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ERA Acute

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The ERA Acute methodology will be the new industry standard environmental risk assessment (ERA) method on NCS in 2019, replacing the currently used MIRA method.

ERAs are carried out with the purpose to assess and ensure acceptable environmental risk for oil and gas offshore operations, aiming to minimize the risk to the environment. ERA Acute has been developed by leading ERA experts, and provides the mean to evaluate the potential risk from an acute oil spill in the marine environment.

The ERA Acute method includes four environmental compartments: the sea surface, shoreline, water column and seafloor. ERA Acute uses input data from an oil spill trajectory model and biological resource data, and calculates the potential environmental risk (impact and recovery time) for biological resources in all compartments.

The ERA Acute software tool provides relevant visualization of the output results from the ERA Acute method, such as maps, graphs and tables. The tool has applications for environmental risk management, such as a risk matrix and a comparison tool which may support a spill impact mitigation analysis (SIMA).

Report 4: ERA ACUTE PHASE 3 SHORELINE - Development of shoreline Compartment Algorithms

Authors: Odd Willy Brude, Marte Rusten, Marte Braathen (DNV-GL)

The report (2015) presents the ERA Acute method for the shoreline compartment. The report gives a detailed description on how the ERA Acute method calculates the potential impact and recovery for the shoreline after a potential acute oil spill.

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ERA ACUTE PHASE 3 SHORELINE

Development of Shoreline Compartment Algorithms

Statoil and Total

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1 EXECUTIVE SUMMARY

This report describes the ERA acute phase 3 algorithms for the impact, lag and restoration phases after damage by acute oil pollution for the shoreline compartment. The scientific rationale behind the calculation steps as well as required data and data structure necessary for implementation in a software tool is described in detail. The proposed model is simple and transparent and provides a more precise expression of damage to shore after oiling than the currently used MIRA-approach.

In general, all compartments base their impact calculations on the following parameters:

- P_{exp} (probability for exposure to the oil present in the grid cell)
- P_{let} (probability for mortality based on the exposure)
- N (resource unit/parameter for which an impact is calculated)
- T_{imp} (duration of impact)
- T_{lag} (duration of lag phase before restoration can begin)
- T_{res} (duration of restoration time)

Different from the other compartments the resource unit (N) for shoreline is suggested to be "km coastline" for each specified habitat type. Habitats will be classified according to the ESI ranking system, with sea turtle beaches ranked within the ESI 3A subgroup. We propose an approach based on acute lethality threshold values (mm thickness of oil). The damage can then be expressed as affected area with oiling above threshold value (km) * time for recovery (years). A summary of the proposed model is given below and illustrated in Figure 1.

Impact

The shoreline impact will be calculated for each ESI ranking and can be summarized to an overall impact estimate. Information about ESI-status and tidal range must be prepared as part of the habitat grid in the oil spill model. The shoreline lethal threshold values for invertebrate epi fauna (ESI 1-10) is set to 0,1 mm, whereas the lethal threshold value for wetland vegetation (ESI 8-10) is set to 1 mm.

Information about oil thickness (T) can be derived from the amount of oil stranded (V) in a grid cell divided by the length of the coastline (L) within the grid cell multiplied with the width of oiling (Wimp) on the shoreline:

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

Given the slope (sl) associated with each ESI ranking, the tidal range (TR) and a patchiness factor of 20 % the width (Wimp) of oiling in each segment can be calculated by:

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

Based on accumulated oil volume on the shoreline (Vcell 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) related to each ESI ranking (r) for a given oil viscosity:

$$Weight_r = L_r \times OHC_r$$

The volume per ESI ranking is then:

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

And further 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 upon effect or no effect for each ESI ranking in each grid cell.

The total impact for each ESI ranking (r) is then 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.

$$Imp = \sum_{r} Imp_r$$

Lag phase

The expression for the duration of the lag phase is based on ESI status, hydrodynamic energy and oil types according to a look-up table (Table 11). The classification of oil types is based on a recommendation by NOAA founded on experience data about how the different oil types affect shorelines and how hard they are to clean up. Oil type 1 include very light oils (like jet fuels and gasoline), oil type 2 refer to light oils (like diesels and light crudes), oil type 3 include medium oils (like most crude oils) and oil type 4 include heavy oils (like heavy crude oils).

Table 11. Look-up table lag phase

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

Restoration phase

The expression for the duration of the restoration phase is based on ESI status according to the following look-up table (Table 12).

Table 12. Recovery rates after shoreline oiling

Habitat (ESI shoreline classification)	***Vegetation or Structure: Years to 99% Recovery***	***Benthic Invertebrates: Years to 99% Recovery***
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 Rip rap-structures (6) Exposed tidal flats (7 and 9)	-	3
Wetland: Emergent Marsh (10A, 10B)	15	5
Wetland: Swamp (10C, 10D)	20	5

Damage expression

The overall damage expression for shoreline, either as the sum of all ESI impacts or separated into the different affected ESIs, is given by the following expression:

$$Imp = \sum_r Imp_r \times (T_{res} + T_{lag})$$

Risk Matrix

Damage to shoreline after oiling can be classified according to the company's severity categories and plotted in a risk matrix as illustrated in Figure 6.

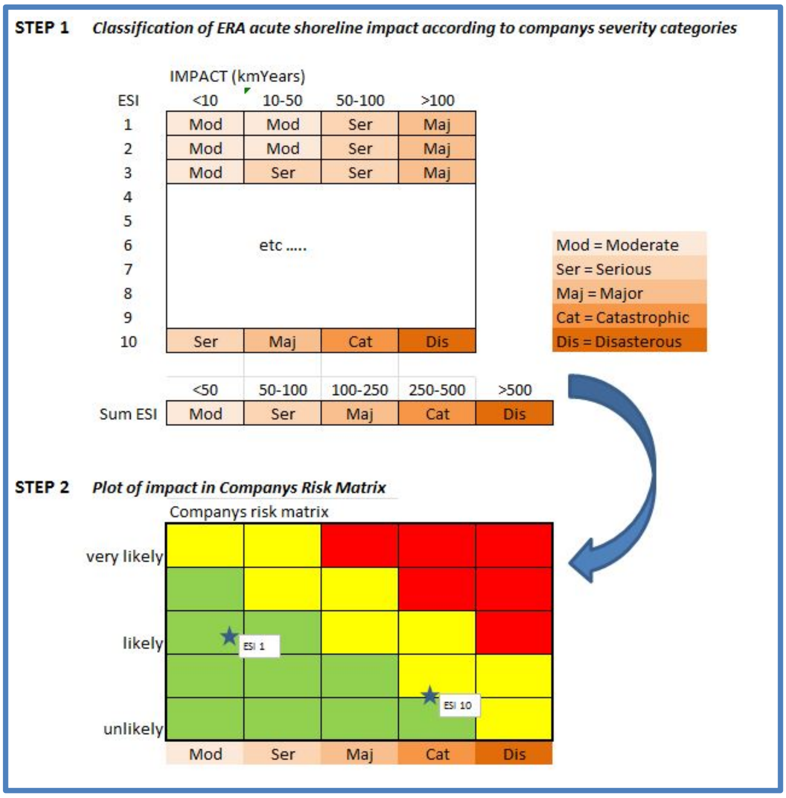

Figure 6. Implementation of results in a risk matrix format.

Comparison with MIRA/ OLF, 2007

The main differences in the calculation of damage to shore by acute oil pollution by the ERA acute Phase 3 approach and the MIRA-method is illustrated in Table 13.

Table 13. Calculation of damage to shoreline after acute oil pollution in ERA Acute Phase 3 and the OLF 2007/MIRA approach.

Function	ERA Acute	OLF 2007
Impact function	• Uses accumulated oil volume in defined grid cells • Uses ESI shoreline classifications, oil holding capacity and tidal range to redistribute oil volumes to various parts of the shoreline within the grid cell • Uses ESI shoreline specific threshold values for thickness of oil on shore to calculate if a segment is impacted or not	• Defines each habitat as the grid cell size (10x10 km) • Uses categorized accumulated oil volumes in defined grid cells (1-100; 100-500; 500-1000 and >1000 tons) • Uses shoreline substrate and wave exposure classified into 3 sensitivity groups • Uses the combined sensitivity within a grid cell to calculate an average impact (=recovery time) for the grid cell based on the oil volume category
Lag phase	• Uses oil dependent but volume independent lag times for medium and low energy shorelines	• Part of the total recovery time estimate
Restitution model	• Uses ESI shoreline specific restoration times for restoration of benthic invertebrates and/or vegetation/structure of shoreline habitat • Expresses the damage as impacted km-years for each ESI shoreline type (including sub group of turtle beaches)	• Uses the combined sensitivity within a grid cell to calculate average impact (=recovery time in years) for the habitat based on the oil volume category • Apply a probability distribution between different recovery times based on historical spills

New from level A

The main difference from the level A approach is the implementation of information about the sensitivity of shoreline resources expressed by the ESI shoreline classification system.

Conclusion

Based on the lack of precise experience- and scientific data we have suggested a rather simple but robust approach for the expression of damage to shore after oiling. The method is to a large degree build upon the ESI-classification system and other recommended practices for modeling of damage to shore by acute oil pollution. A refinement compared to the MIRA-method is to use ESI specific oil holding capacities and tidal range to redistribute oil volumes within a grid cell allowing for more detailed impact expression. By including an oil-specific lag phase for the medium and low energy shorelines we have built-in an additional element compared to MIRA, reflecting the longer oil exposure scenarios these habitats can experience. Due to a lack of scientific evidence, the proposed lag times are best estimates based on expert judgments. A closer link between the volume of stranded oil and the recovery and lag phases would be beneficial, but we were not able to find data supporting such refinement. The spill volume is however to some extent covered by the impact algorithm: as a larger spill result in more km affected shoreline than a smaller spill. To get a better understanding of how the ERA acute phase 3 algorithms for shoreline is reflecting acute damage to shore compared to real life and also other modelling approaches , thorough testing should be undertaken.

