ssep	Soct	Snov	Sdec
17578	Pelagic diving seabird	Puffin	NW Atlantic PuffinAH	0.001706	0.001706	0.001706	0.000547	0.000547	0.000547	0.000547	2.80E-06	2.80E-06	2.80E-06	0.001706	0.001706
17579	Pelagic diving seabird	Puffin	NW Atlantic PuffinAH	0.001996	0.001996	0.001996	0.000707	0.000707	0.000707	0.000707	3.00E-06	3.00E-06	3.00E-06	0.001996	0.001996
17785	Pelagic diving seabird	Puffin	NW Atlantic PuffinAH	0.000478	0.000478	0.000478	6.81E-05	6.81E-05	6.81E-05	6.81E-05	1.97E-06	1.97E-06	1.97E-06	0.000478	0.000478
17786	Pelagic diving seabird	Puffin	NW Atlantic PuffinAH	0.00068	0.00068	0.00068	0.000103	0.000103	0.000103	0.000103	2.03E-06	2.03E-06	2.03E-06	0.00068	0.00068
17787	Pelagic diving seabird	Puffin	NW Atlantic PuffinAH	0.000894	0.000894	0.000894	0.000127	0.000127	0.000127	0.000127	2.14E-06	2.14E-06	2.14E-06	0.000894	0.000894
17788	Pelagic diving seabird	Puffin	NW Atlantic PuffinAH	0.001161	0.001161	0.001161	0.000165	0.000165	0.000165	0.000165	2.32E-06	2.32E-06	2.32E-06	0.001161	0.001161
17789	Pelagic diving seabird	Puffin	NW Atlantic PuffinAH	0.001586	0.001586	0.001586	0.000267	0.000267	0.000267	0.000267	2.63E-06	2.63E-06	2.63E-06	0.001586	0.001586
17790	Pelagic diving seabird	Puffin	NW Atlantic PuffinAH	0.00213	0.00213	0.00213	0.000536	0.000536	0.000536	0.000536	3.26E-06	3.26E-06	3.26E-06	0.00213	0.00213
17993	Pelagic diving seabird	Puffin	NW Atlantic PuffinAH	0.000135	0.000135	0.000135	1.94E-05	1.94E-05	1.94E-05	1.94E-05	3.44E-06	3.44E-06	3.44E-06	0.000135	0.000135
17994	Pelagic diving seabird	Puffin	NW Atlantic PuffinAH	0.000206	0.000206	0.000206	2.77E-05	2.77E-05	2.77E-05	2.77E-05	2.54E-06	2.54E-06	2.54E-06	0.000206	0.000206
17995	Pelagic diving seabird	Puffin	NW Atlantic PuffinAH	0.000308	0.000308	0.000308	4.01E-05	4.01E-05	4.01E-05	4.01E-05	2.17E-06	2.17E-06	2.17E-06	0.000308	0.000308
17996	Pelagic diving seabird	Puffin	NW Atlantic PuffinAH	0.00046	0.00046	0.00046	6.17E-05	6.17E-05	6.17E-05	6.17E-05	2.09E-06	2.09E-06	2.09E-06	0.00046	0.00046
17997	Pelagic diving seabird	Puffin	NW Atlantic PuffinAH	0.000648	0.000648	0.000648	8.60E-05	8.60E-05	8.60E-05	8.60E-05	2.10E-06	2.10E-06	2.10E-06	0.000648	0.000648
17998	Pelagic diving seabird	Puffin	NW Atlantic PuffinAH	0.00087	0.00087	0.00087	0.000111	0.000111	0.000111	0.000111	2.16E-06	2.16E-06	2.16E-06	0.00087	0.00087

Figure 5 Example of a VEC data set prepared for full risk assessment with monthly values on population share in each grid cell.

> The actual preparation of VEC data could be very time-consuming, and the definition of the VEC boundaries (population or habitat, local, regional or national) has a big impact on the result since ERA Acute will calculate results on the basis of the user-defined boundary (impact related to definition) – in other words, loss of regional population, loss in specific area and so forth.

Boundaries would typically be case-specific and could be related to total population, regional population, time-specific population or area-specific population or habitat. The VEC boundaries should be thoroughly evaluated before preparing VEC data, and the choice of population (restoration) model should relate to the VEC boundary definition.

It is strongly recommended that users of ERA Acute for a specific geographical area apply the same boundaries and definitions in order to make comparison and interpretation of results easier.

Recommended values for parameters in the sea surface compartment are given in appendix A

3.7 Levels A1 and A2: perform environmental impact screening

3.7.1 Necessary input data

- Results from stochastic oil-spill simulations (see section 3.4).
- Frequency for each DSHA and probability split between scenarios in a DSHA.
- Either no VEC data (level A1) or VEC data with presence/no presence (level A2) in grid cells.

3.7.2 Impact calculation

- Calculate the impact for each grid cell from each simulation in accordance with the compartment-specific algorithms in chapter 2. An oil-spill simulation is valid for the months it covers. If one starts on 15 May and involves a spill duration of 20 days plus 15 days of subsequent observation, the simulation is valid for 35 days from the starting date – in other words, for May and June.
- Aggregate monthly results with average and maximum number of cells impacted. The aggregation must be confined to valid months and grid cells.
- Aggregate monthly results with maps of average, maximum and minimum mortality in each grid cell (from all simulations in the month). The aggregation must be confined to valid months and grid cells.

3.7.3 Results

Results from a level-A screening are restricted to showing impact areas on maps and inspecting the cells impacted. The screening level will indicate where to expect an impact, the magnitude of the impact in different areas, and how this will change over the year.

