EIF

Environmental Impact Factor for Drilling Discharges

Environmental risk-based decision support tool
to assist the oil industry in establishing cost-effective mitigation measures for
reducing potential harmful discharges to the marine environment

Dose-related risk and effect assessment

Produced water

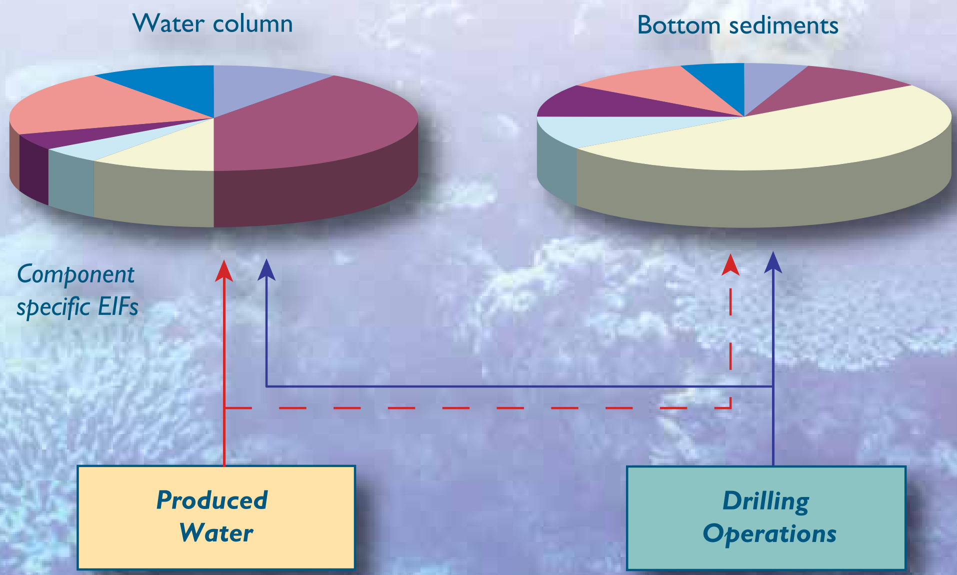
Following the Norwegian authorities' requirements in 1997 of "zero discharges to sea" within the end of 2005, the operating companies on the Norwegian shelf initiated the development of a modelling tool used for guidance of management decisions for reduction of potential harmful environmental effects associated with produced water discharges. This effort was embodied in the DREAM (Dose-related Risk and Effect Assessment Model) project, from which the Environmental Impact Factor for produced water (EIF_{PW}) was developed.

The EIF_{PW} was developed as a management tool to be applied by the oil industry. Its calculation is based on internationally agreed procedures for hazard and risk assessment, as defined by the European Union (EU), which includes the PEC/PNEC ratio approach, also termed risk characterisation ratio (RCR). The PEC/PNEC ratio approach compares the Predicted Environmental Concentration (PEC) of a pollutant with the predicted environmental tolerance level or the concentration below which the likelihood of adverse effects in the environment is considered to be acceptable (PNEC = Predicted No Effect Concentration).

A three-dimensional, time variable concentration field is modelled for each of the produced water compound groups as input to the PEC/PNEC calculation and EIF_{PW} determination. Both the fate modelling and the risk modelling are carried out by the DREAM computer model.

A major data collection study was performed as part of the development of DREAM to obtain data of sufficient reliability to be selected for determination of PNEC values. The establishment of PNEC values was based on the principles described in the EU Technical Guidance Document (EC, 1996 and 2003).