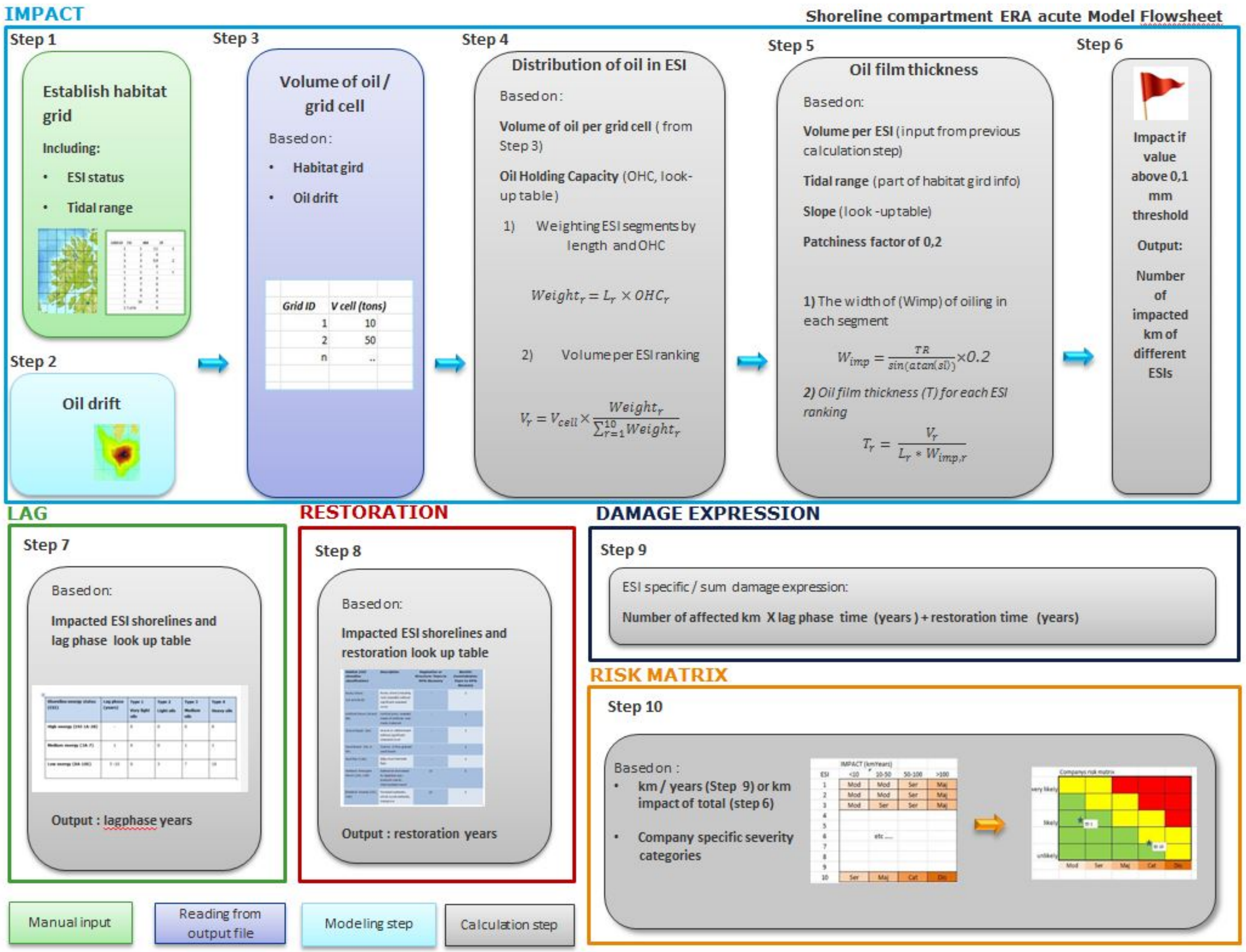

Figure 1. Flow sheet illustrating the main steps and calculations in the ERA acute Phase 3 Shoreline Compartment

2 INTRODUCTION

2.1 Background

The goal in developing ERA acute is to generate a robust and transparent model for risk assessment of acute oil pollution. The model is considered for global use, by expert users.

All compartments base their impact calculations on the following parameters:

- P_{exp} (probability for exposure to the oil present in the grid cell)
- P_{let} (probability for mortality based on the exposure)
- N (resource unit/parameter for which an impact is calculated)
- T_{imp} (duration of impact)
- T_{lag} (duration of lag phase before restoration can begin)
- T_{res} (duration of restoration time)

The current phase 3 involves a complete revision of current scientific basis and suggestions for implementation of algorithms in ERA Acute level B for the shoreline compartment; specifically algorithms related to impact, lag-phase and restitution modelling. Different from the other compartments the resource unit for shoreline is suggested to be "km coastline" for each specified habitat type, and this will be used in the parameters above. We propose an approach based on acute lethality threshold values (mm thickness of oil). The damage can then be expressed as affected area with oiling above threshold value (km) * time for recovery (years). Exposure will be determined by the oil drift modelling.

2.2 Previous work (EIF Acute)

ERA Acute builds on the EIF Acute project (2003-2006) where shoreline compartment was documented by (Hoell and Gramme, 2006). P_{exp} in the shoreline compartment should theoretically vary with the substrate's ability to sequester oil, degree of exposedness with respect to location in the outer, exposed coastal areas or in the more sheltered areas etc. However, for the data set of the Norwegian coastline included, these two parameters were already integral parts of the Principal sensitivity index (P_i). P_{exp} were therefore set to 1. Oil amounts per km coast were used for calculations of lethal effects given exposure and modifications regarding different types of coastal segments were suggested to be attributes of the data set and included in the P_{let} calculations of the shoreline compartment. Hoell et al (2005) stated that in other geographical areas, the P_{exp} factor may be used differently and independently, e.g. if substrate data are available, and the necessary impact and time factors must be ascribed to the certain substrate types and/or wave-exposure degrees.

The probability of lethal effects in the shoreline and intertidal compartment were assessed as follows:

- at a film thickness on the shoreline <10 µm, P_{let} = 0 % i.e. this is the threshold film thickness as in levels I and II, below which there is "no lethal risk".
- at a film thickness >14 mm; literature indicated that lethal probability P_{let} = 100 %.

- between these two values, the lethality will lie between 0 and 100 %, with no indications in literature from oil spills, that there is a general “dose-response” curve as may be derived from toxicological experiments. For the sake of simplicity, a linear function between 10 µm and 14 mm was assumed.

The value of P_{let} calculated from the film thickness calculated from the amounts of stranded oil (in tonnes/km coast). In addition specific lag and restoration times were prepared for certain substrate types. The restitution values were based on the abundance of key species (as determined for communities typical for Norwegian areas) in the coastal segment. For soft substrate key species, the parameters were set to 4 or 7 years, based on experience and depending on wave exposure (Hoell et al 2005).

2.3 Summary of existing methodologies and data

2.3.1 MIRA

Metode for miljørettet risikoanalyse (MIRA) was developed during 1995-96 for NOROG (previously OLF) in collaboration project between Norsk Hydro and Det Norske Veritas (DNV now DNVGL). A number of updates have been made after the initial development. In the MIRA method, sensitivity to oil exposure is indexed based on physical properties of different coastal habitats; substrate and degree of exposure to waves and currents. Sensitivity to biological resources on the seafloor (benthos) as well as in the inter-tidal zone portion are not taken into account in the sensitivity index and the reason is simply that such resources were not sufficiently mapped when the MIRA method was established during the mid-1990’s. The rationale behind the damage key is thus that biological resources will recover alongside the physical substrate that they depend upon.

Based on studied recovery periods of coastal habitats following historical oil spills (including Exxon Valdez and Amoco Cadiz), they estimated the predicted restitution time for a number of substrate categories with various degree of exposure to waves and currents (table below). It is worth underlining that this study did not relate restitution time with stranded oil amounts, the reason being lacking data for several of the studied spills.

For coastal habitats belonging to the highest sensitive category (S3, marked in red in the above table), the restitution time following oil exposure is hence predicted to be in the range 5-20 years, however without relating damage with oil amounts. The first damage key reflected these numbers with a 50:50 probability weighting for 5-10 years, and 10-20 years restitution time, respectively, following an intermediate oil spill of 150-1500 tons per 15x15 km grid cell. For a smaller spill (1-150 tons per 15x15 km grid cell on the shoreline), probabilities were simply moved down by one damage category, yet maintaining the 50:50 division between two adjacent damage categories.

For a large oil spill >1500 tons per 15x15 km grid cell, the restitution time is predicted to always exceed 10 years, with 80 % probability for 10-20 years, and 20 % probability for >20 years restitution time.

Damage predictions following a small or a large oil spill are hence not related to empirical data in the same way as for an intermediate spill, but rather leans on the assumption that there is a relationship between spilled oil amount and the degree of damage to coastal habitats.

Table 1. *The relationship between substrate category, degree of exposure, and expected time for recovery (restitution time) as a result of oil pollution. NA = not applicable. From SFT (1993). Colour codes relate to the sensitivity index for exposed and sheltered habitats: green code = sensitivity 1, yellow code = sensitivity 2, red code = sensitivity 3.*

Main categories	Substrate categories		Exposed	Moderately exposed	Sheltered
Seashore	Muddy beach/ shore meadow		NA	5-15 y	10-20 y
	Sandy beach [1)]		1-5 y	3-10 y	5-10 y
	Sea cliff		NA	NA	NA
	Gravelly beach [1)] & rocky/ bare rock-face shores		1-5 y	3-10 y	5-10 y
Intertidal shore	Hard bottom seafloor		1-3 y	5-15 y	10-25 y
	Soft bottom seafloor	Mud/meadow	NA	5-15 y	10-20 y
		Sand/gravel	1-5 y	3-10 y	5-10 y

Linear vs. continuous effect and damage functions

As shown for the existing effect and damage look-up table in the MIRA method, one can establish coarse relations between oil amounts on shore and observed or estimated recovery from historical spills, without explaining the actual exposure and effect mechanisms. This means that the effect- and damage key incorporates all variation that is observed and that may be explained by different effect parameters like wave and tidal energy, oil thickness and coverage and biological productivity. An obvious benefit of establishing such coarse relations / categorizations are that there can be established a rough estimate on the outcome without knowing specific parameters causing the variation in effect and damage. Another approach would be to go for a rough expected value based on the observed data, but then one needs to address variation and give an estimate on the confidence interval (se sketch in figure below). If uncertainty is not addressed, one would still have a rough estimate on the expected damage, but as variation in damage in most compartments (incl. shoreline) from oil spills has proven to be huge, this method is very limited in terms of addressing the full range of possible impact and possibly adverse impacts that needs to be evaluated in a consequence and risk assessment. This approach could be supported by further sensitivity assessments.

