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Development of a Risk-Based Environmental Management Tool for Drilling Discharges. Summary of a Four-Year Project

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EDITOR'S NOTE:

This is 1 of 5 papers reporting on the results of a 4-year project to develop an environmental risk-based decision support tool, to assist the oil industry in establishing cost-effective measures for reducing risk to the marine environment from drilling discharges.

ABSTRACT

This paper briefly summarizes the ERMS project and presents the developed model by showing results from environmental fates and risk calculations of a discharge from offshore drilling operations. The developed model calculates environmental risks for the water column and sediments resulting from exposure to toxic stressors (e.g., chemicals) and nontoxic stressors (e.g., suspended particles, sediment burial). The approach is based on existing risk assessment techniques described in the European Union technical guidance document on risk assessment and species sensitivity distributions. The model calculates an environmental impact factor, which characterizes the overall potential impact on the marine environment in terms of potentially impacted water volume and sediment area. The ERMS project started in 2003 and was finalized in 2007. In total, 28 scientific reports and 9 scientific papers have been delivered from the ERMS project (http://www.sintef.no/erms).

Keywords: ERMS   Drilling discharges   Marine impacts   Environmental risks

INTRODUCTION

In 1998, following the Norwegian authorities' requirements in 1997 of "zero discharges to sea by the end of 2005," exploration and production companies active on the Norwegian shelf initiated the development of a risk assessment tool for environmental management of produced water discharges. This effort was embodied in the Dose-Related Risk and Effect Assessment Model (DREAM) project. From this project the environmental impact factor for produced water (EIF_{PW}) was developed (Johnsen et al. 2000). The EIF_{PW} is an indicator of environmental risk whose purpose is to aid the industry in the development of a "zero harm" strategy and selection of cost–benefit based solutions. The use of this tool is presently required from Norwegian authorities in reporting and planning of environmental management actions for reduction of potential harmful environmental effects associated with produced water discharges. In order to develop the toolbox for environmental management further, the Environmental Risk Management System (ERMS) Joint Industry Project was established to develop an EIF for drilling discharges (EIF_{DD}).

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During drilling, a mixture of water, clay, and chemicals is used. This "drilling mud" is pumped down through the drill string and transports the cuttings created at the drill bit back to the surface. Furthermore, it cools and lubricates the drill bit and provides stability to the bore hole. Depending on the base fluid, different types of mud are referred to as oil-based mud, synthetic-based mud, or water-based mud. Drilling muds are usually reprocessed and recycled during drilling. However, when the mud characteristics are altered they may be discharged to the environment (if permitted by local regulations), re-injected into a well, or sent to shore for reprocessing or disposal.

Most drilling of offshore oil and gas wells in the North Sea (including the Norwegian Sector), the Gulf of Mexico, and other offshore production areas is achieved with water-based mud (Frost et al. 2006). This is due to strict regulations on discharges of oil-based mud and synthetic-based mud as a result of their potential environmental impacts. Discharge of oil-based mud was prohibited within the region falling under the Oslo–Paris convention (OSPAR) in 1984, while discharges of oil-based mud as contamination on cuttings have been prohibited in Norway since 1993 (and 1996 within the OSPAR area). The use of synthetic-based mud in the North Sea has been minor after 2001.