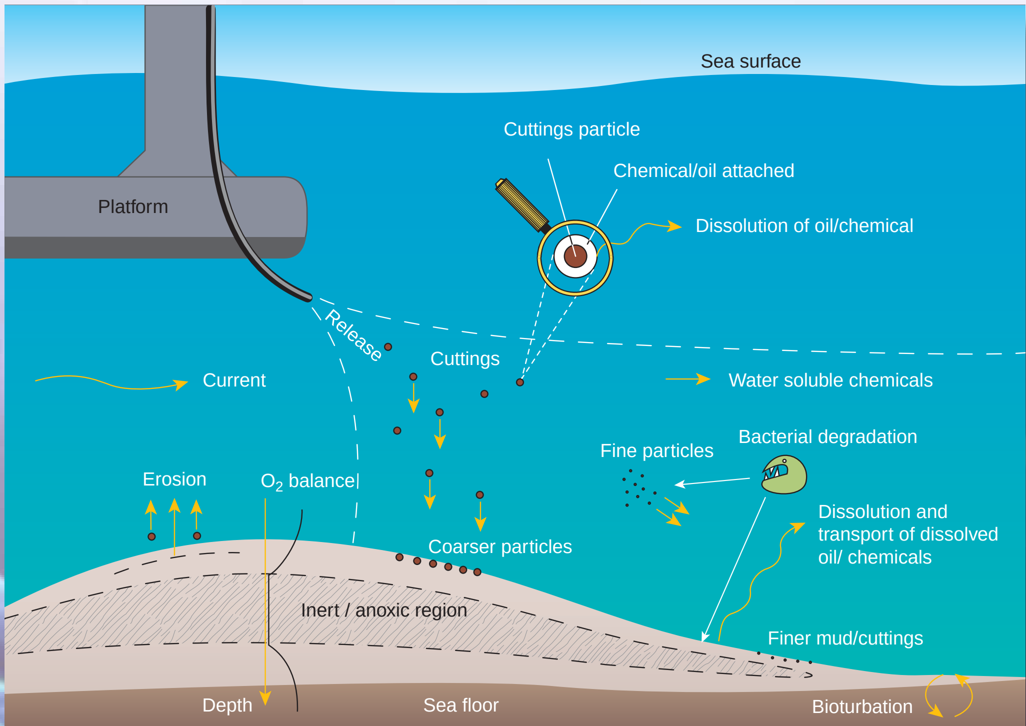
The EIF approach, implemented in DREAM, has proven to be very useful in decision-making on implementation of produced water treatment techniques and the use of offshore E&P chemicals and represents the state of the art in marine water column risk assessment tools.

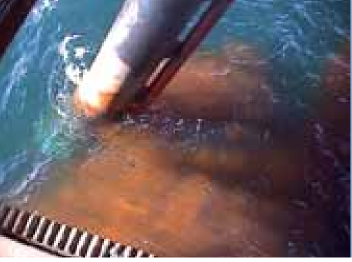


From produced water to drilling discharges

The EIF_{PW} was well received by the Norwegian authorities and is now in use by the operating companies on a regular basis, both on the Norwegian shelf as well as in other areas internationally. To enlarge the application area of the EIF concept and the risk-based management tool DREAM further, the ERMS (Environmental Risk Management System) joint industry program was established to develop a prognosis tool for the estimation of ecological risks arising from planned drilling discharges. This prognosis tool should calculate an EIF for drilling discharges (EIF_{DD}) comparable to the EIF_{PW}. Both EIFs will form an integrated system to enable the oil companies to perform risk calculations for different discharge scenarios during different operations (production and drilling).

At the concept development stage of the EIF_{DD} it was important to identify the main sources of environmental risk from discharges during drilling. For the EIF for produced water the main source of risk was seen to be the toxicity of produced water components in the water column. For drilling discharges the picture was more complicated. As drilling of oil and gas wells generate large volumes of drilling mud and cuttings, potential impacts related to discharge of particulates needed to be included. This resulted in an evaluation where toxic and non-toxic disturbances in the water column and on seafloor sediments was included.





Framework for EIF drilling discharges

Internationally agreed principles for risk assessment were applied for the development of the EIF_{DD}. First relevant stressors related to the drilling discharges were identified by **hazard identification**. This resulted in the following stressors being included in the model development:

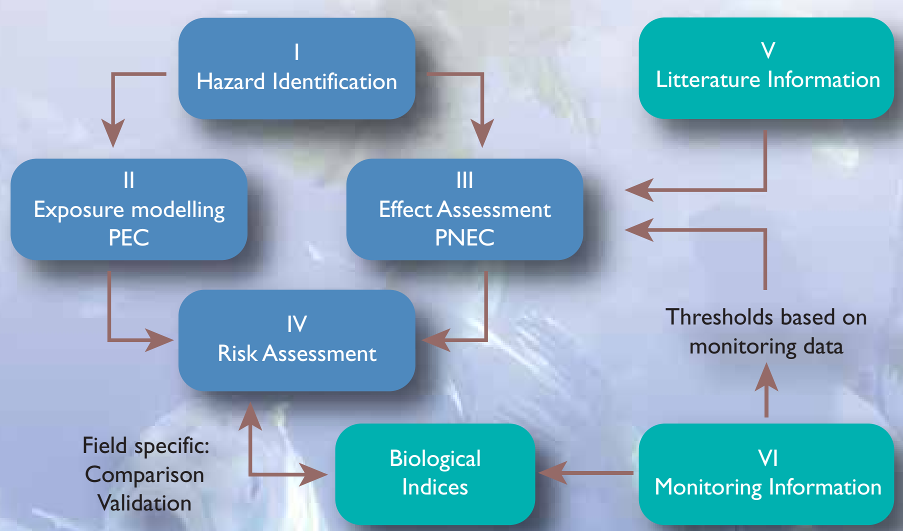
- Water column:
  - Toxicity of chemicals.
  - Physical effects of suspended matter.
- Sediments:
  - Toxicity of chemicals (organic chemicals and heavy metals).
  - Burial of organisms.
  - Change in sediment structure – grain size.
  - Oxygen depletion