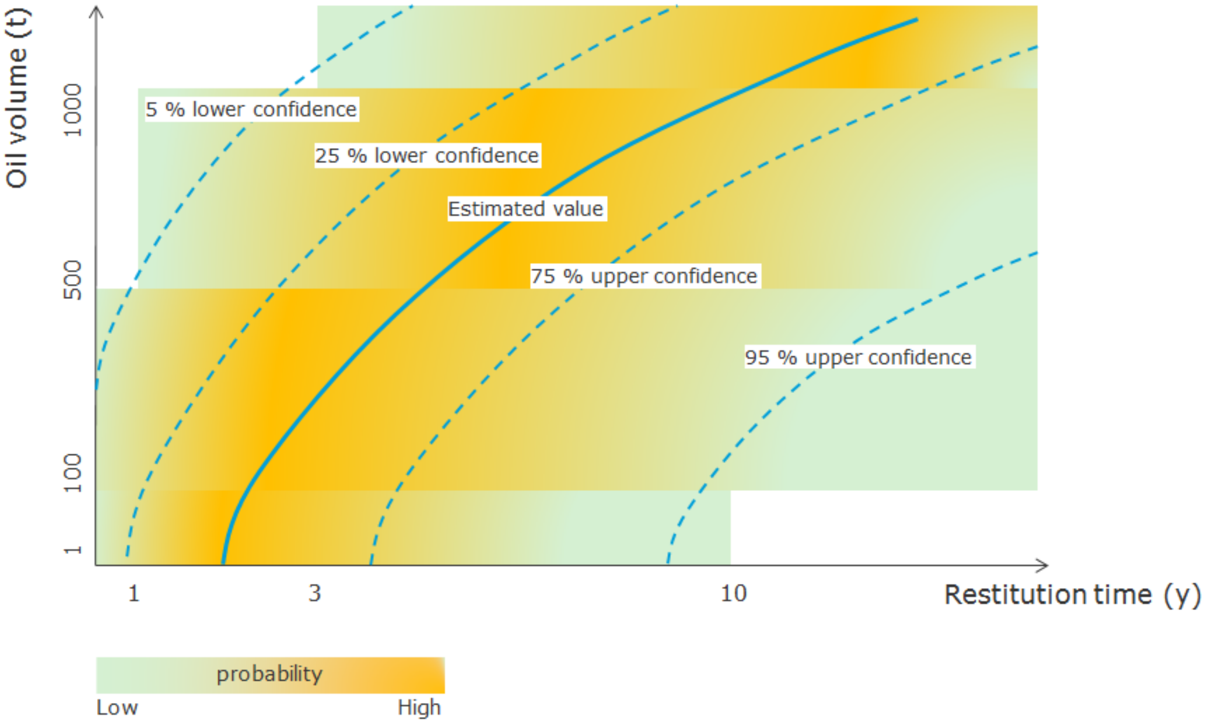

Figure 2. *An illustration of how the MIRA effect and damage key links oils volumes in grid cells towards probability for different restitution times for the most sensitive shoreline habitats (via simple probability distributions). An alternative approach would be to estimate the expected recovery period and then give a measure on the variation or uncertainty at given confidence intervals (blue lines).*

If one is able to start exploring specific parameters and connect them with effect, damage or recovery, a more detailed approach could be taken. For instance, if we are able to find an oil film threshold thickness for lethal effects on various shoreline habitats, that parameter may be separated out as an effect parameter and a continuous effect relationship established as a function of the area impacted above the threshold. Still there could be other important parameters affecting the actual estimate of film thickness (e.g. actual wave exposure and remobilization) and the more they influence the result and the greater uncertainty that is connected to them, the more they call for a coarse approach that embraces that uncertainty. The use of simpler oil mass in grid cells could thus still be an option.

Based on the limited and very weak foundation for the MIRA effect- and damage keys for shoreline habitats, there seems to be a potential for at least a combined approach with more specific dose-response relationships for some effect, damage or recovery parameters and more generic categorizations of all other effect and damage contributors.

2.3.2 Environmental Sensitivity Index (ESI)

Classifications of the shoreline in terms of habitat types, where different habitats are ranked for their sensitivity for an oil spill, are beneficial when working with damage of oil to shorelines. A classification scheme that has obtained international acceptance is the ESI index developed by NOAA (NOAA, 2002). In its present form the ranking system is developed for sub-arctic, temperate, and tropical zones as well as some shoreline types unique to the Arctic zone. The ESI classification scheme is based on an understanding of the physical and biological character of the shoreline environment, not just the substrate type and grain size. Relationships among physical processes, substrate type, and associated biota produce specific geomorphic/ecologic shoreline types, sediment transport patterns, and predictable patterns in oil behaviour and biological impact.

The shoreline rankings are defined using the following factors influencing sensitivity to oiling:

- Relative exposure to waves and tidal energy
- Biological productivity and sensitivity
- Substrate (grain size, permeability, trafficability and mobility)
- Shoreline slope
- Ease of cleanup
- Time of restoration

The ranking scale goes from 1 to 10, where the lower rankings represent shorelines that are less susceptible to damage by oiling and shorelines with a higher ranking are more likely to experience damage by oiling. A complete list of ESI shoreline classifications are presented in Table 2. The classification is provided for estuarine, lacustrine and riverine types of environmental settings. "Estuarine" represent river mouth environments with salt – or brackish water. "Lacustrine represent environments related to lakes and "Riverine represent environments related to rivers (particularly large rivers).

Table 2. ESI shoreline classifications. 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 man-made structures	Exposed, solid man-made structures	Exposed, solid man-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
6B	Riprap Gravel beaches (cobbles and boulders)*	Riprap	Riprap
6C*	Riprap		
7	Exposed tidal flats	Exposed tidal flats	
8A	Sheltered scarps in bedrock, mud, or clay Sheltered rocky shores (impermeable)*	Sheltered scarps in bedrock, mud, or clay	
8B	Sheltered, solid man-made structures Sheltered rocky shores (permeable)*	Sheltered, solid man-made structures	Sheltered, solid man-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

10E	Inundated low-lying tundra
* A category or definition that applies only in Southeast Alaska. ** In tropical climates, 10D indicates areas of dominant mangrove vegetation.	

Norwegian developments on shoreline sensitivity

The ESI index includes a combination of habitat, exposure and cleanup effort. In Norway, there have been similar developments in the form of prioritisation, to the extent of implemented GIS models and cleanup protocols. The initial outline and categorization may be found in the Norwegian Environmental Agency guideline for shoreline cleanup (2000), which was subsequently further detailed and incorporated in the ActLog decision support tool, developed for Norwegian operators and the Norwegian Coastal Authority in 2003 (see e.g.(Skeie et al., 2006)). In an ERA context, sensitivity of intertidal habitats on Svalbard (Moe et al., 2000) was implemented for the coastline of mainland Norway ((Brude et al., 2003). During the MS Server oil spill on the west coast of Norway, the prioritisation model was further developed (Spikkerud et al., 2008), and this revised model for prioritisation is now implemented in the Norwegian Coastal Administration model applied in oil spills.

2.3.3 Sea Turtle Beaches

Female turtles must return to land to nest, generally crawling up a dark beach to above the high-tide line at night, although female Kemp's ridley turtles nest predominantly during the day, as do olive ridleys, which nest in a large mass. The general requirements for a nesting beach are that it is

high enough to not be inundated at high tide

has a substrate that permits oxygen and carbon dioxide to diffuse into and out of the nest

is moist and fine enough that it won't collapse during excavation.

The female uses her front flippers to toss loose surface sand aside to excavate a large body pit, then uses her hind flippers as "scoops" to dig a flask-shaped egg chamber, into which she deposits approximately 100 parchment-shelled eggs, about the size of Ping-Pong balls (larger for leatherbacks). Once the eggs are deposited, she covers the eggs with moist sand and again uses her flippers to broadcast sand around the nesting area to disguise the exact location of the egg chamber. She then returns to the sea, providing no further parental care (Shigenaka, 2010).

After an incubation period of about two months, hatchlings of all species dig their way up to the surface all together. Thus the majority of hatchlings emerge from the nest on a single night in a group numbering between 20 and 120, with only a few stragglers hatching on successive nights. High surface-sand temperatures can inhibit hatchling movement, so most emergences occur at night, after the sand has cooled, although daytime emergences on cloudy days or after a rain are not uncommon (Shigenaka, 2010).

3 IMPACT PHASE

The shoreline impact will be calculated for each ESI category individually and can then be summarized to an overall impact estimate. ESI data must then be prepared as part of the habitat grid in the oil spill model (e.g. OSCAR) in order to for the model to take into account the holding capacity of oil on various substrates (of applicable in the oil drift model).

Based on the MIRA-methodology (OLF, 2007) work done in Norway on shoreline sensitivity, ESI classification, available information in scientific literature and experience data we propose to base the assessment of impact from oil on shore on shoreline specific threshold values (oil thickness in mm).

Oil thickness on the shoreline is a result of the amount spilled, the spill trajectory, the characteristics of the oil (viscosity and adhesiveness), steepness of the shoreline slope, tidal conditions at the time of shoreline impact, and the porosity of the surface (Etkin et al., 2007)

Shoreline surface oiling is generally described in a two-step process; first with regard to surface oil cover, as shown in Table 3, and then this is modified by the thickness of the oil, as shown in Table 4.

Table 3. Surface oil cover category (width x surface distribution area) as used in Shoreline Cleanup Assessment Team Data (after Etkin et al., 2007)

Distribution	Width of oiled area			
	Wide (>6 m)	Medium (3 - 6 m)	Narrow (0.5 – 3 m)	Very Narrow (<0,5 m)
Continuous (91 – 100%)	Heavy	Heavy	Moderate	Light
Broken (51 – 91%)	Heavy	Heavy	Light	Light
Patchy (11 – 51%)	Moderate	Moderate	Light	Very Light
Sporadic (1 – 10%)	Light	Light	Very Light	Very Light
Trace (<1%)	Very Light	Very Light	Very Light	Very Light

Table 4. Surface Oil Category (surface oil cover category x thickness data) as used in Shoreline Cleanup Assessment Team Data (after Etkin et al 2007)

Thickness	Surface oil cover category			
	Heavy	Moderate	Light	Very Light
Pooled (>1.0 cm)	Heavy	Moderate	Moderate	Light
Cover (0.1 – 1.0 cm)	Heavy	Moderate	Light	Very Light
Coat (0.01 – 0.1 cm)	Moderate	Moderate	Light	Very Light
Stain / film (<0.01 cm)	Light	Light	Very Light	Very Light

The width or cross-shore distribution of oiling after the Deepwater Horizon (DWH) Oil Spill incident in 2010 varied substantially and was controlled by beach morphology and wave conditions. The oiling was bound landward by the maximum high tide and concentrated surface-oil contaminants were often found along this maximum high-tide border (Wang and Roberts, 2013).