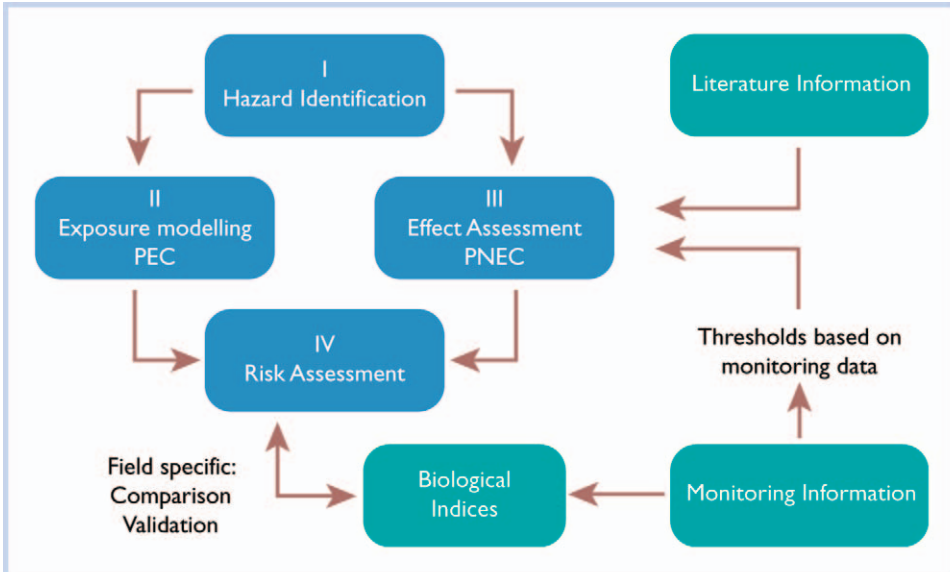

Figure 1. Framework for the environmental impact factor for drilling discharges (EIF_{DD}) indicating the different steps in the risk assessment process.

MATERIALS AND METHODS

Similar to the international agreed principles for risk assessment (EC 2003) the following steps were carried out in developing the EIF_{DD}:

- Hazard identification,
- Exposure modeling,
- Effect assessment,
- Risk assessment, and
- Validation

Figure 1 provides an overview of how these main activities were linked within the ERMS project. When defining the EIF_{DD} it was important to focus on the main environmental hazards from the drilling discharges (I). For this purpose a literature study was carried out and available information from historical field surveys was studied. In order to incorporate identified stressors in a risk assessment model, the challenge was to obtain an adequate estimation of the environmental exposure levels (II). For the prediction of concentrations of chemicals in the water column, DREAM software was used (Reed et al. 2001; Reed and Hetland 2002). For the calculation of the behavior of particles, the ParTrack model (Rye et al. 1998, 2004) for calculation of deposition of particles (cuttings, barite, etc.) on the sea floor was used. However, a combined model predicting fate and potential impacts from drilling discharges to both the water column and the sediment was not available (Khondaker 2000) and needed to be developed in this project.

For the derivation of effect levels (III) both literature and monitoring information was available. Guidelines from the European Commission's Technical Guidance Document for Risk Assessment (EU-TGD) were followed for the derivation of predicted no effect concentrations (PNECs; EC 2003). Additionally the theory of species sensitivity distributions was used (Aldenberg et al. 2002). For risk assessment (IV) for single stressors the ratio of predicted environmental concentration (PEC) and PNEC is prescribed by the EU-TGD. For the evaluation of the overall risks from complex mixtures to species assemblages the guidelines from De Zwart and Posthuma (2005) were available. Monitoring information was available for validation purposes.

RESULTS

As a result of the literature review 6 stressors related to the discharge of drilling waste to the marine environment were identified (Frost et al. 2006; Smit, Jak, et al. 2006). Of these 6 stressors, 2 of them occur in the water column (toxicity of chemical substances and physical effects of suspended clay particles) and 4 stressors occur in the sediment (toxicity of chemical substances, burial of organisms, oxygen depletion, and change in sediment structure). Special attention was paid to heavy metal impurities in barite (Neff 2008). In order to calculate the levels of these stressors, elements of the ParTrack model were incorporated in DREAM (Rye et al. 2006a, 2006b, 2008). The new version of DREAM was able to calculate 3-dimensional and time variable exposure levels in the water column and the sediment for both toxic and nontoxic stressors. The fate of the compounds in the discharge is calculated under the influence of ambient currents, turbulence and mixing, evaporation at the sea surface, and reduction of concentrations due to biodegradation. Figure 2 provides 3 model results showing the exposure of a chemical in the water column (Figure 2A), a chemical in the sediment (Figure 2B), and the deposited layer thickness (Figure 2C).