For the identified stressors the DREAM model was developed further to carry out **exposure modelling** of drill cuttings and the components in drilling muds. Exposure modelling could then be carried out simultaneously in both the sediment and water column compartments.

Through a literature study information for the **effect assessment** of the identified stressors was collected.

The main challenge in the establishment of effect threshold levels for the EIF_{DD} was to apply existing protocols for the definition of environmentally safe levels to the non-toxic stressors. For the sake of compatibility, principles described by the European Union (EU) in the Technical Guidance Document (EC, 1996, 2003) were applied as possible for the non-toxic stressors as well. Figures for the sensitivity of biota (Predicted No Effect Concentrations (PNECs) and Species Sensitivity Distributions (SSDs)) were defined for all stressors.

The EIF_{DD} is finally calculated in the **risk assessment**. Environmental risks for all stressors in the two marine compartments are estimated by calculation of PEC/PNEC ratios. In order to combine and compare the contribution of different stressors to the overall risk, the SSDs are applied. Based on modeled exposure the risk probability represented by the Potentially Affected Fraction (PAF) is calculated. Single-stressor PAF values are combined into a joint risk probability, the multi-stressor PAF. The spatial extent (volume or area) over which the multi-stressor PAF exceeds 5% is taken as a basic value for the EIF_{DD} in the water column as well as in the sediment.



The DREAM model

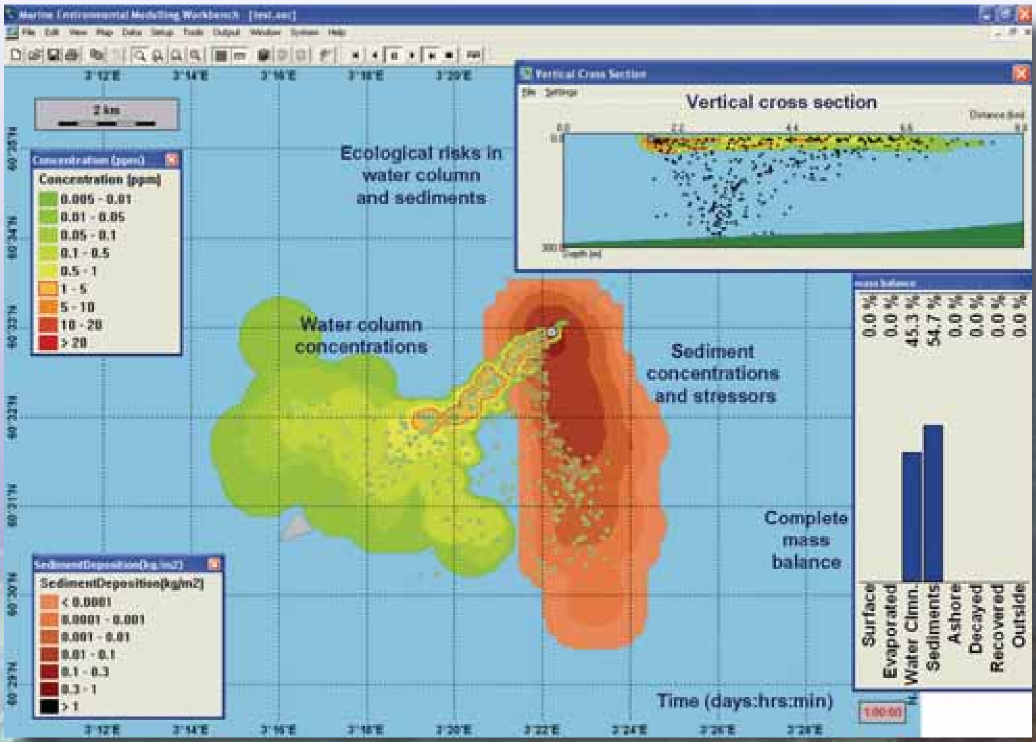
The DREAM model, originally developed as a biology-based exposure and effect assessment model for fish and zooplankton, can be applied to calculate the potential impacts on the sediment in addition to potential impacts in the water column from discharges from production and drilling activities. It includes calculation procedures for both the EIF_{PW} and the EIF_{DD}, which are based on scientifically sound and internationally agreed principles for hazard and risk assessment. Both EIFs are developed along the same lines, defining water volumes and sediment areas with risk > 5%, corresponding to a nominal PEC/PNEC > 1 for multiple stressors.