Michel et al. (2013), summarized the extent and degree of shoreline oiling from the Deepwater Horizon Oil Spill and found that 25 % (1773 km of 7057 km surveyed) of the surveyed shorelines were oiled at some time. This is lower than other huge oil spills ranging from 91,6 % at the Gulf War oil spill in Kuwait in 1991 to 38,5 % at the T/V Exxon Valdez oil spill in Alaska in 1989 (see Table 5).

Table 5. Comparison of the length of shoreline oiled for systematic surveys. After Michel et al. (2013)

Spill Name/Date	Oil Type/Volume	Shoreline Area Oiled	Shoreline Surveyed (km)	Shoreline Oiled (km)
T/V *Exxon Valdez* March 1989 [16]	Alaska North Slope crude oil/260,000 barrels	Prince William Sound, Kenai Peninsula, and Kodiak Strait, Alaska	5,459	2,100
Gulf War oil spill February-May 1991 [17]	Kuwait crude oil/10,800,000 barrels	Saudi Arabia shoreline of the western Arabian Gulf (limited but unknown area oiled in Kuwait)	772	707
T/V *Selendang Ayu* December 2004 [18]	Intermediate fuel oil 180+ marine diesel/ 8,434 barrels	Western shoreline of Unalaska Island, Alaska	763	418
M/V *Cosco Busan* November 2007 [19]	Intermediate fuel oil 380/1,380 barrels	Central San Francisco Bay and outer shorelines north and south of the Golden Gate, California	379	147
Deepwater Horizon, April-August 2010	MC-252 Louisiana crude oil/4,900,000 barrels	Northeastern Gulf of Mexico	7,057	1,773

The importance of tidal range in shoreline oiling is considerable and while the oiled band width defined as Heavy for the Exxon Valdez response surveys was >6 m, the analogue for the Deepwater Horizon response was >1.8 m, reflecting the differences in tidal range among the regions (5 m in Alaska and 1 m in the Gulf of Mexico). Along the Arabian Gulf, the width of the oiled band was often in the tens of meters and exceeded 1–2 km on the extensive intertidal flats with mostly 100% oil coverage with deep penetration into the sediments (Hayes et al., 1993).

3.1 Effect levels

It is proposed to use different effect levels for vegetation (macro-algae & aquatic herbs/trees) and invertebrate epifauna. Dense beds of seaweed and aquatic plants form the habitat on which several invertebrates depend, and impact on vegetation will therefore indirectly also affect invertebrate epifauna ("habitat destruction").

We separate between two major types of vegetation; brown macro-algae ("seaweed") growing on protected, rocky shores, and herbaceous plants and trees (sea meadows, salt marshes, mangrove) growing along protected coasts with muddy/sandy sediments. No further distinction is made for invertebrate epifauna which is therefore considered equally sensitive in contact with various substrates (vegetation or rock).

French-McCay (2009) reviewed the literature on acute effect levels in invertebrate epifauna and tropical and subtropical plants (salt marshes and mangroves). Based on several studies, she concluded that 1 mm of oil is required to impact marsh or mangrove plants during the growing season, which was identified as the most sensitive season. Thus, 1 mm is suggested as the acute effect level in herbs and trees growing along flat shorelines with soft sediments and sorting under ESI categories 8-10 (Table 2). It is assumed that all sorts of aquatic plants (herbs and trees) have 100% coverage.

In the same review, French-McCay (2009) identified 0.1 mm as the acute effect level in epifaunal invertebrates living in intertidal habitats on hard substrates, i.e. invertebrates were identified as more sensitive to oiling than vegetation. If the effect level 0.1 mm is applied to all epifaunal invertebrates, this implies that invertebrates associated with seaweed and aquatic plants may be impacted although the vegetation remains unaffected from a lethal and reproductive point of view. This is however not taken into account in ERA Acute where vegetation “defines” the oil sensitivity of substrates covered and dominated by macro-algae and plants. An overview of suggested effect levels is presented in Table 6.

Table 6. Shoreline lethal threshold values.

Shoreline	***ESI ranking***	***Lethal threshold value***
Wetland vegetation	8-10	1 mm
Invertebrate epifauna	1-10	0,1 mm

3.2 Sea turtles

While eggs, embryos, and hatchlings are likely to be more vulnerable to volatile and water-soluble contaminants than adults (Shigenaka, 2010), only one identified study has directly examined the effects of oil compounds on sea turtle eggs. Fritts and McGehee (1982) found that 30 ml of oil poured onto the sand over eggs lowered survival in embryos, whereas 30 ml of oil mixed into the sand around the eggs did not. The effects of beach oiling on nesting females’ behaviour and physiology were not investigated (Fritts and McGehee, 1982). Females may refuse to nest on an oiled beach, and crossing it could cause external oiling of the skin and carapace. Fritts and McGehee (1982) noted that the oil behaved like any other flotsam; not all beach areas received equal amounts, and most of it was deposited just above the high-tide line. The latter point is significant for planning and response because most turtles nest well above the high-tide level. One implication of nesting behavior is that under normal circumstances, nest sites are less likely to be directly affected by stranding oil. Another study determined that oil covering different portions and different proportions of the surface of sea turtle eggs affects hatching success (Philott and Parmenter, 2001). For example, an egg’s upper hemisphere is the primary gas exchange surface during early incubation. If oil covers enough of the upper surface to impede gaseous exchange, higher mortality in embryos will occur.

Shigenaka (2010) suggest that it is unlikely that turtle nests would be directly impacted if shorelines were oiled after eggs had been deposited, since females typically dig nests well above the high-tide line. It is therefore suggested that nesting beaches for sea turtles follow the same approach as other beaches when it comes to impact quantification, and that the beaches are identified as unavailable to turtle nesting as long as they are above general threshold levels for impact for the particular ESI ranking they belong to (ESI 3A subgroup).

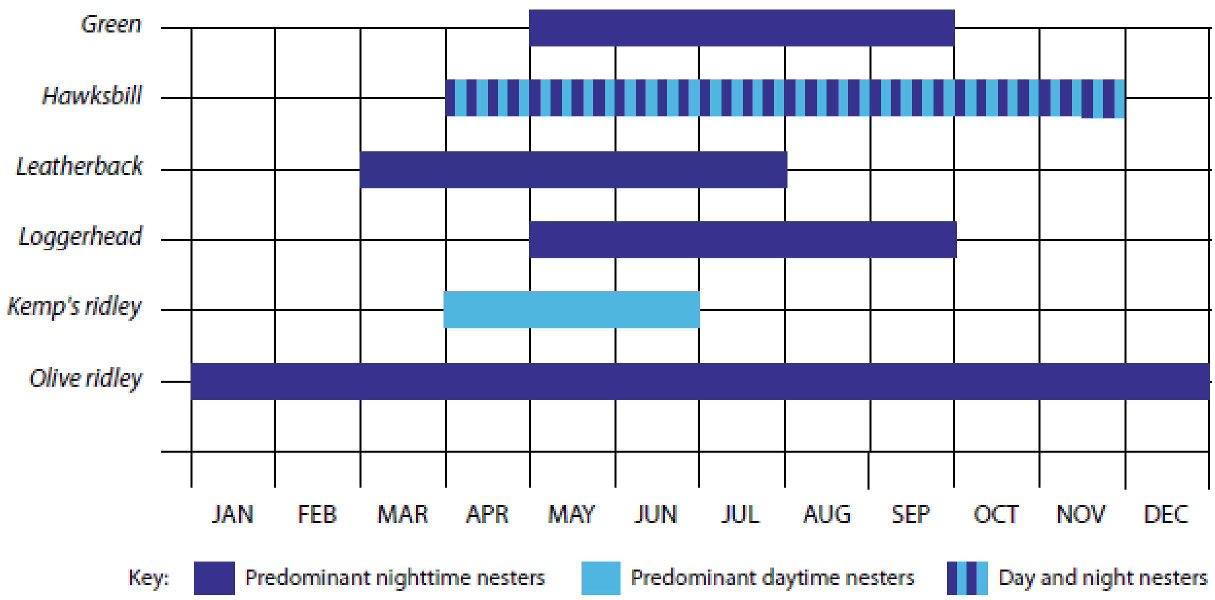

Figure 3. Times when oil near or on nesting beaches will have the most effect on turtles, by species. Shigenaka (2010) from (Miller, 1997) and US Fish and wildlife service (2003)

3.3 Suggested model implementation

Oil–shoreline interaction – or ‘‘beaching’’ (the term that prevails in literature) processes are complicated and – still – not deeply understood, due to the great amount of parameters and uncertainties involved in the physical problem. Wave and tide action on the foreshore, combined with the complex two-phase flow (water–oil) and ongoing oil weathering, seem to create an insurmountable obstacle for the detailed representation of the phenomenon (Samaras et al., 2014).

The outcome of the oil spill model will be an accumulated oil volume for each defined shoreline grid cell. Accumulation of oil on shore up to an empirically-derived oil-holding capacity is used by most oil spill models that include some kind of shore interaction algorithm (Etkin et al., 2007).

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

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

Coastline length should preferably be given for each shoreline grid cell, but might be approximated by the length of the diagonal (D) in the grid cell i.e. L=D.

Samaras et al. (2014) used tidal range (TR) and beach slope (sl) in order to define the width of the impacted coastal zone (W_{imp}) by:

$$W_{imp} = \frac{TR}{\sin(\mathrm{atan}(sl))}$$

This method is also proposed for ERA acute, however with modifications for patchiness in oiling (see 3.3.1).

As detailed information on beach slope is generally not available, beach slope parameters could be assumed for the various ESI index classes, as in MMA 2002 (Table 7).

Table 7. Definition of ESI from specific data. Source (MMA 2002)

Coastal Geomorphology	*Degree of exposition to Waves*	*Slope Intertidal*	*Kind of Substratum*	*Penetration Oil in the Substratum*	*ESI*	*Color*
Exposed cliff, impermeable artificial structures	High	> 30°	Cliff	Impermeable	1	Dark purple
Platforms eroded by action of waves	High	< 30°	Rocky substratum	Impermeable	2	Light purple
Fine and medium sand beaches	---	< 5°	Fine and medium sand	Semi-Impermeable (< 10 cm)	3	Dark blue
Beaches of sand and gravel	---	5 - 15°	Coarse grain size	Permeable (≤ 25 cm)	4	Blue
Beaches of sand and gravel	---	8 - 15°	Sand and gravel	≤ 50 cm	5	Light blue
Beaches of gravel and rip-rap	---	10 - 20°	Gravel	highly permeable	6	Green
Exposed flat intertidal areas	Variable high to medium	< 3°	Sand	limited penetration	7	Light yellow
Protected cliffs	Low	> 15°	Rocky substratum	---	8	Yellow
Protected flat intertidal areas	Low	< 3°	Mud	Low permeability	9	Orange
Salt marshes, mangroves	Medium to low	< 10°	Mud sand	Low permeability	10	Red

For salt marshes, the effective width of oiling is usually less than the close-to-zero slope would indicate. Findings from the Deepwater Horizon incident indicates that oil stranded along the marsh edge and bulk oiling usually spread into the marsh no more than about 10–15 m perpendicular to the shoreline due to the small tidal range (~0.5 m), the density of the vegetation, and the residual oil's high viscosity (Michel et al., 2013). Suggested shoreline slope model values for the various ESI rankings are shown in Table 8, and in particular for the flat ESI substrates, a slope of 3 degrees is suggested as a model approximation.