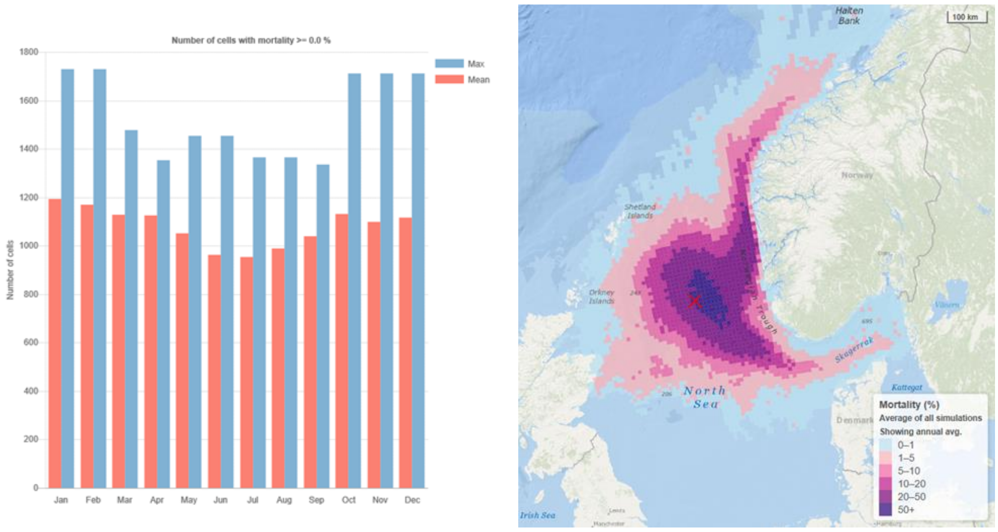


Figure 6 Example of a presentation of monthly impact (number of grid cells with an impact above a certain threshold value) on the left and average impact (mortality) in each grid cell on the right.

Where level A2 is concerned, the impact area will be restricted to where the species are present at different times of the year and is illustrated in Figure 7.

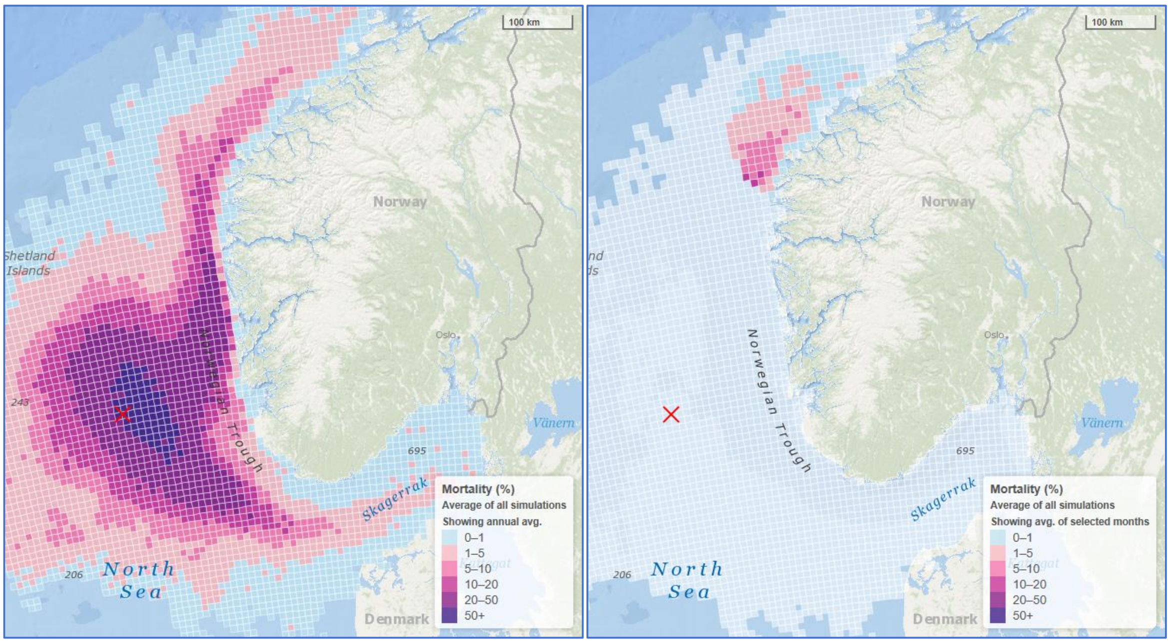


Figure 7 Example of presentation of average impact (mortality) for a seabird to the left (level A1), and restricted to where the species is present in the breeding season to the right (level A2).

3.8 Level B: perform damage-based analysis

3.8.1 Necessary input data

- Results from stochastic oil-spill simulations as specified in section 3.4
  - simulation results with a thickness threshold of two µm for seabirds
  - simulation results with thickness threshold 10 µm for marine mammals. For conservative calculations, the two µm results could also be used for marine mammals
  - simulation results without threshold values for the shoreline compartment. Simulations with a two µm threshold could also be used to save modelling time
  - oil drift should include the QSAR method for the water column
  - simulation results from single simulations in NetCDF format for shoreline (if applicable).
- VEC data (level A3) with distribution in grid cells as specified in section 3.6
  - where the sea surface compartment is concerned, calculations also include shoreline habitat files containing relevant shoreline cells which provide the lag time to be utilised
- VEC data parameters (see appendix A for recommended values)
  - sea surface compartment
    - for each VEC data set, specify the species sensitivity factor, growth rate, density factor and recovery threshold level (TRL)
  - shoreline compartment

        - no additional parameters needed. Tidal range should be given in the VEC data for each grid cell
    - water column compartment
        - for each VEC dataset, specify whether the species is long-lived or not and give the critical mortality for the spawning population
    - seafloor compartment (on hold, further VEC data need to be established).