DREAM calculates the physical-chemical fates of the various compounds in the discharges in three spatial dimensions and time.

The model includes processes like near-field mixing, dilution in the sea due to currents and turbulence, and biodegradation of organic compounds in the discharge. The model can include hundreds compounds simultaneously in the discharge and multiple release locations.

The model also computes deposition of particulate matter on the sea floor, including chemicals that are attached or adsorbed to particulates. In the sediment, the deposited matter is subject to bioturbation and biodegradation.

The figure below provides an example of output of the fate calculations of the model.



Comparison to field data

Model results and validation

The EIF_{DD} (Environmental Impact Factor for Drilling Discharges) is calculated for both impacts in the water column and in the sediment. The risk calculation results are presented as a single EIF value for each environmental compartment and as pie charts to show the relative contributions from the various stressors. During the development phase of the EIF_{DD}, case studies were performed by the participating oil companies in order to compare results and perform qualification of the DREAM model.

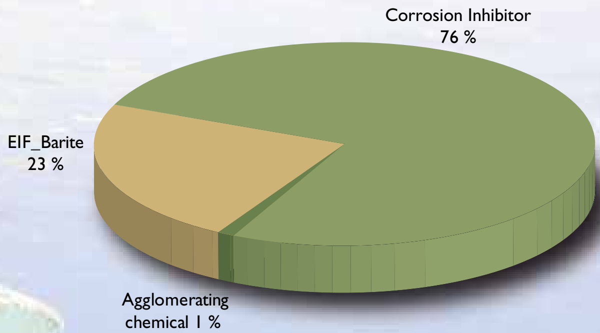
Effort has been put into the validation of the methods applied in the model development and in the results coming from the model. Data from the Norwegian Oil Association database, containing datasets from the monitoring of the benthic communities around the petroleum installations on the Norwegian Continental Shelf (NCS) since 1990 have been examined. Validation of the toxicity thresholds derived from the literature was performed by comparing them to threshold levels for impacts on the sediment caused by previous discharges assessed from field data.

Generally, there was good correlation between the PNEC values used in the DREAM model and the thresholds derived from the field data on the NCS.

As a part of the EIF_{DD} development program a field experiment was conducted in 2003 with sampling in the water column and in the sediments during an actual production drilling carried out in the North Sea. The data from this field trial have been used to validate methods for carrying out risk analysis offshore and for comparison with results from the model.

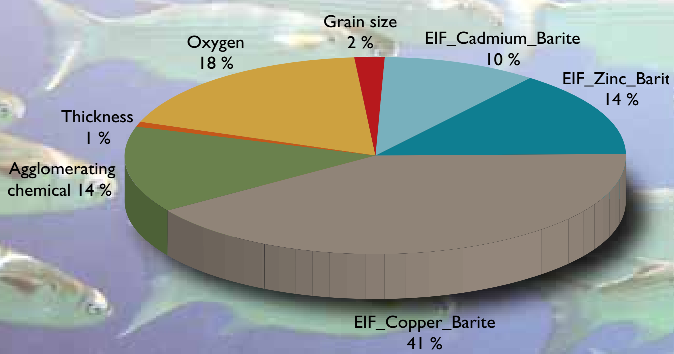
Risks for the water column, example:

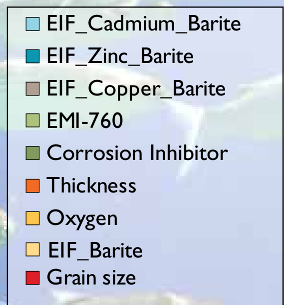
Weighted contribution to risk, EIF = 111



Risks for the sediment, example:

Weighted contribution to risk, EIF = 76





Reports and publications prepared under the ERMS program

Reports

ERMS Report no. 1: Brakstad, F., M.K.Ditlevsen, M.Reed, 2003. Sensitivity study of the EIF-calculations in DREAM 2.0. SINTEF report no. STF66 F03014 - Open.