Table 8. Suggested shoreline slope values to be used in ERA acute for various ESI rankings. After NOAA (2002)

ESI ranking	Short description	Shoreline slope	Model value (degrees)
1	Exposed, Impermeable Vertical Substrates	is 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 meters wide.	10
3	Semi-Permeable Substrate, Low Potential for Oil Penetration and	the slope is very low, less than five degrees	3

	Burial		
4	Medium Permeability, Moderate Potential for Oil Penetration and Burial	The slope is intermediate, between 5 and 15 degrees.	10
5	Medium-to-High Permeability, High Potential for Oil Penetration and Burial	The slope is intermediate, between eight and 15 degrees	12
6	High Permeability, High Potential for Oil Penetration and Burial	The slope is intermediate to steep, between ten and 20 degrees	15
7	Exposed, Flat, Permeable Substrate	They are flat (less than 3 degrees)	3
8	Sheltered Impermeable Substrate, Hard	Slope is generally steep (greater than 15 degrees), resulting in a narrow intertidal zone.	20
9	Sheltered, Flat, Semi-Permeable Substrate, Soft	The substrate is flat (less than 3 degrees)	13
10	Vegetated Emergent Wetlands	The substrate is flat	3

Etkin et al., 2007 reports that: A model to accurately simulate these interactions taking into account all of the characteristics of the oil, the shore, waves, and other environmental factors, while useful for some purposes, is impractical for an oil spill risk analysis modelling application that is run in a stochastic manner. A more simplified approach is required.

The conclusions of the study were that oil-holding capacity (OHC) based on shoreline type and oil type was the best methodology to achieve this goal of a simplified approach to shoreline oiling interactions in oil spill risk analysis modelling. Likewise, Samaras et al. (2014) concluded after extensive literature review that improvement regarding predicted oil amounts hitting the coast should be based on OHC, parameterized for different coastal types. Etkin et al. (2007) concluded that the values of holding capacity by shoreline type would be most practically applied in a simple stochastic oil risk or oil trajectory/fate model would be a combination of 1) the Boufadel methodology (hydraulic holding capacity model) for light oils that would easily penetrate beach sediments and not be expected to have any appreciable surface buildup; and 2) the SCAT methodology for medium-heavy oils that would both partially penetrate beach sediments and accumulate on the shoreline surface. As the Boufandel methodology requires more field data to be implemented, and given the scarity of such data, it is suggested to apply the SCAT metodology in ERA acute – with various OHC values for light, medium and high vicosity crude oils (see Table 9).

Table 9. Oil Holding capacities with estimated area holding capacities (from Etkin et al.2007)

Shoreline Type	Maximum Surface Oil Thickness (mm) By Viscosity			Subsurface Oil-Holding Capacity		Estimated Maximum Holding Capacity (m^3 Oil/m^2 Sediment)*		
	Light <30 cS	Medium 30 – 2,000 cS	High >2,000 cS	Oil Depth (mm)	Oil content by volume (%)	Light <30 cS	Medium 30 – 2,000 cS	High >2,000 cS
Rocky cliff	0.5	2	2	0	0	0.0005	0.0020	0.0020
Sandy beach	4	17	25	50	9.8	0.0040	0.0170	0.0250
Sand/gravel	2	9	15	180	8.3	0.0021	0.0091	0.0151
Tidal flat	3	6	10	0	0	0.0030	0.0060	0.0100
Rocky shore	1	5	10	0	0	0.0010	0.0050	0.0100
Marsh	6	30	40	-	-	0.0060	0.0300	0.0400
Peat scarp	1	4	10	0	0	0.0010	0.0040	0.0100

*Based on addition of maximum oil surface thickness (assuming 100% coverage) to subsurface oil content.

The practical implementation of this in ERA acute is that there may be several different ESI rankings within each grid cell, and then the accumulated shoreline volume must be redistributed to the various ESI habitats according to their respective oil-holding capacities given in Table 9.

It would be very beneficial if this could be handled within the oil spill model and for OSCAR this then needs to be implemented in stochastic modelling (in addition to deterministic modelling as of today). If this implementation is made available, the preferable export would be oil volume per ESI category in each grid cell.

Sea turtle nesting beaches must be mapped separately and would be addressed as a sub-group of the ESI rank 3A. Impact to such beaches is proposed to follow the same calculation steps as for the other ESI shoreline rankings.

3.3.1 Patchiness in oiling

The patchiness or coverage of oil within a model grid cell should also be taken into account as oil most probably will not be evenly distributed on the shoreline. The patchiness of oil distribution will depend on factors like the characteristics (complexity) of the shoreline (length and remobilization properties), local wind and current conditions that influence oil stranding patterns over time and the characteristics of the oil/emulsion. No good information has been found in literature to predict the actual distribution of oil on a shoreline. The oiled band width for defined as Heavy (in the SCAT approach) for the *Exxon Valdez* response surveys was >6m, whereas for the *Deepwater Horizon* response it was >1.8 m, reflecting the differences in tidal range among the regions (5 m in Alaska and <1 m in the Gulf of Mexico).

As the tidal range is part of the Width of coastal impact (W_{imp}) calculation, an approach to address the issue of patchiness would therefore be to base the impact calculations on a Patchy (11-51 %) distribution of oil instead of a Continuous (>90%) distribution. A 20 % coverage is suggested as a slightly conservative value for a patchy oil distribution and the calculation of impact width should be rewritten as:

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

3.3.2 Calculation example

Based on accumulated oil volume on the shoreline (V_{cell} from the oil spill modelling) and oil density, the distribution of oil in various ESI habitats in the grid cell can be estimated (Figure 4). This is done by weighting the various ESI segments by their length (L) and by applying the Oil-Holding Capacity (OHC) (see Table 9) related to each ESI ranking (r).

$$Weight_r = L_r \times OHC_r$$

The volume per ESI ranking is then:

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

Given the slope (sl) associated with each ESI ranking, the tidal range (TR) and a patchiness factor of 0,2the width (W_{imp}) of oiling in each segment can be calculated by :

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

And further 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 upon effect or no effect for each ESI ranking in each grid cell.

INPUT values:			
Oil viscosity	1000	*cS*	used in look-up table on holding capacity
Cell volume	10	*tons*	comes from oil drift
Tidal range	1	*m*	used in width calculation

ESI	Length	OHC	Weight	Volume	Slope	Width	Thickness	Impact	
1	1	2,7	2,7	208	35	0,4	0,541	1,0	*Exposed rocky headlands (ESI 1)*
2	1	2,7	2,7	208	10	1,2	0,178	1,0	*Eroding wave cut platforms (ESI 2)*
3	1	23,3	23,3	1791	3	3,8	0,468	1,0	*Exposed fine-grained sandy beaches (ESI 3)*
4	1	12,4	12,4	953	10	1,2	0,819	1,0	*Exposed coarse-grained sandy beaches (ESI 4)*
5	1	12,4	12,4	953	12	1,0	0,977	1,0	*Exposed tidal flats with compact fine sediment (ESI 5) coarse-gr*
6	1	12,4	12,4	953	15	0,8	1,207	1,0	*Exposed pebble beach (ESI 6) or sandy or gravel beach (ESI 6a)*
7	1	8,2	8,2	630	3	3,8	0,165	1,0	*Boulders (ESI 7)*
8	1	6,8	6,8	523	20	0,6	0,861	1,0	*Sheltered rocky shores (ESI 8)*
9	1	8,2	8,2	630	3	3,8	0,165	1,0	*Sheltered sandy-silty to silty tidal flats (ESI 9)*
10	1	41	41	3151	3	3,8	0,824	1,0	*Salt marshes (ESI 10)*
	10		130,1	10000				10,0	
	km	*m3 oil* / *m2 sedim*		*kg*	*deg*	*m*	*mm*	*km*	

Look-up table for oil holding capacity (OHC)

	Oil viscosity		
ESI	**<30 cS**	**30-2000 cS**	**>2000 cS**
1	2,8	2,7	1,8
2	2,8	2,7	1,8
3	22,7	23,3	22,3
4	11,9	12,4	13,5
5	11,9	12,4	13,5
6	11,9	12,4	13,5
7	17	8,2	8,9
8	5,7	6,8	8,9
9	17	8,2	8,9
10	34,1	41	35,7

Look-up table for slope

ESI	Slope
1	35
2	10
3	3
4	10
5	12
6	15
7	3
8	20
9	3
10	3

Figure 4. Example of calculation of oil volume and then oil film thickness for each ESI ranking within a model grid cell.

The total impact for each ESI ranking (r) is then given by the total length (L) for all grid cells where the thickness (T) is above the threshold value (TH):

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

The overall impact for the shoreline compartment is given by the sum of all ESI impacts:

$$\boldsymbol{Imp} = \sum_{\boldsymbol{r}} \boldsymbol{Imp_r}$$

4 LAG AND RESTORATION PHASE

Oil behaviour at the shoreline depends on a number of interrelated factors including oil properties, coast type and beach properties in addition to coastal hydrodynamics (Samaras et al., 2014). The recovery of a shoreline habitat after exposure to oil is a stepwise process. First oil is removed by natural processes (or clean-up) so that the shoreline is eligible for recovery and recolonization of species. Then, the local biological community will develop in a successive manner until it reaches a near-pre-spill state. Literature regarding the recovery rates of shorelines after damage by oiling for modelling purposes is reviewed in detailed by French-McKay (French-McCay, 2009) and summarized in Table 12.

Shoreline oiling resulting from Deepwater Horizon spill has also provided some new insights into the persistence of oil on different shorelines (mainly sandy beaches and marches) and their recovery times (Michel et al., 2013; Turner et al., 2014b; Yin et al., 2015). It is of course too early to conclude on the long term effects of this incident on the Gulf of Mexico shorelines.