3.8.2 Results

The outcome of the calculations will be the various endpoints of impact, restitution and RDF for each VEC in each compartment. Results can be aggregated to scenario, DSHA and case levels.

Impact in terms of population loss, larval loss or kilometres of shoreline impact should be presented with probabilities for various impact categories classified in accordance with Table 13. See the example in Figure 8 for a seabird and in Figure 9 for shoreline (sum of all ESI impacts).

Table 13 Suggested impact categories for presentation of ERA Acute results.

	Impact categories						
VEC	Cat 1	Cat 2	Cat 3	Cat 4	Cat 5	Cat 6	Cat 7
Seabirds, marine mammals (pop loss)	< 1%	1–5%	5–10%	10-20%	20-30%	30-50%	50-100%
Fish larvae (larval loss)	< 1%	1–5%	5–10%	10-20%	20-30%	30-50%	50-100%
Shoreline. Invertebrates (ESI 1-10)	0-1 km	1-50 km	50-250 km	250-500 km	500-1 000 km	1 000-2 000 km	>2 000 km
Shoreline. Flora (ESI 8-10)	0-1 km	1-30 km	30-150 km	150-300 km	300-600 km	600-1 200 km	> 1 200 km

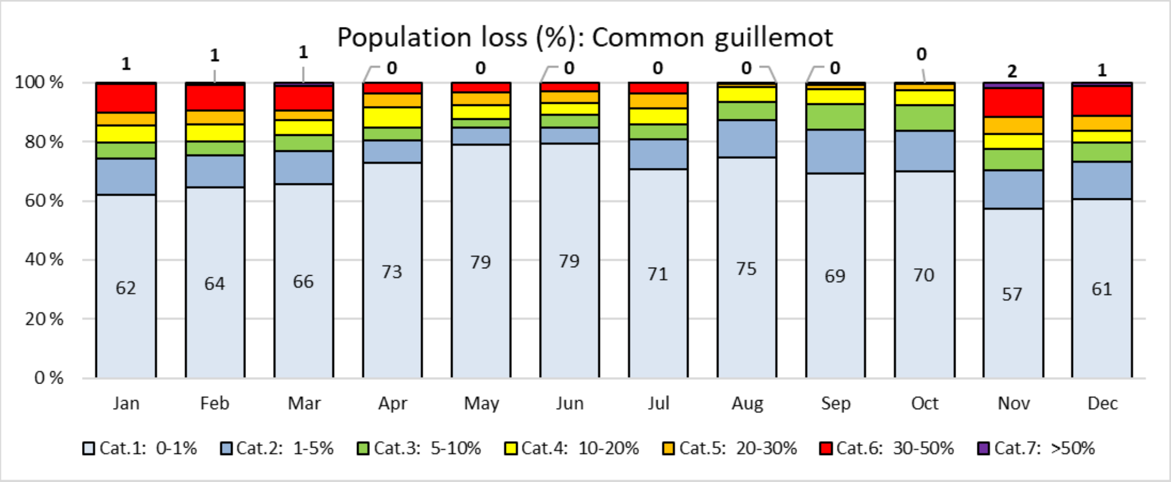


Figure 8 Example of probability for population loss in six predefined impact categories for a pelagic seabird.

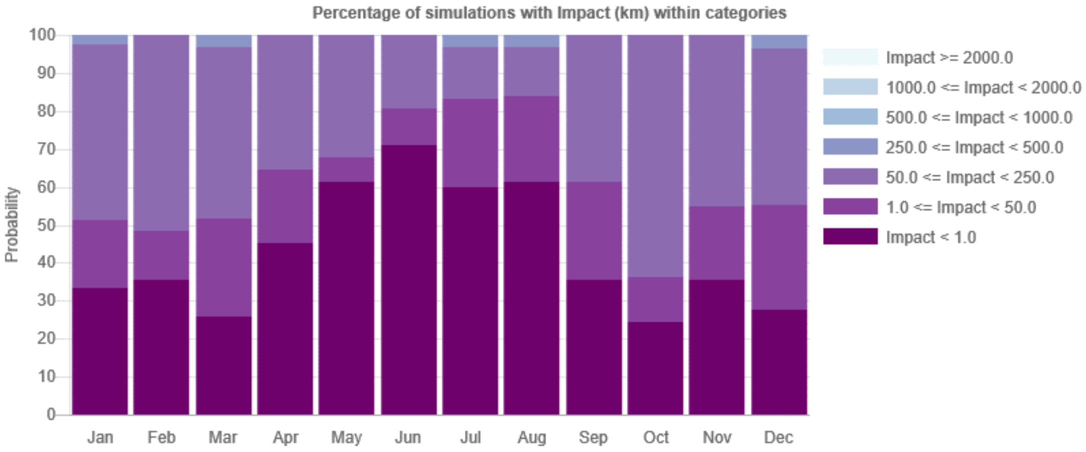


Figure 9 Example of impact probability in six predefined impact categories for shoreline fauna (sum of all ESI rankings).

Shoreline impact should also be presented with average impact per ESI shoreline ranking, as exemplified in Figure 10.