For the evaluation of single stressors the ratio of PEC and PNEC as prescribed by the EU-TGD was used. Following the guidelines from the EU-TGD PNECs for both the water column and the sediment were defined for toxic stressors (Källqvist 2007; Altin et al. 2008). For nontoxic stressors PNECs were derived using the species sensitive distribution approach (Smit, Holthaus, et al. 2006; Smit, Tamis, et al. 2006; Smit, Holthaus, et al. 2008; Smit, Jak, et al. 2008). Figure 3 provides 3 typical model results showing the ratio of PEC and PNEC for a chemical in the water column (Figure 3A), a chemical in the sediment (Figure 3B), and the deposited layer thickness (Figure 3C).

Additionally for each stressor identified, a species sensitive distribution was constructed in such a way that the 5th percentile of the distribution corresponded to the PNEC (Smit, Jak, et al. 2008). Assuming that the theory described by De Zwart and Posthuma (2005) is also applicable to combinations

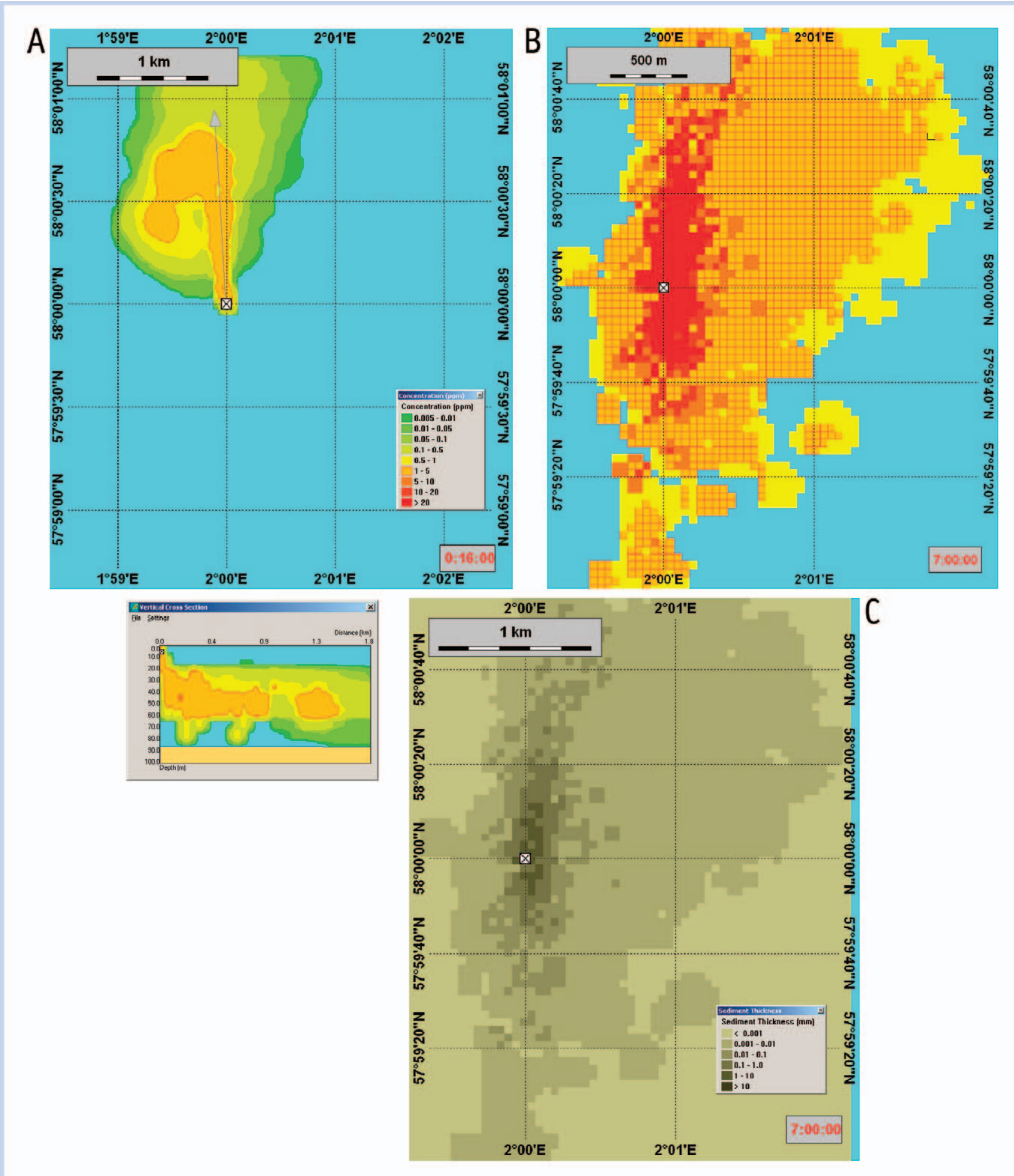

Figure 2. Three snapshots of an exposure calculation using Dose-Related Risk and Effect Assessment Model (DREAM). The cross indicates the discharge location. (**A**) A bird's view (**upper**) and a vertical cross section (**lower**) of the concentration of a water soluble chemical present in a drilling discharge. The cross section is from the main plume direction as indicated by the arrow in the upper figure. (**B**) The concentration of a lipophilic chemical in the sediment. (**C**) The thickness of the deposited layer on the sediment sea floor.

of toxic and nontoxic stressors, the constructed species sensitive distributions for the various stressors were used to calculate the potentially affected fraction of species as a result of the simultaneous exposure to multiple stressors (msPAF). Finally the developed model calculates the EIF. The value of the EIF is related to the recipient water volume and sediment surface area where msPAF exceeds 5% (Smit, Rye, et al. 2008). The selected unit for the EIF for the 2 compartments was a water volume of 100 m $\times$ 100 m $\times$ 10 m for the water column and 100 m $\times$ 100 m sediment surface area for the sediment. The advantage of the EIF method is that it calculates the overall risk and the contribution to risk from all stressors (Figure 4).