The recovery phase after shoreline oiling can be divided into a lag phase and a restoration phase. The lag phase can be defined as the period of oil thickness above the effect-threshold value identified in section 3. The duration of the lag phase will depend on oil related parameters (volume/thickness, oil type, weathering state), the amount of hydrodynamic energy (waves and tides) acting on the shoreline, the oil holding capacity of the shoreline in addition to oil degradation processes (biological and chemical) and cleaning activities. Based on observation data it has been proven difficult to identify direct links between the volume of oil spilled on a shoreline and the length of the recovery phase. There are examples of that a small to moderate sized spills can have environmental impacts on par with much larger spills (Finlayson et al., 2015).

The restoration phase is defined as the period from when oiling is below the effect threshold value until vegetation and invertebrates has reached 99% of the pre spill function. Usually no distinction between lag and restoration phases is made when recovery rates of shorelines damaged by oil is reported, meaning that implementation of observed recovery times as time for restoration can be conservative.

In the following sections results from a literature survey aiming at identifying and assessing factors potentially affecting the duration of the lag and restoration phases after shoreline oiling will be presented and recommendations for model implementations are put forward.

4.1 The lag phase

Once attached to the shoreline, oil fate can roughly be broken down into two scenarios, either being washed off/released and restrained into the near shore or being deposited on the beach surface. Oil that has stranded on the surface has the potential to penetrate into the subsurface layer. Penetration is to a large degree dependent on the type of shoreline (substrate) and oil in subsurface layers infers longer lag-times. The washing off, or release of oil from a shoreline is largely influenced by the hydrodynamic energy level and the oil holding capacity of the shoreline, whereas the shoreline intrinsic oil degradation processes determine the rate of degradation of oil in subsurface layers.

The hydrodynamic energy level

The hydrodynamic energy level, wave-energy flux and tidal energy flux, of a coastline is decisive for the degree of exposure, impact and persistence of stranded oil.

The wave energy flux is a function of the average wave height measured over at least one year. A shoreline with a high wave energy flux is exposed to high waves and the impact of spilled oil is reduced because offshore directed currents transport oil away from the shoreline. Wave generated currents will also mix and rework costal segments leading to a release or burial of oil. It is also a fact that organisms adapted to living on high energy flux shorelines are accustomed to short-term perturbations in the environment and might be less susceptible to long term damage caused by oiling than organisms living in more stable environments. The tidal energy flux refers to the potential for tidal currents to remove, build and move intertidal sand or gravel that bury the oil. In general highly mobile substrates harbour fewer species than stable substrates (NOAA, 2002).

Also shoreline slope is affecting the natural cleanup of a shoreline. Steep intertidal areas are usually subject to abrupt wave run-up and breaking enhancing natural cleanup. Flat areas are characterized by low wave energy and oil is to a larger extent remaining in the intertidal zone.

Experience from shoreline oiling after the DWH spill also illustrate how erosion and depositional processes of the beach cycle, seasonal wind pattern and storms to a large extent impact how oil became buried, exposed and remobilized (Michel et al., 2013).

In the ESI shoreline classification system, shorelines are classified as high energy, medium and low energy shorelines. High energy shorelines (1A - 2B) are regularly exposed to large waves and strong currents. Oil will be removed rapid through natural removal processes. Medium energy shorelines (3A-7) often have seasonal patterns in storm frequency and wave size. Removal of oil will be when next high energy event occurs (days or months after the spill). Low energy shorelines are sheltered from wave and tidal energy (8A-10E) and oil will be removed slowly by natural removal, usually within years.

Oil holding capacity (OHC)

The OHC is defined as the maximum volume of oil a beach (shoreline) can accumulate. OHC is related to the shorelines permeability to oil which is also reflected in the ESI-classification system. Impermeable substrates are ranked low (i.e. rocky shores are classified as ESI 1) and more permeable substrates are ranked higher (i.e. wetland and marches belong to ESI 10). As part of the development of the impact algorithms (Section 3), the OHC is implemented in the prediction of oil amounts hitting the coast. For the lag phase, OHC can be used for estimating the time of release of the beached oil particles enabling predictions of the time before the amount (mm) of stranded oil is below the threshold value of effect. This could be based on the probability of release of beached oil for different coast types. Samaras et al (2014) have developed a new approach for the calculation of permanent oil attachment to the coast in oil spill models. This approach builds upon the half –life approximation of release of oil from different shorelines. To our understanding the model most likely only reflect oil attached to the surface and to a lesser degree reflect oil that has penetrated into the sediments and as a result a less relevant tool to predict removal of oil from subsurface layers. Precise knowledge linking volume to release-rate of oil from subsurface layers for sheltered areas are in general scarce, but experience data from the Exxon Valdez incident indicate that oil can be present for a long time after a spill (Boehm et al., 2008; Taylor and Reimer, 2008). The persistence of oil in subsurface areas will to a large degree depend on the oil degradation processes.

Oil degradation processes

In addition to factors like holding capacity and energy level influencing the physical removal of oil, shoreline intrinsic oil degradation processes also influence the duration of the lag phase. The rate of this process is dependent on factors like the chemical composition and weathering status of the oil, temperature and oxygen level. Crude oil is a complex mixture of thousands of chemical components. The relative compositions vary, giving rise to crude oils with different chemical and physical properties.

Crude oil reaching the shore has undergone a weathering process on the way. The degree of weathering depends on factors such as time at sea, chemical properties, and weather conditions such as temperature, sunlight and wind. Weathering processes at sea include evaporation, dissolution, emulsification, photolysis, spreading, microbial degradation, dispersion and vertical diffusion. Crude oil reaching the shore may be in shape of tar-balls, sheen, droplets or mousse (emulsion)(Turner et al., 2014a).

In general, the higher the molecular weight of PAHs, the higher the hydrophobicity and toxicity, and the slower the compound is to degrade. Collectively, these physicochemical properties mean that mid-length aromatic hydrocarbons are not readily volatilized or leached from soil and can remain toxic unless degraded to non-toxic forms (Turner et al., 2014a).

Yin (Yin et al., 2015) monitored the changes in the weight of laboratory weathered oil from the Macondo blowout. The data showed that within 5 h about 33% of the oil mass was volatilized, and within a day about 39% of the oil mass was removed. The rate of evaporation declined considerably after about 12 h; and after 6 days of evaporation about 44% of the total oil mass was removed from the system. Turner et al have performed a study of PAH degradation in the salt marshes that were heavily oiled by the Macondo oil in summer 2010. In October 2012, 28 alkanes had declined to <10% of their peak concentration, however, still remaining 15 times higher than before the oiling. The lighter alkanes in the parent oil were largely absent. The concentrations of 43 aromatics, in contrast, were fairly stable and five of them increased. Of these five, the authors speculate that the relatively light PAHs, naphthalene and C1-naphthalenes, are more likely to be of concern as being a toxic burden larger than when first oiled. The reason for this increase is unknown, and may be accompanied by unidentified degradation products from the unexplored 98% of the oil that is not routinely documented. The average concentration of PAHs remaining as of June 2013, equals or exceeds the level at which stressors occur in the common marsh fish, *Fundulus grandis*, plants, and insect community. At current trajectories of change, some hydrocarbons will remain for many more decades, as will the impacts, which remain subtle and largely unexplored (Turner et al., 2014a). Culbertson et al. performed a series of studies in marsh sediments in Buzzards Bay in Massachusetts 35 years after a large spill of fuel oil. Biological effects were noted in fiddler crabs, and ribbed mussels inhabiting the oiled marsh. In addition, they found reduced stem density and biomass of salt mash grass in the affected area (Culbertson et al., 2008a; Culbertson et al., 2007; Culbertson et al., 2008b). Field observations in Prince William Sound 13 years after the Exxon Valdez incident have identified significant oiling at selected sites that were resurveyed following SCAT field observation procedures (Taylor and Reimer, 2008). Both surface and sub-surface oiling conditions in shoreline sediments were documented. The survey found isolated occurrence of oil on surface in the form of weathered asphalt pavement at 15 of 39 sites. The occurrences in 2002 closely match the occurrences in the initial survey. The subsurface patches were however more discontinuous and thinner than they were in earlier surveys. Despite evidence of continued oil degradation, both at the surface and in the subsurface, degradation rates are low. The slow weathering rates are a consequence of the oil residue being incorporated in finer sediments isolated from active weathering processes (Taylor and Reimer, 2008).

As illustrate above, some data are available about the degradation rates of different components of oil in different shoreline habitats. Unfortunately there is still not enough information for us to be able to make a recommendation regarding the duration of the lag phase based on intrinsic oil degradation processes in various ESI habitats. To capture oil specific effects, we recommend to use the classification proposed by NOAA (Table 10) grouping oils into four basic types (from very light to heavy oils). The classification is based on experience from how they affect shorelines and how hard they are to clean up. A general summary of how each type of oil can affect the shoreline is presented in Table 10.

Table 10: How different oil types can affect shorelines (Source: NOAA, http://response.restoration.noaa.gov/oil-and-chemical-spills/oil-spills/oil-types.html)

Type 1: Very Light Oils (Jet Fuels, Gasoline) • Highly volatile (should evaporate within 1-2 days). • High concentrations of toxic (soluble) compounds. • Localized, severe impacts to water column and intertidal resources. • No clean-up possible.
Type 2: Light oils (Diesels, No. 2 Fuel Oil, Light Crudes) • Moderately volatile; will leave residue (up to one-third of spill amount) after a few days. • Moderate concentrations of toxic (soluble) compounds. • Will “oil” intertidal resources with long-term contamination potential. • Clean-up can be very effective.
Type 3: Medium oils (Most Crude Oils) • About one-third will evaporate within 24 hours. • Oil contamination of intertidal areas can be severe and long-term. • Oil impacts to waterfowl and fur-bearing mammals • Clean-up most effective if conducted quickly
Type 4: Heavy Oils (Heavy Crude Oils, No 6 Fuel Oil, Bunker C) • Little or no evaporation or dissolution. • Heavy contamination of intertidal areas likely. • Severe impacts to waterfowl and fur –bearing mammals (coating and ingestion) • Long-term contamination of sediments possible. • Weathers very slowly • Shoreline clean-up difficult under all conditions.

4.1.1 Recommendations lag phase

The lag phase of a shoreline after oiling is influenced by volume, oil type and weathering state in addition to the shoreline’s hydrodynamic energy level, the oil holding capacity and intrinsic oil degradation processes. As outlined above, there is a lack of evidence linking some of these factors to shoreline specific lag times and based on available data we propose to base our recommendations about the lag-time period mainly on the hydrodynamic energy level in combination with oil type specific impacts, as illustrated in Table 11.