ERMS Report no. 2: Jensen, H.V., A.G.Melbye, H.Rye, 2004. ERMS Field Trial during production drilling at Sleipner Vest Alfa Nord. September 2003. Cruise report. SINTEF Report no. STF66 F04012 – Open.

ERMS Report no. 3: Smith, M.G.D., R.G.Jak, H.Rye, T.K.Frost, 2006. Framework for the Environmental Impact Factor for drilling discharges. TNO Report no. 2006-DH-R0045/B – Open.

ERMS Report no. 4: Frost, T.K., I.Nilssen, J.Neff, D.Altin, K.Eide Lunde, 2006. Toxicity of Drilling Discharges. Open

ERMS Report no. 4A: Kjeilen-Eilertsen, G., S.Westerlund, 2004. Input from RF-AM to literature study task 1 toxicity: metals. Akvamiljø Report no. AM-2004/023 - Open.

ERMS Report no. 5: Trannum, H.C., H.P.Mannvik, M.Melhus, S.Cochrane, 2006. Evaluation of methods for analysing and modelling changes in benthic communities. Akvaplan-NIVA Report no. APN-411.2792 – Open.

ERMS Report no. 6: Smit, M.G.D., K.I.E.Holthaus, N.B.H.M.Kaag, R.G.Jak, 2006. The derivation of a PNEC-water for weighting agents in drilling mud. TNO Report no. TNO 2006-DH-0044/A - Open.

ERMS Report no. 7: Trannum, H.C., R.Palerud, 2004. Sediment sampling at Sleipner Vest Alfa Nord (SVAN). Cruise report. Akvaplan-NIVA Report no. APN-411.3041.1 – Open.

ERMS Report no. 8: Pinturier, L., 2004. Evaluation of the EIF variability linked to the computation of the model and between users. Total E&P Norge Report no. GDOC#711455 – Restricted.

ERMS Report no. 9: Smit, M.G.D., J.E.Tamis, R.G.Jak, C.C.Karman, G.Kjeilen-Eilertsen, H.Trannum, J.Neff, 2006. Threshold levels and risk functions for non-toxic sediment stressors: burial, grain size changes and hypoxia. Summary. TNO Report no. TNO 2006-DH-0046/A – Open.

ERMS Report no. 9A: Trannum, H.C., 2004. Calculation of PNEC for changed grain size based on data from MOD. Akvaplan-NIVA Report no. APN-411.3088.1 - Open.

ERMS Report no. 9B: Kjeilen-Eilertsen, G., H.Trannum, R.Jak, M.Smit, J.Neff, G.Durell, 2004. Literature report on burial: derivation of PNEC as component in the MEMW model tool. Akvamiljø Report no. AM-2004/024 - Open.

ERMS Report no. 10: Smit, M.G.D., K.I.E.Holthaus, J.E.Tamis, C.C.Karman, 2005. From PEC_PNEC ratio to quantitative risk level using Species Sensitivity Distribution. TNO Report no. B&O-DH-R-2005/181 – Open.

ERMS Report no. 11: Cazes, L., 2003. Benchmarking PROTEUS / DREAM. Ajilon Engineering Report – Restricted.

ERMS Report no. 12: Trannum, H.C., F.Brakstad, J.Neff, 2006. Sediment characterisation and parameter estimation. ERMS task 3. Akvaplan-NIVA Report no. APN-411.3119 - Open.

ERMS Report no. 13: Brakstad, F., H.C.Trannum, 2005. ERMS, Validation of PEC, PNEC and Risk by field data (part I). MUST Report no. RTD05 F05005 – Open.

ERMS Report no. 14: Grung, B., F.Brakstad, Birkely, S.R., 2005. NOEC Field validation part II: the Mowing Window Approach. MUST Report no. RTD05 F05005 - Open.

ERMS Report no. 14A: Brakstad, F., A.Bjørgesæter, S.Dahle, 2006. MEMO: Field validation part II; Comparison of SSD and MWM approaches. MUST Report no. RTD0602 – Open.

ERMS Report no. 15: Bjørgesæter, A., 2006. Field Based Predicted No Effect Concentrations (F-PNECs) for macro benthos on the Norwegian Continental Shelf. UoO Report – Open.