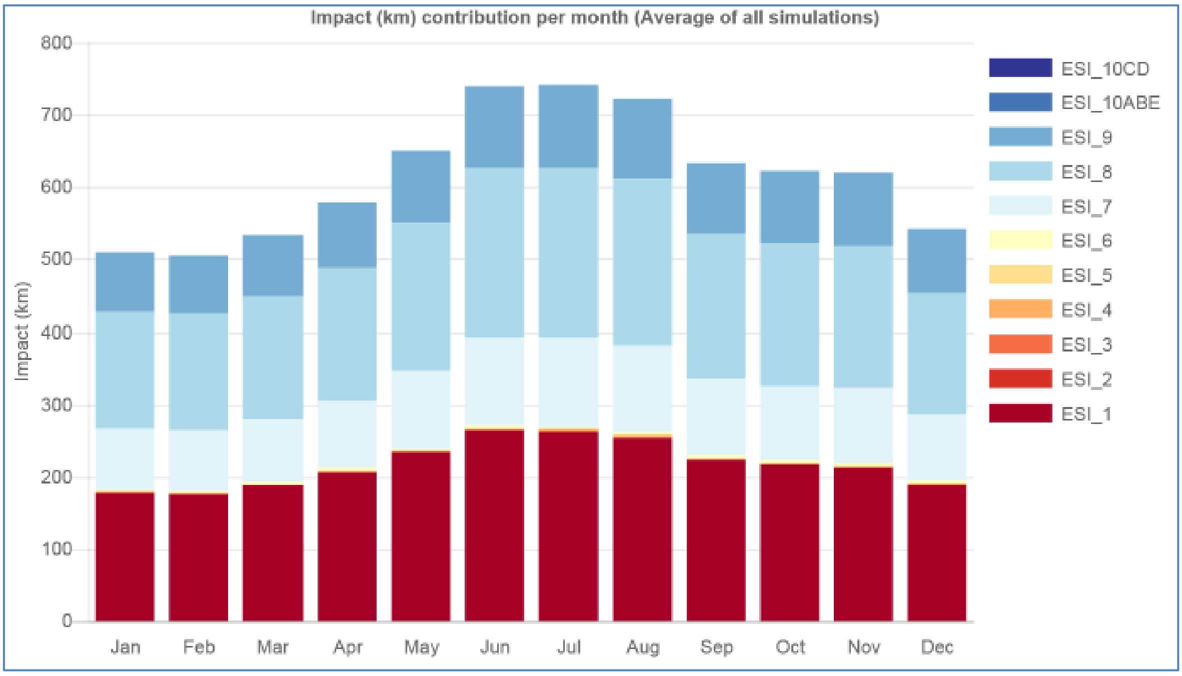


Figure 10 Example of presentation of average impact per ESI shoreline ranking for shoreline fauna.

Where the species or habitats experiencing the greatest impact is concerned, presenting the average impact area on a map for various seasons will be relevant. See the examples in Figure 11.

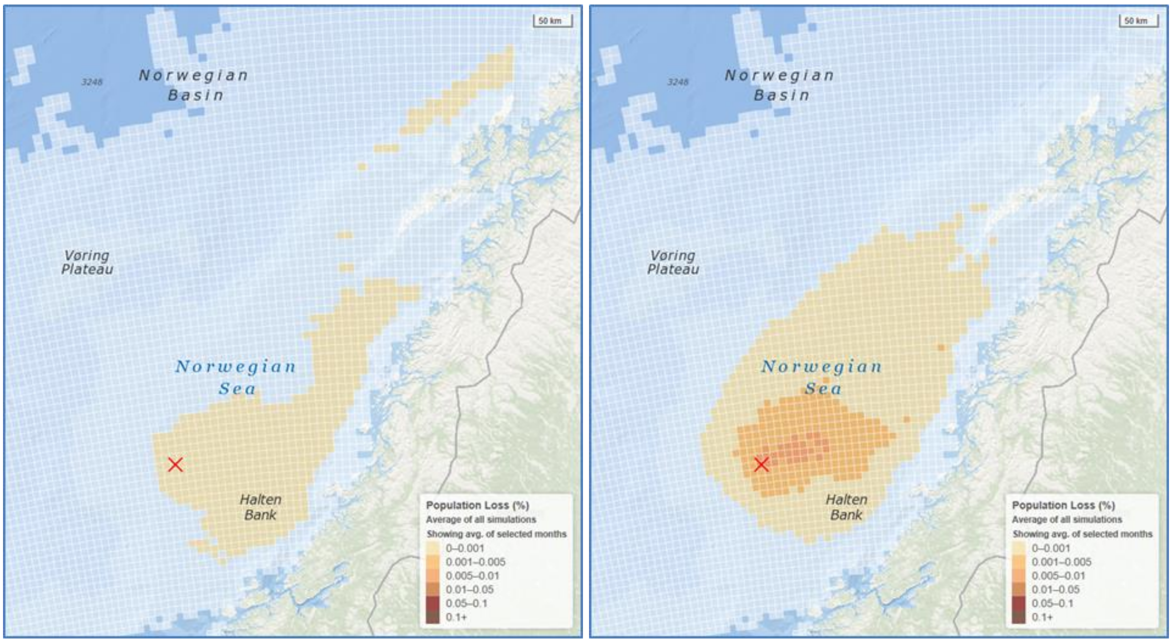


Figure 11 Example of the presentation of average impact for a seabird species in the winter (left) and autumn (right) seasons.

With the shoreline, showing both the average impact per grid cell and the 95 percentile worst-case impact will be relevant for oil-spill contingency planning (see Figure 12).