Because of the quick removal of oil from high energy shorelines a separate lag-phase in the damage expression would only be relevant for medium and low energy shorelines. The recovery time for high energy shorelines can be based on the length of the restoration phase only (see chapter 4.2). Medium energy shorelines can slightly conservatively be assigned a lag time of one year when hit by medium and heavy oil based on the natural physical removal processes described above. Based on a lack of experience data, it is challenging to assign a specific lag time period for low energy shorelines. For modelling purposes we think it would be beneficial to include a lag phase to the low energy shorelines (ESI 8-10) of three to 10 years. This assures that the oiling of sheltered shorelines are better reflected in the damage expression.

Table 11: Lookup table lag-phase

Shoreline energy status (ESI)	***T_{lag} (years)***	***Type 1 Very light oils***	***Type 2 Light oils***	***Type 3 Medium oils***	***Type 4 Heavy oils***
High energy (ESI 1A-2B)	-	0	0	0	0
Medium energy (3A-7)	0-1	0	0	1	1
Low energy (8A-10E)	3-10	0	3	7	10

4.2 The restoration phase

The restoration of plant or invertebrate production in an oiled habitat is assumed to follow a sigmoid function. Literature regarding the recovery rate of benthic invertebrates, vegetation or other structural organisms after the structural organisms are killed or severely damaged is reviewed in detailed in (French-McCay, 2009) and summarized in Table 12.

Assumed values of t_{rec}, the time to 99% recovery, for vegetation or species important for the structure of a habitat, are specific to habitat type and are based on experiences from observations of natural recovery following disturbance (including spills) and from habitat creation projects. Values vary from 3 to 20 years. Time for recovery of benthic invertebrates to 99% of function/pre spill situation is estimated as 3-5 years, based on a natural recovery cycle. French-McKay do not discriminate between a lag phase and a restoration phase and the proposed values might be a conservative estimate when looking at restoration separate from the lag phase.

Table 12 Recovery rates for vegetation or other structural organisms, and for benthic invertebrates where habitat structure is not impacted (Adapted from (French-McCay, 2009)

Habitat (ESI shoreline classification)	***Vegetation or Structure: Years to 99% Recovery***	***Benthic Invertebrates: Years to 99% Recovery***
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 Rip rap-structures (6) Exposed tidal flats (7 and 9)	-	3
Wetland: Emergent Marsh (10A, 10B)	15	5
Wetland: Swamp (10C, 10D)	20	5

The rationale /observation data and assumptions supporting the proposed recovery-times, in addition to some new findings after the Deepwater Horizon incident, are summarized below:

Rocky, Man-made and Artificial shores

Artificial shores, rock and gravel beaches are assumed to have recovered three years after oil exposure. This is based on 7 different large oil spills all affecting rocky shorelines. Shorelines left untreated had in general a much faster recovery rate than shorelines attempted cleaned by different approaches. Recovery rates from shores which were left untreated was reported to be 1 year for the Esso Bernicia spill (Shetland Islands in1987), the Tsesis spill (Baltic Seas in 1977) and following a medium crude oil spill in Panama (French-McCay, 2009). 2-5 years recovery of flora and fauna was reported after the Nakhodas spill in Japan and was also used in support of a recovery rate of 3 years.

Sand Beaches and Mud flats

Mud flats are assumed to recover at the same rates as sandy beaches. Experience from Panama, France, and the Baltic Sea (French-McCay, 2009) indicate that recovery rates are variable and to a large degree depending on conditions and disturbance during the spill response. A value of three years is proposed for modelling purposes.

Michel et al. (2013) have reviewed the results from the shoreline cleanup program after the Deepwater Horizon spill. After the incident, shoreline assessment teams (SCAT-program) documented stranding of oil on 1,773 km of shoreline. Beaches comprised 50,8%, marshes 44,9% and other shoreline types 4,3 % of the 1773 km oiled shoreline. Shoreline cleanup activities were authorized on 73% of the beaches. Shorelines characterized as heavily oiled went from a maximum of 360 km, to 22,4 km in year later and to 6,4 km after two years, indicating a relatively fast recovery of the sandy beaches in the area. For amenity beaches the cleanup endpoint was “No visible oil above background levels or as low as reasonable practical concerning the allowed treatment methods and net environmental benefit”, whereas for non-amenity beaches and federally managed land the cleanup endpoint was < 1% visible oil. Although the long term effects of the DWH spill on the Gulf of Mexico beaches is not known, early observations support a recovery rate of three years.

Saltmarsh and Other Emergent Wetlands

Where saltmarsh structure is lost, 15 years is assumed required for full recovery of all parts of the ecosystem. If the function is not lost , 5 years is assumed for recovery of other functions, including invertebrate populations (French-McCay, 2009). Experience from the DWH spill will eventually shed more light on the long term effect of oiling of wetlands as around 40% of the oiled shoreline was wetlands (Turner et al., 2014b). It has been demonstrated that oil can have long term detrimental effects on marsh plant health (McClenachan et al., 2013). Heavy oiling weakens the soil, creating a deeper undercut of the upper 50 cm of the march edge causing an accelerating rate of erosion. Observations have indicated that it can take 2 years to document the effects of heavy oiling has had on the marsh shoreline and that the presence of aboveground vegetation alone may not be an appropriate indicator of recovery. The dominant salt march grass in costal Louisiana is *Spartina alterniflora.* An important function of this species is to increase marsh resistance to erosion. Results of laboratory and field studies have shown that high amounts of oil can have significant negative impact on both above ground and belowground production. Heavily oiled marches are eroding faster than non-oiled marches over the first 18 months post oil spill. This finding is consistent with Alexander and Webb (1987) finding that shoreline erosion continue through 32 months. The full extent of the DWHs impact to marsh erosion rates may not be evident for many years; the weakening of the soil and possible decrease in organic matter accumulation could lead to submergence of the marshes (McClenachan et al., 2013). Early observations support the proposed 15 years recovery time.

Forested and Shrub Wetlands (Swamps)

Marshes, mangroves and other vegetated wetlands are the most sensitive habitats because of their high biological use and value, difficulty to cleanup and potential for long-term impacts to many organisms (NOAA, 2002). Mature mangrove trees are 50-70 years old and recolonization is slow. NOAA (2010) has estimated time until complete recovery after oiling to be between 10-50 (?) years. French-McCay proposes to use 20 years recovery time for modeling purposes. In the model it is assumed that replanting is performed, eliminating the recolonization lag.

4.2.1 Recommendations restoration phase

We propose to use the ESI specific recovery times presented in Table 12.

The final damage expression (*Damage*) will be given as impact multiplied with time to recovery and thus expressed as km years for each ESI rank (*r*)

$$Damage_r = \sum_{cell} Imp_r$$

And finally the total damage can be given by the sum of damage on all ESI rankings

$$Damage = \sum_{r} Damage_r$$

INPUT values:											
Oil viscosity	1000	*cS*	Input from oil drift modelling- used in look-up table on holding capacity								
Cell volume	2	*tons*	Input from oil drift modelling								
Tidal range	1	*m*	user input - used in width calculation								
ESI	**Length**	**OHC**	**Weight**	**Volume**	**Slope**	**Width**	**Thickness**	**Impact**	**Lag**	**Recovery**	**Damage**
1	1	2,7	2,7	42	35	0,4	0,108	1,0	0	3	3
2	1	2,7	2,7	42	10	1,2	0,036	0,0	0	3	0
3	1	23,3	23,3	358	3	3,8	0,094	0,0	1	3	0
4	1	12,4	12,4	191	10	1,2	0,164	1,0	1	3	4
5	1	12,4	12,4	191	12	1,0	0,195	1,0	1	3	4
6	1	12,4	12,4	191	15	0,8	0,241	1,0	1	3	4
7	1	8,2	8,2	126	3	3,8	0,033	0,0	1	3	0
8	1	6,8	6,8	105	20	0,6	0,172	1,0	7	3	10
9	1	8,2	8,2	126	3	3,8	0,033	0,0	7	3	0
10	1	41	41	630	3	3,8	0,165	1,0	7	5	12
	10		130,1	2000				6,0			37,0
	km	*m3 oil*		*kg*	*deg*	*m*	*mm*	*km*	*Years*	*Years*	*KmYears*
		m2 sedim									

Figure 5: Example of calculation of lag and restoration and final damage on a single grid cell with a medium oil where habitat structure is not impacted.

5 RISK MATRIX

The results of the damage calculation can be expressed in a risk matrix- format. First, the impact must be classified according to the company's severity categories (Step 1 in Figure 6). Impact can either be expressed as km/year or as impacted km compared to the total habitat. Impact is calculated for each simulation in a scenario and risk may be calculated as either average impact over all simulations or as a probability distribution of different impacts from all scenarios. Impact is then plotted in the company's risk matrix as illustrated in Step 2 in Figure 6.

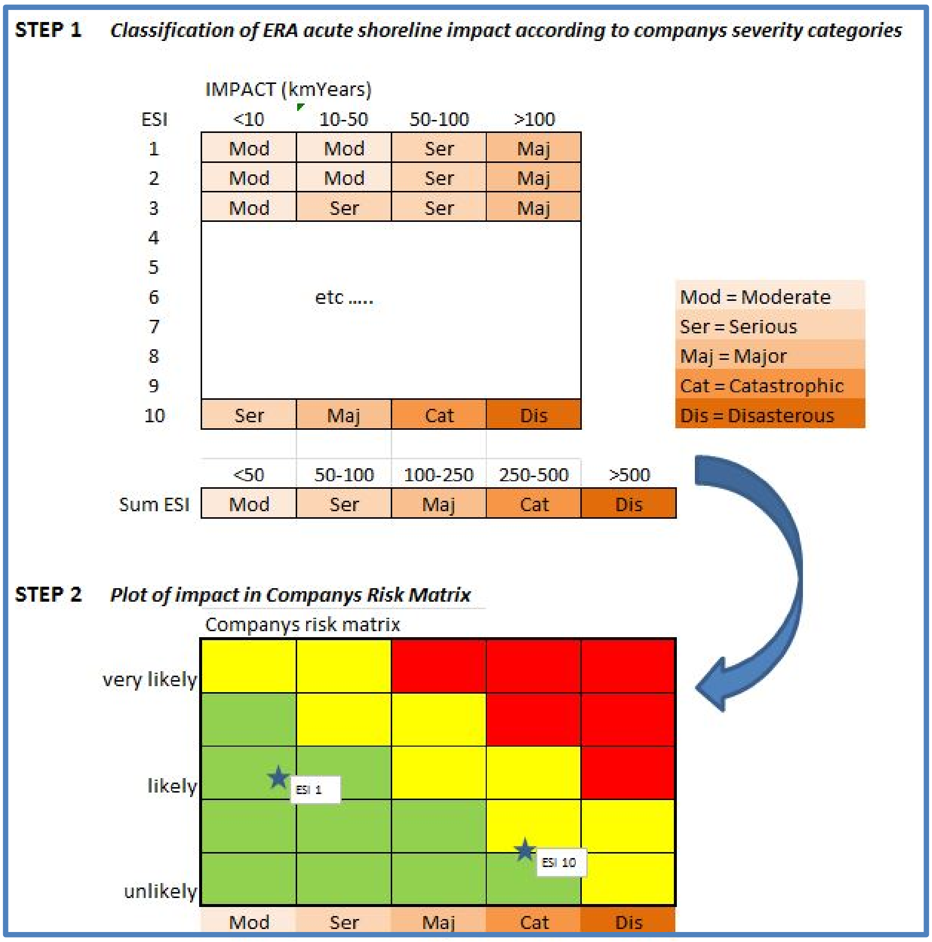

Figure 6. Implementation of results in a risk matrix format.