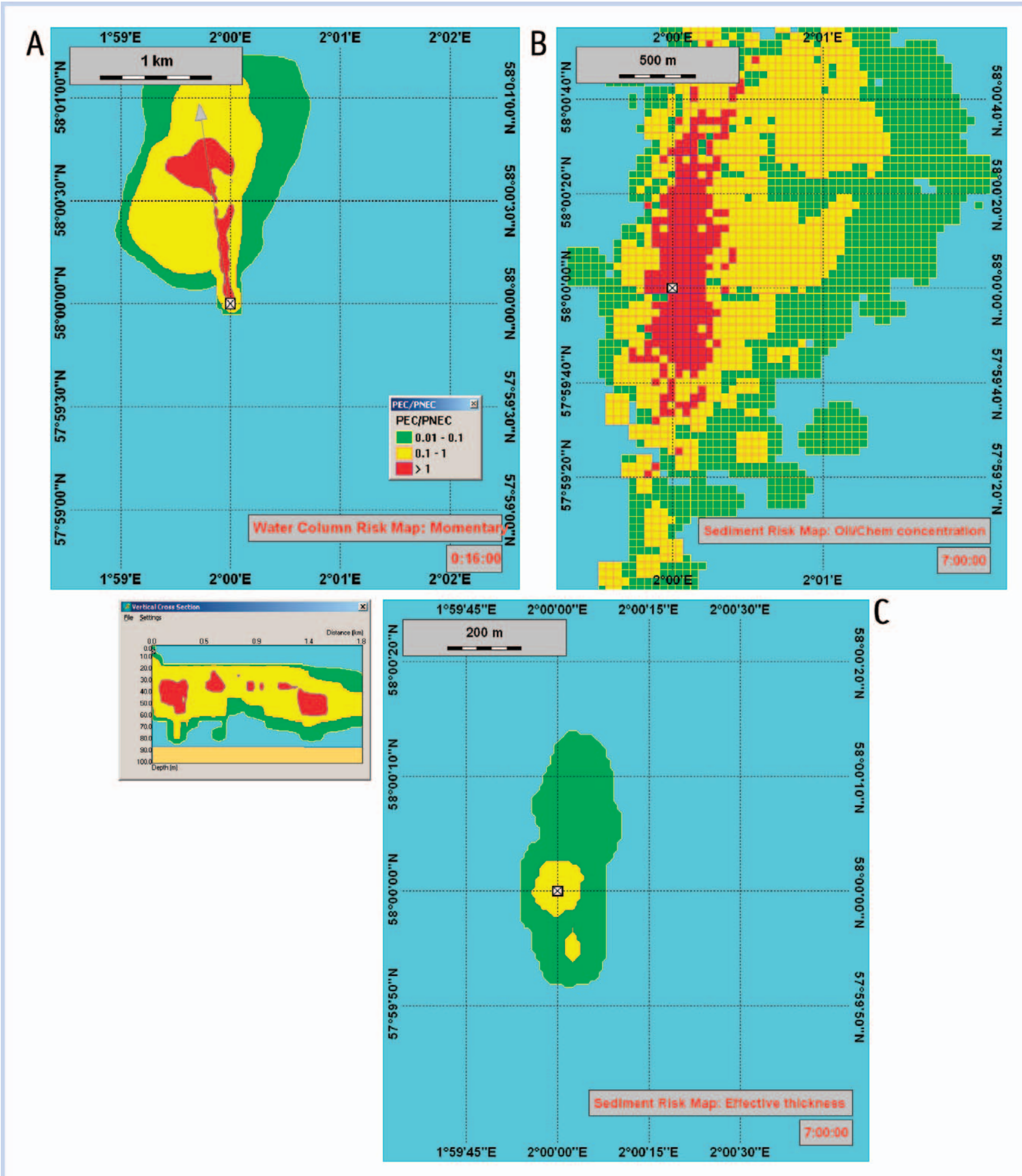

Figure 3. Three snapshots of a risk calculation using Dose-Related Risk and Effect Assessment Model (DREAM). The cross indicates the discharge location. (**A**) A bird's view (**upper**) and a vertical cross section (**lower**) of the risk of a water soluble chemical present in a drilling discharge. The cross section is from the main plume direction as indicated by the arrow in the upper figure. (**B**) The risk caused by a lipophilic chemical in the sediment. (**C**) The risk due to the thickness (burial) of the deposited layer on the sediment sea floor.

For validation purposes literature derived threshold effect levels have been compared to field-derived threshold levels based on sediment data from the Norwegian continental shelf. Generally, there was good correlation between the PNEC values derived from the equilibrium partitioning method and the field-derived thresholds (Brakstad and Trannum 2005; Grung et al. 2005; Leung et al. 2005; Altin et al. 2008).

CONCLUSION

This paper summarizes the achievements of the ERMS project. Table 1 provides an overview of publications describing the results of the ERMS project in detail. Up to now, no holistic framework was available for prognostic risk assessment of discharges causing toxic and nontoxic stress. The developed model includes the calculation of fates of