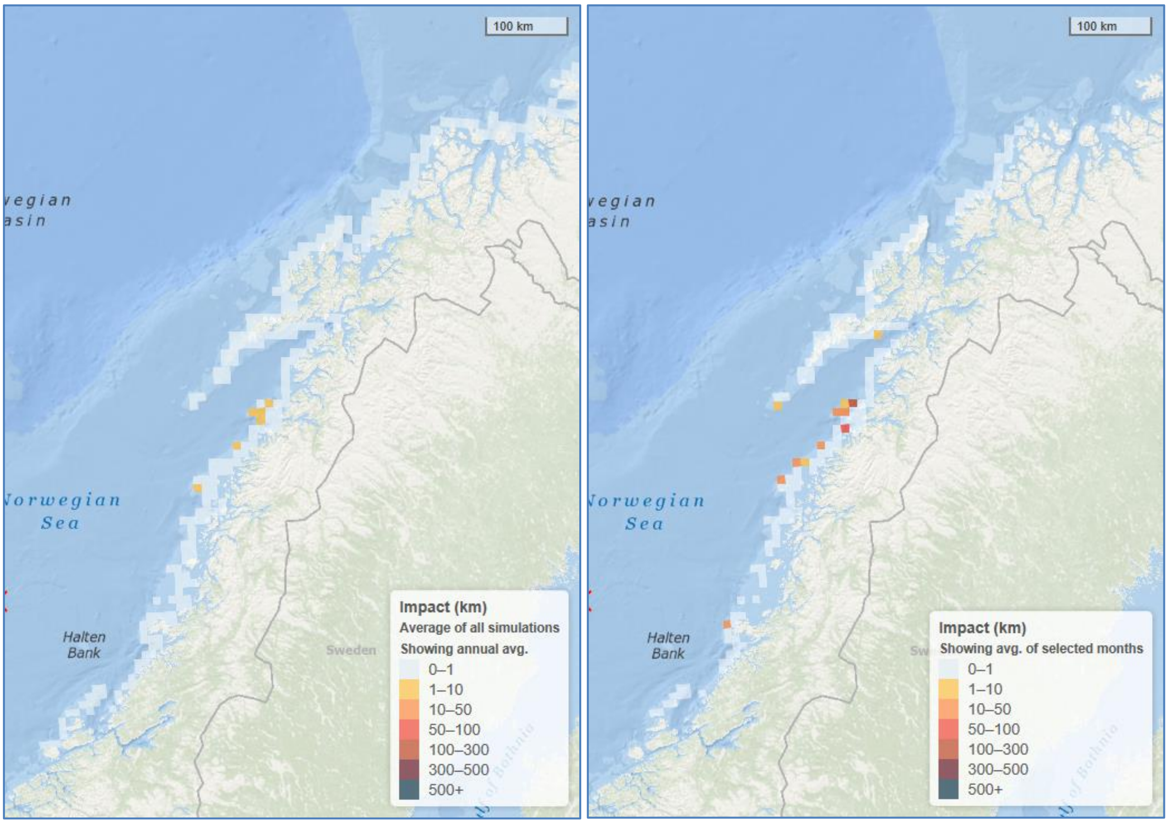


Figure 12 Example of presentation of average impact for the shoreline flora (left) and the 95 percentile worst case impact (right).

Where the sea surface and water column compartments are concerned, total recovery time for the population should also be presented and follow the categorisation given in Table 14. Optionally, categories 4-7 could be merged into a category with recovery times of more than 10 years. See an example of the result in Figure 13.

Table 14 Suggested recovery categories for presentation of ERA Acute results.

VEC	**Recovery time categories**						
	Cat 1	**Cat 2**	**Cat 3**	**Cat 4**	**Cat 5**	**Cat 6**	**Cat 7**
Seabirds, marine mammals, fish	<1 year	1-5 years	5-10 years	10-20 years	20-30 years	30-40 years	>40 years
Shoreline	<1 year	1-3 years	3-5 years	5-7 years	7-9 years	9-11 years	>11 years

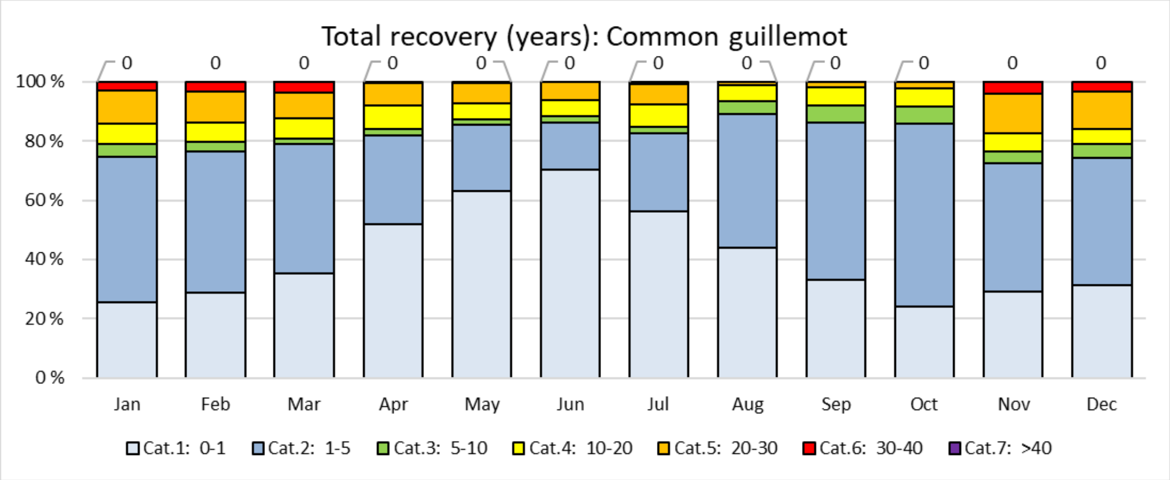


Figure 13 Example of presentation of probability for different recovery times for a seabird species.