ERMS Report no. 16: Trannum, H.C., A.Pettersen, F.Brakstad, 2006. Field trial at Sleipner Vest Alfa Nord: Effects of drilling activities on benthic communities. Akvaplan-NVA Report no. APN-411.3041.2 – Open.

ERMS Report no. 17: Brørs, B., B.Høverstad, M.Reed, 2005. A 3-Dimensional Hydrodynamic Dataset for the Coast of Brazil. SINTEF Report no. STF80MK F05125 – Confidential.

ERMS Report no. 18: Rye, H., M.Reed, I.Durgut, M.K.Ditlevsen, 2006. Documentation report for the revised DREAM model. SINTEF Report no. STF80MK F06224 – Open.

ERMS Report no. 19: Reed, M., M.K.Ditlevsen, H.Rye, B.Hetland, M.Gerea, I.Durgut, B.Høverstad, K.Skognes, Ø.Johansen, O.M.Aamo, N.Ekrol, K.Downing, 2006. MEMW Users Manual (Marine Environmental Modelling Workbench) OSCAR, DREAM and ParTrack Models – V. 3.2. SINTEF Report no. STF80MK F06198 – Confidential.

ERMS Report no. 20: Berland, H., H.Rye, S.Sanni, 2006. ERMS- and PROOF programmes: Experimental validation of drilling effects in the field. Akvamiljø Report no. AM 2006/004 – Open.

ERMS Report no. 21: Rye, H., Ø.Johansen, I.Durgut, M.Reed, M.K.Ditlevsen, 2006. Restitution of an impacted sediments. SINTEF Report no. STF80MK A06226 – Open.

ERMS Report no. 22: Thorne Schaaning, M., T.Bakke, 2006. Remediation of sediments contaminated with drill cuttings. NIVA Report no. 5188-2006 – Open.

ERMS Report no. 23: Johansen, Ø., I.Durgut, 2006. Implementation of the near-field module in the ERMS model. SINTEF Report no. STF80MK A06204 – Open.

ERMS Report no. 24: Singsaas, I., M.G.D.Smit, E.Garpestad, I.Skare, K.Bakke, L.Falcao Veiga, M. Buffagni, O.A. Follum, S. Johnsen, U.E. Moltu: 2007. Environmental Risk Management System (ERMS). A summary report. SINTEF Report no. STF80MK A06368 – Open.

Publications

Altin, D., T.K.Frost, I.Nilssen, 2007: "Approaches for derivation of Environmental Quality Criteria for substances applied in risk assessment of discharges from offshore drilling operations".

Grung, B., F.Brakstad, H.Trannum, S-R.Birkely, 2007: "A multivariate approach to establishing No Observed Effects Concentrations of chemical stressors from field data".

Neff, J., 2007: "Estimation of the Bioavailability of Metals from Drilling Mud Barite".

Rye, H., M.Reed, I.Durgut, M.K.Ditlevsen, 2006: "The use of the diagenetic equation to predict impacts on sediment due to discharges of drill cuttings and mud". Paper proceedings from the 9th. Marine Environmental Modelling Seminar, Rio de Janeiro, Brazil, Oct. 9-11, 2006.

Rye, H., M.Reed, T.K.Frost, M.G.D.Smit, I.Durgut, Ø.Johansen, M.K.Ditlevsen, 2007: "Development of a numerical model for calculation of exposure to toxic and non-toxic stressors in water column and sediment from drilling discharges".

Singsaas, I., E.Garpestad, I.Skare, K.Bakke, L.Falcao Veiga, M. Buffagni, O.A. Follum, S. Johnsen, U.E. Moltu, 2007: "Environmental Risk Management System (ERMS) – development of a risk-based environmental management tool for drilling discharges. A Summary paper".

Smit, M.G.D., R.G.Jak, H.Rye, T.K.Frost, I.Singsaas, C.C.Karman, 2007: "Evaluation of environmental risks from toxic and non-toxic stressors; a proposed concept for a risk-based management tool for offshore drilling discharges".

Smit, M.G.D., K.I.E.Holthaus, H.Trannum, J.Neff, G.Kjeilen-Eilertsen, R.G.Jak, I.Singsaas, M.A.J.Huijbregts, A.J.Hendriks, 2007: "Species sensitivity distribution for suspended clays, burial and grain size change in the marine environment".

Reports and publications on: http://www.sintef.com/erms

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