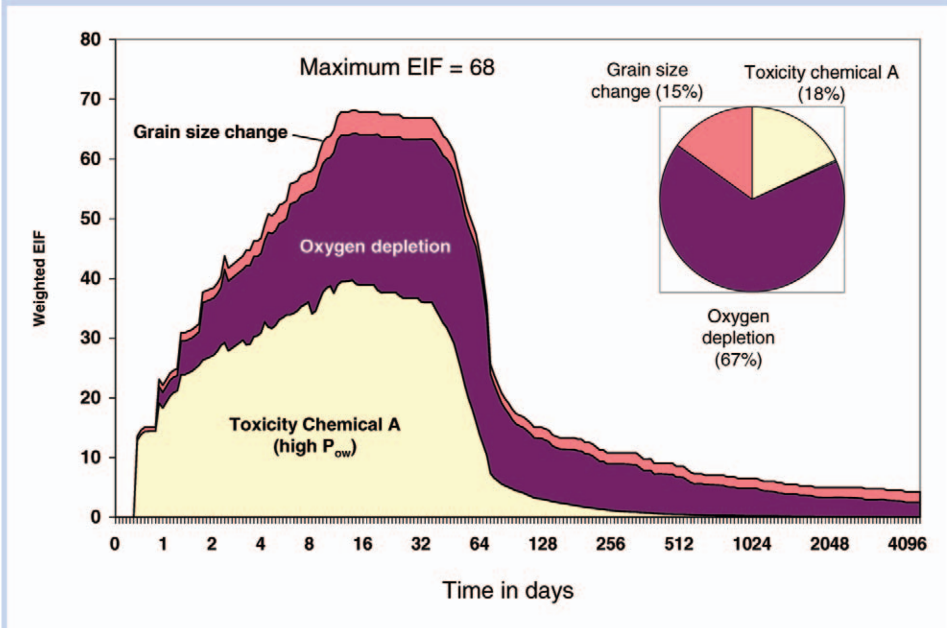

Figure 4. Typical environmental impact factor (EIF) output of the Dose-Related Risk and Effect Assessment Model (DREAM) model for the sediment (area with msPAF >5%; see text for msPAF definition). The EIF is calculated as a time profile and the contribution of the main stressors to the overall risk is presented as a pie chart. The figure illustrates how the biodegradation of the chemical A in the sediment causes a reduction of the risk contribution from that chemical with time due to the biodegradation.

different components in the discharge to the water column and to the sediment. And, in line with recommendations given by Khondaker (2000), the model also includes a full risk assessment module. By using the accepted guidelines for risk assessment from the EU-TGD (EC 2003) together with the well-documented principles for probabilistic risk assessment (Aldenberg et al. 2002), the described concept provides a sound basis for the evaluation of drilling discharges. Further improvement of the tool should be placed in the light of relevance of the environmental risks from drilling discharges compared to other risks related to other discharges from offshore oil and gas installations.

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Table 1. Overview of the different papers describing the topics in the development of the EIF for drilling discharges in detail

Topic	Title	Reference
Exposure	Development of a numerical model for calculating exposure to toxic and nontoxic stressors in the water column and sediment from drilling discharges	Rye et al. 2008
	Estimation of the bioavailability of metals from drilling mud barite	Neff 2008
	The use of the diagenetic equations to predict impact on sediment due to discharges of drill cuttings and mud	Rye et al. 2006b
Effects assessment	Approaches for derivation of environmental quality criteria for substances applied in risk assessment of discharges from offshore drilling operations	Altin et al. 2008
	Species sensitivity distributions for suspended clays, sediment burial and grain size change in the marine environment	Smit, Holthaus, et al. 2008
Risk assessment	Assessment of environmental risks from toxic and nontoxic stressors; a proposed concept for a risk-based management tool for offshore drilling discharges	Smit, Jak, et al. 2008
Validation	A multivariate approach to establishing no observed effect concentrations of chemical stressors from field data	Grung et al. 2008
	Deriving sediment quality guidelines from field-based species sensitivity distributions	Leung et al. 2005

scientific input during the program. Contractors in the program included Akvaplan-niva (Norway), Battelle (USA), MUST (Norway), RF-Akvamiljø (Norway), SINTEF (Norway), TNO (Netherlands), and University of Oslo (Norway). This paper has been technically reviewed by companies and contractors but the contents and conclusions do not necessarily reflect their views and practices.

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