The environmental damage given by the RDF should be categorised in accordance with the level of seriousness on the basis of the RDF classification given in Table 15. See the example of a presentation of results in Figure 14.

Table 15 Suggested damage categorisation based on RDF values for presentation and evaluation of ERA Acute results.

RDF categories							
VEC	None/ insignificant	Minor (low)	Moderate	Major	Severe/ serious	Very severe/ serious	Extreme (disastrous)
Seabirds, marine mammals, fish (population loss years)	<10	10-50	50-100	100-200	200-400	400-800	>800
Shoreline. Invertebrates (km-y)	<10	10-350	350-2 000	2 000-4 000	4 000-8 000	8 000-16 000	>16 000
Shoreline. Flora (km-y)	<5	5-150	150-750	750-1 500	1 500-3 000	3 000-6 000	>6 000

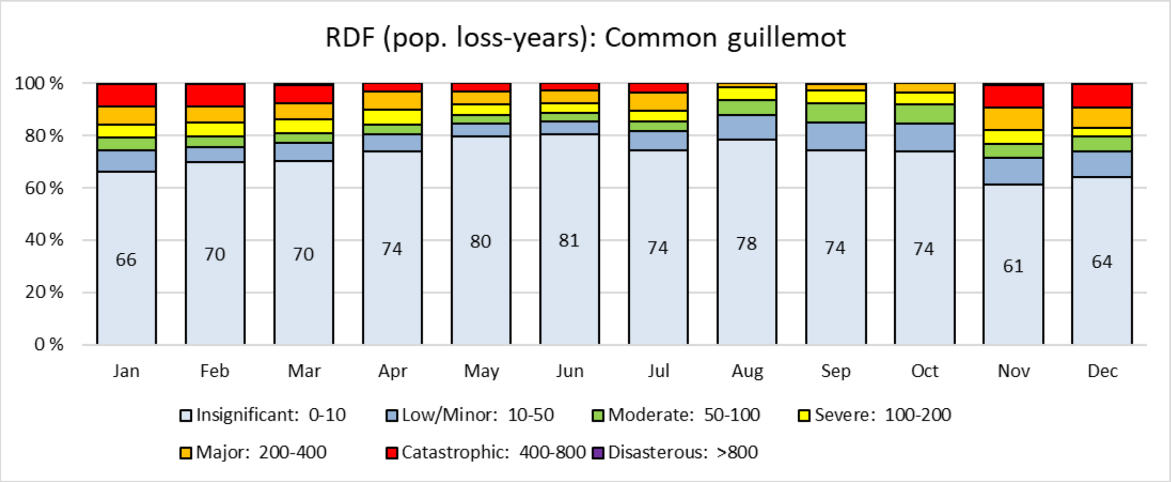


Figure 14 Example of presentation of monthly probability for different damage categories (based on RDF) for a seabird species.

3.8.3 Environmental risk evaluation

The main purposes of a damage-based risk calculation are to:

- assess whether the company's environmental acceptance criteria have been met
- identify which VECs are exposed to the highest environmental risk
- identify and visualise which geographical areas make the biggest contribution to environmental impact and risk
- identify differences in environmental risk at different times of the year (months/seasons)
- identify which scenarios or DSHAs are associated with the greatest environmental risk
- establish the best possible basis for selecting risk-reducing measures, including input to oil-spill response planning.

As such, the calculated risk should be evaluated against the eRAC for each compartment and discussed in relation to the bullet points above. Risk could be presented in a risk matrix (see the example in Figure 15).