6 COMPARISON WITH MIRA (OLF, 2007)

Based on the lack of precise experience- and scientific data we have suggested a rather simple but robust approach for the expression of damage to shore after oiling. The method is to a large degree build upon the ESI-classification system and other recommended practices for modelling of damage to shore by oiling (French-McCay, 2009).

The impact algorithm is based on ESI specific shoreline slope, tidal range, oil holding capacity of the shoreline as well as oil viscosity in the calculation of a thickness value in mm. This threshold value is then compared against a set of defined effect threshold values. The total impact for each ESI ranking is given by the total length for all grid cells where the thickness is above the threshold value. This differs from the MIRA approach where categories of accumulated oil and the combined sensitivity within a grid cell is used to express impact, meaning that a small fraction of a highly vulnerable shoreline (i.e mangrove) will not be reflected account in the impact expression. A refinement compared to the MIRA approach is also to use ESI specific oil holding capacities and tidal range to redistribute oil volumes within a grid cell. The ERA acute approach is thus allowing for a more detailed expression of impact than the MIRA method. By including a lag phase for the medium and low energy shorelines we have built-in an additional element compared to both MIRA and French-McCay (2009), reflecting the longer oil exposure scenarios these habitats experience as a function of the low degree of physical and chemical weathering processes influencing persistence of oil on sheltered shorelines. Due to a lack of scientific evidence, the proposed lag times are best estimates based on expert judgements. A closer link between the volume of stranded oil and the recovery and lag phases would be beneficial, but again we were not able to find data supporting such refinement. It is worth mentioning that the spill volume of oil is covered by the impact algorithm: as a larger spill result in more km affected shoreline than a smaller spill. The main differences from the MIRA-method (OLF, 2007) are summarized in Table 13.

To get a better understanding of how the ERA acute phase 3 algorithms is working, thorough testing and comparisons with the MIRA approach should be undertaken.

Table 13. Main differences in the calculation of damage to shoreline after acute oil pollution in ERA Acute Phase 3 and the OLF 2007/MIRA approach.

Function	ERA Acute	OLF 2007
Impact function	• Uses accumulated oil volume in defined grid cells • Uses ESI shoreline classifications, oil holding capacity and tidal range to redistribute oil volumes to various parts of the shoreline within the grid cell • Uses ESI shoreline specific threshold values for thickness of oil on shore to calculate if a segment is impacted or not	• Defines each habitat as the grid cell size (10x10 km) • Uses categorized accumulated oil volumes in defined grid cells (1-100; 100-500; 500-1000 and >1000 tons) • Uses shoreline substrate and wave exposure classified into 3 sensitivity groups • Uses the combined sensitivity within a grid cell to calculate an average impact (=recovery time) for the grid cell based on the oil volume category
Lag phase	• Uses oil dependent but volume independent lag times for medium and low energy shorelines	• Part of the total recovery time estimate
Restitution model	• Uses ESI shoreline specific restoration times for restoration of benthic invertebrates and/or vegetation/structure of shoreline habitat • Expresses the damage as impacted km-years for each ESI shoreline type (including sub group of turtle beaches)	• Uses the combined sensitivity within a grid cell to calculate average impact (=recovery time in years) for the habitat based on the oil volume category • Apply a probability distribution between different recovery times based on historical spills

7 SUGGESTED TECHNICAL DESCRIPTION

7.1 Input data

7.1.1 Oil drift simulations

External oil drift simulation should provide .txt files with:

- **volume of oil / gridcell (V_{cell})**
- **viscosity / grid cell**

7.1.2 Habitat grid

Habitat grid must be provided as an excel file containing information about:

- **Grid ID**
- **km of ESI shorelines within each grid cell**
- **tidal range**

7.1.3 Look-up tables

Look up tables must be provided in excel files containing info about:

- **ESI specific look-up table with viscosity dependent oil holding capacity**
- **ESI specific look-up table with information about slope**
- **ESI specific look-up table regarding lag phase**
- **ESI specific look –up table regarding recovery phase**

8 REFERENCES

Boehm, P.D. et al., 2008. Distribution and weathering of crude oil residues on shorelines 18 years after the Exxon Valdez spill. Environ Sci Technol, 42(24): 9210-6.

Brude et al., 2003. Strand – Olje. Implementering av Damα-Shore for norskekysten. Alpha Miljørådgivning as.

Culbertson, J.B., Valiela, I., Olsen, Y.S., Reddy, C.M., 2008a. Effect of field exposure to 38-year-old residual petroleum hydrocarbons on growth, condition index, and filtration rate of the ribbed mussel, Geukensia demissa. Environ Pollut, 154(2): 312-9.

Culbertson, J.B. et al., 2007. Long-term biological effects of petroleum residues on fiddler crabs in salt marshes. Marine Pollution Bulletin, 54(7): 955-962.

Culbertson, J.B., Valiela, I., Pickart, M., Peacock, E.E., Reddy, C.M., 2008b. Long-term consequences of residual petroleum on salt marsh grass. Journal of Applied Ecology, 45(4): 1284-1292.

Etkin, D.S., French-McCay, D., Michel, J., 2007. Review of the State of the Art on Modelling Interactions between Spilled Oil and Shorelines for the Development of Algorithms for Oil Spill Risk Analyses Modelling, Cortland Manor. New York, pp. p157.

Finlayson, K., Stevens, T., Arthur, J.M., Rissik, D., 2015. Recovery of a subtropical rocky shore is not yet complete, four years after a moderate sized oil spill. Mar Pollut Bull, 93(1-2): 27-36.

French-McCay, D., 2009. State-of the -Art and Resarch Needs foor Oilspill Impact Assessment Modelling. Proccedings of the 23nd AMOP Technical seminar on Environmental Contamination and Response Emergencies Science Division, Environment Canada, Ottawa, ON, Canada, pp. 601-653.

Fritts, T.H., McGehee, M.A., 1982. Effects of petroleum on the development and survival of marine turtle embryos. Contract No. 14-16-0009-80-946, FWS/OBS-82/37. U.S. Fish and Wildlife Service, U.S. Department of the Interior, Washington, D.C.

Hoell, E., Gramme, E., 2006. EIF-Acute; Effect of oil spills on biological resources; sea surface and shoreline compartments. Hydro Report. 133 pp.

McClenachan, G., Turner, R.E., Tweel, A.W., 2013. Effects of oil on the rate and trajectory of Louisiana marsh shoreline erosion. Environmental Research Letters, 8(4): 044030.

Michel, J. et al., 2013. Extent and degree of shoreline oiling: Deepwater Horizon oil spill, Gulf of Mexico, USA. PLoS One, 8(6): e65087.

Miller, J.D., 1997. Reproduction in sea turtles. In: The Biology of Sea Turtles, Vol. I, P. L. Lutz and J. A. Musick, eds. CRC Press, Boca Raton, Fla. pp. 51–81.

Moe et al., 2000. The Svalbard Intertidal Zone: A Concept for the Use of GIS in Applied Oil Sensitivity, Vulnerability and Impact Analyses.

NOAA, 2002. Environmental sensitivity index guidelines . Version 3.0. NOAA Technical Memorandum NOS OR&R 11. Dated March, 2002.

OLF, 2007. Metode for miljørettet risikoanalyse (MIRA) - revisjon 2007. OLF rapport.

Philott, A.D., Parmenter, C.J., 2001. Influence of diminished respiratory surface area on survival of sea turtle embryos. J. Experim. Zool.289(5): 317–321.

Samaras, A.G., De Dominicis, M., Archetti, R., Lamberti, A., Pinardi, N., 2014. Towards improving the representation of beaching in oil spill models: a case study. Mar Pollut Bull, 88(1-2): 91-101.

Shigenaka, G., 2010. Oil and Sea Turtles. BIOLOGY, PLANNING, AND RESPONSE.
National Oceanic and Atmospheric Administration • National Ocean Service • Office of Response and Restoration. Reprinted July 2010.

Skeie et al., 2006. High resolution oil spill response planning for operations in a sensitive Arctic environment. Sharing information between operators, national authorities, local oil spill response groups and the general public, SPE International Conference on Health, Safety, and Environment in Oil and Gas Exploration and Production, Abu Dhabi.

Spikkerud et al., 2008. Strand - Strandsaneringsverktøy, DNV.

Taylor, E., Reimer, D., 2008. Oil persistence on beaches in Prince William Sound – A review of SCAT surveys conducted from 1989 to 2002. Marine Pollution Bulletin, 56(3): 458-474.

Turner, R.E., Overton, E.B., Meyer, B.M., Miles, M.S., Hooper-Bui, L., 2014a. Changes in the concentration and relative abundance of alkanes and PAHs from the Deepwater Horizon oiling of coastal marshes. Mar Pollut Bull, 86: 7.

Turner, R.E. et al., 2014b. Distribution and recovery trajectory of Macondo (Mississippi Canyon 252) oil in Louisiana coastal wetlands. Mar Pollut Bull, 87(1-2): 57-67.

U.S. Fish and Wildlife Service Data from web site: http://northflorida.fws.gov/seaturtles/turtle-facts-index.htm.

Yin, F., John, G.F., Hayworth, J.S., Clement, T.P., 2015. Long-term monitoring data to describe the fate of polycyclic aromatic hydrocarbons in Deepwater Horizon oil submerged off Alabama's beaches. Sci Total Environ, 508: 46-56.

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