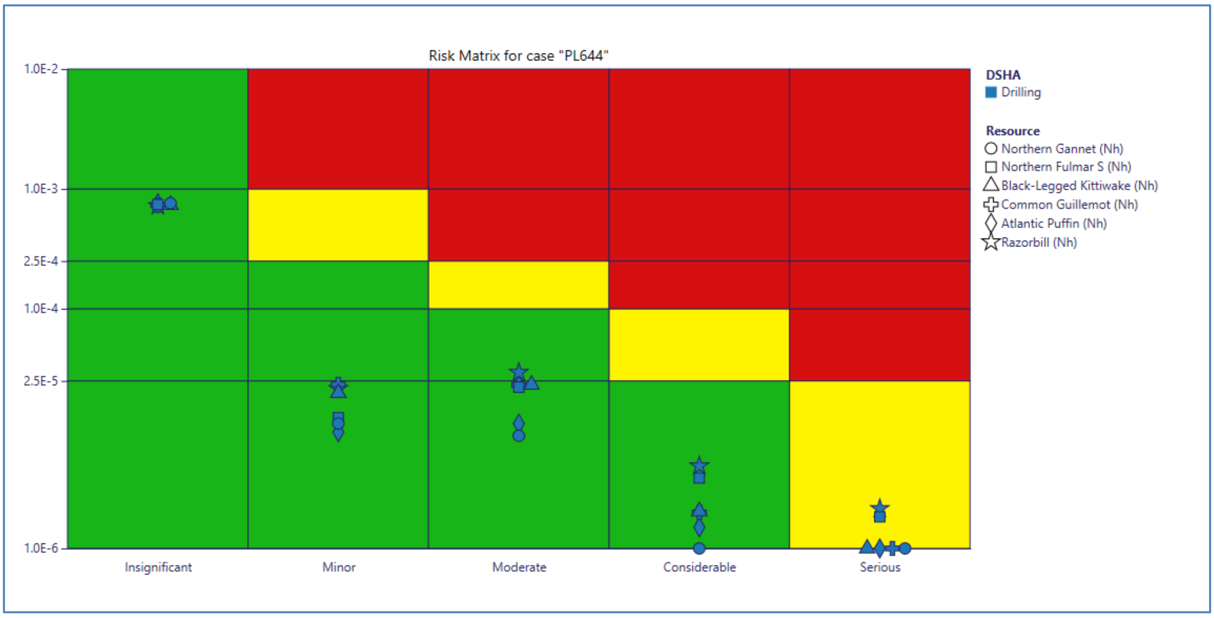


Figure 15 Environmental risk for seabird species presented by frequency for different damage categories in a risk matrix, where red areas indicate unacceptable risk levels, yellow is the area where risk-reducing measures should be considered and green indicates acceptable risk without further mitigation.

3.9 Risk-reducing measures and net environmental benefit

The ERA Acute methodology, with its continuous impact and risk functions, is well suited for quantifying the effect of various risk-reducing measures.

Any preventive measures which influence the DSHA spill likelihood or frequency go directly into scaling the risk level, and are easy to implement in ERA Acute since no recalculations of impact and restitution would be required. The risk level would only be scaled with an adjusted frequency. This is also the case for changes in probability between different scenarios in a DSHA, although that requires some recalculation of the weighting of results in the output.

Where consequence-reducing measures such as oil-spill response are concerned, such measures could be included in the oil-spill model and produce new results. ERA Acute calculations must then be performed on the new set of oil-drift results, allowing the impact and risk output with response options then to be compared with the base case (no response option). See the example in Figure 16. A separate module has been built into the ERA Acute software tool which permits easy comparison of impact and risk for each environmental compartment. ERA Acute can therefore provide a quantitative input to a net environmental benefit assessment (Neba).

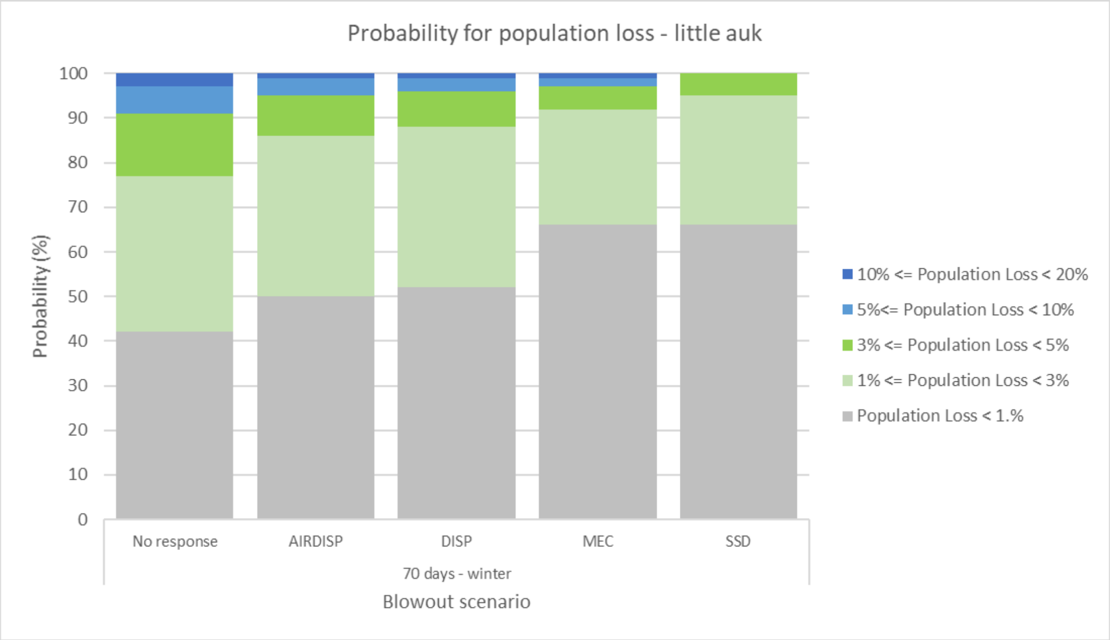


Figure 16 Presentation of environmental impact in terms of population loss for little auks without (no response) and with response options. AIRDISP = aerial dispersion; DISP = vessel dispersion; MEC = mechanical recovery and SSD = subsea dispersion.

3.10 Environmental risk communication

Establishing risk brings together the information from the previous stages. A clear and balanced picture of the risk exposure should be presented by giving the likelihood for different consequences or consequence categories resulting from the oil-spill scenarios and activities.

The overall risk level and the main factors contributing to the risk should be identified and presented. The overall risk level incorporates the risk from many activities and operations and their relevant oil-spill scenarios.

The risk should be presented for the different environmental compartments (such as sea surface, water column, shoreline and seafloor) and attention should be concentrated mainly on the VECs with the highest risk level.

3.11 Uncertainty in analysis

A presentation of the sensitivity in the results with respect to variations in the input data is recommended. This will provide information on whether changes in the input data have strong, moderate or limited influence on the results of the assessment. If the sensitivity of the assessment is high for certain input data, the precision and quality of these data need to be carefully addressed in the assessment. For the parameters which are recommended for use with the individual compartments, sensitivity calculations have been carried out as part of the ERA Acute joint industry project (JIP) (Acona 2018). A description of general uncertainty handling in ERA Acute is described for the parameters in Akvaplan-niva (2019), based on a scoring system by DNV GL (2015b).

4 REFERENCES

Acona 2018. WP2a. *Sensitivity and uncertainty testing*. ERA Acute project report, ERA Acute 2A-2

Akvaplan-niva 2017. *WP2a – Seafloor Compartment Sensitivity Testing and Norwegian Sea Test Case Data*. ERA Acute project report, ERA Acute 2A-3.

Akvaplan-niva 2019. *WP 5 ERA Acute Methodology Uncertainty Feasibility Study*. Akvaplan-niva report no 60043.05

Acona (2014). *ERA Acute Phase 3 – Surface compartment*. Acona report for Statoil and Total. Report no 37571. v 04. Oslo, 22 May 2015.

DNV GL 2015. *Development of Shoreline Compartment Algorithms*. DNV GL report. 1ILBNGC-9. 43 pp. 2015.

DNV GL 2015b. *A guidance to uncertainties and sensitivities in environmental risk analyses*. DNV GL report no 2015-1204, rev 00.

Sintef and DNV GL (2015). *Joint report – impact and restitution model – water column*. Sintef & DNV GL report. Sintef F26517/DNV GL 1IL8NGC-13. 81 pp. 2015.

ERA Acute – Development of Seafloor Compartment Algorithms – Biological Modelling. Akvaplan-niva report 5425.02. 126 pp. 2015.

Nilsen, H, Greiff Johnsen, H, Nordtug T and Johansen, Ø (2006). *Threshold values and exposure to risk functions for oil components in the water column to be used for risk assessment of acute discharges (EIF Acute)*. Statoil contract no C.FOU.DE.B02.

Akvaplan-niva (2019) based on a scoring system by DNV GL (2015).

APPENDIX A

Table 16. Generic individual behavioural factors (pbeh) table.

Wildlife group			**Thickness (mm)**	p_{beh}		
No	**Name**			**Low**	**Intermediate**	**High**
1	WG1	Pelagic diving seabirds	2	78%	88%	98%
2	WG2	Pelagic surface foraging seabirds	2	45%	51%	56%
3	WG3	Coastal diving seabirds	2	67%	76%	84%
4	WG4	Coastal surface feeding seabirds	2	32%	36%	40%
5	WG5	Wetland surface feeding seabirds	2	48%	54%	60%
6	WG6	Wading seabirds	2	48%	54%	60%
7	WG7	Baleen whales	10	70%	79%	88%
8	WG8	Toothed whale	10	80%	90%	100%
9	WG9	True seals, walrus and sea lions	10	84%	88%	93%
10	WG10	Fur seals	10	63%	78%	93%
11	WG11	Sea cows	10	95%	98%	100%
12	WG12	Aquatic mammals	10	79%	88%	97%
13	WG13	Sea turtles	10	95%	99%	100%

Table 17. Generic individual physiological factors (pphy) table.

Wildlife group			**Thickness (μm)**	p_{phy}		
No	**Name**			**Low**	**Intermediate**	**High**
1	WG1	Pelagic diving seabirds	2	80%	90%	100%
2	WG2	Pelagic surface foraging seabirds	2	80%	90%	100%
3	WG3	Coastal diving seabirds	2	80%	90%	100%
4	WG4	Coastal surface feeding seabirds	2	80%	90%	100%
5	WG5	Wetland surface feeding seabirds	2	80%	90%	100%
6	WG6	Wading seabirds	2	80%	90%	100%
7	WG7	Baleen whales	10	2.5%	5.0%	7.5%
8	WG8	Toothed whale	10	4.0%	8.0%	12%
9	WG9	True seals, walrus and sea lions	10	5.0%	10%	15%
10	WG10	Fur seals	10	50%	72%	93%
11	WG11	Sea cows	10	4%	8%	12%
12	WG12	Aquatic mammals	10	50%	72%	93%
13	WG13	Sea turtles	10	2.0%	4.0%	6.0%

Table 18. Generic fundamental net reproductive rates (R) table.

Wildlife group		**Typical species**	***R***
Name			
WG1	Albatross and skuas	Albatross (southern royal, grey-headed Antipodean, northern royal), skua (brown, great, sub-Antarctic), northern fulmar	1.05
WG2	Auks, petrels and shearwaters	Auks (razorbill, common guillemot, Atlantic puffin), petrels (black, white-chinned, Chatham), shearwaters (Bullers, flesh-footed), black-legged kittiwake	1.10
WG3	Gannets, penguins, gulls and terns	Gannets (northern, masked Australasian), penguins (Snares crested, southern rockhopper, Fiordland crested), gulls (black-backed, lesser black-backed, little) and terns (common white, common, sandwich, Caspian)	1.15
WG4	Cormorants, shags, divers, ducks and geese	Cormorant (great), shags (European, Campbell Island, spotted, Auckland Island), divers (red throated), ducks (common eider, common scooter) and geese (barnacle, snow, Bewicks swan)	1.20
WG5	True seals, sea lions and fur seals, baleen whales	Grey seal, harbour seal, ringed seal, Antarctic fur seal, sub-Antarctic fur seal, blue, humpback and southern right whales	1.13
WG6	Walrus, aquatic mammals	Walrus, polar bear, Eurasian otter, sea otters	1.06
WG7	Toothed whales, sea cows, sea turtles	Bottlenose dolphin, killer whale, harbour porpoise, Florida manatee, sea turtles	1.03