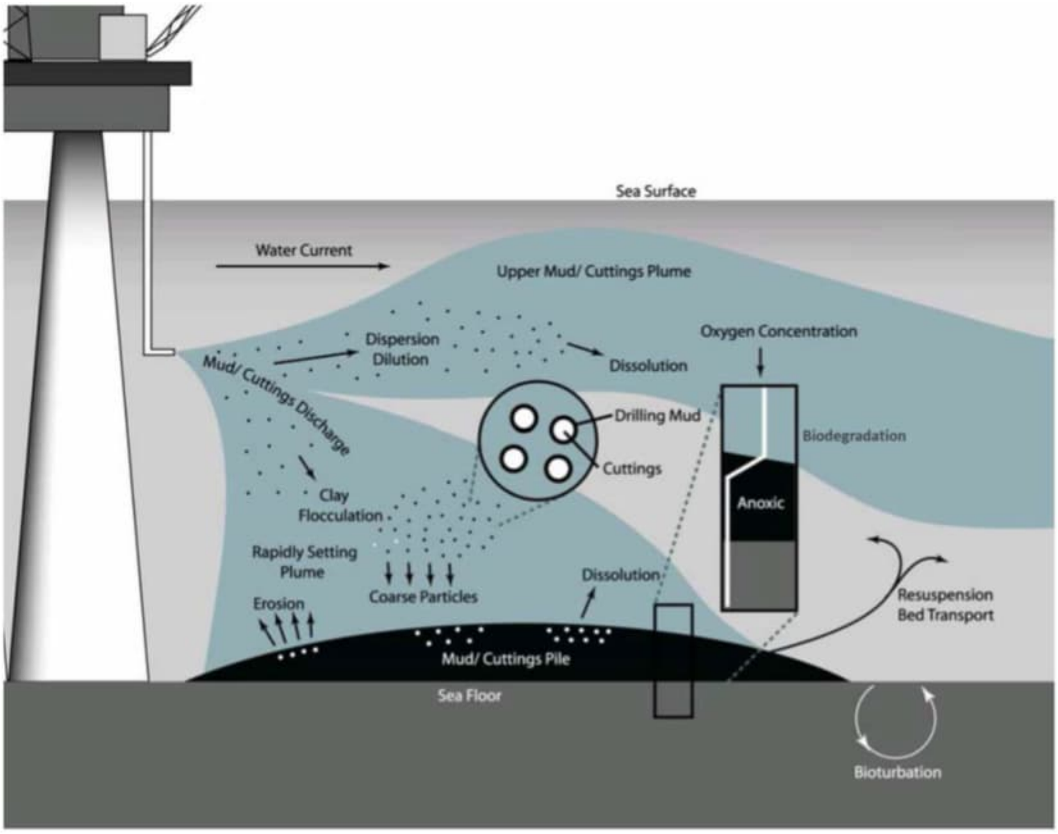

Final Report

Simulations of spreading and deposition from drilling discharges from Block 11B/12B offshore South Africa.

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Final Report

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SUMMARY

Production and appraisal well drilling is proposed in the production development area within offshore Block 11B/12B, South Africa. Considered here are drilling discharges from two locations, Points 4 and 5, which are deemed representative of production and appraisal well drilling operations in the production development area in Block 11B/12B.

SINTEF Ocean used the DREAM model to assess deposition, spreading and potential environmental risk (and the associated EIF values) for the water column and the sediment caused by the planned drilling operations. The present report shows the results from the calculations.

All input data in the report were provided by TotalEnergies EP South Africa B.V. (TEEPSA). The model versions used in the present study are MEMW 14.1 dated 22.11.2022 (Fates and MEMW.exe).

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4.0	2023-08-29	Updated Final report after review
5.0	2023-09-08	Updated Final report

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ABBREVIATIONS

DREAM	Dose related Risk and Effect Assessment Model
EIF	Environmental Impact Factor
ERMS	Environment Risk Management System
GSHHG	Global Self-consistent, Hierarchical, High-resolution Shorelines
HOCNF	Harmonized Offshore Chemical Notification Format
HPWBM	High-performance water-based mud
IBCAO	International Bathymetric Chart of the Arctic Ocean
KOC	Partition coefficient organic carbon - water
LC50	The concentration which causes lethality for 50% of the test specimen
MEMW	Marine Environmental Modelling Workbench
NOEC	No Observed Effect Concentration
PEC	Predicted Environmental Concentration/Change
PNEC	Predicted No Effect Concentration/Change
PLONOR	Pose Little Or NO Risk to the environment
POW	Octanol – water partition coefficient used in the HOCNF testing of offshore chemicals. In the text represented using $\log_{10}$POW.
TGD	Technical Guideline Document (EC 1996)
WBM	Water Based Mud

1 Introduction

Offshore Production Right and Environmental Authorisation Applications for Block 11B/12B
TotalEnergies EP South Africa B.V. (TEEPSA), together with its joint venture partners, QatarEnergy, Canadian Natural Resources International South Africa Limited, and a South African consortium, MainStreet 1549, held an Exploration Right (Exploration Right Ref. No.: 12/3/067) over Block 11B/12B that expired on 06 September 2022. TEEPSA submitted a Production Right (PR) application in terms of Section 83 of the Mineral and Petroleum Resources Development Act, 2002 (Act 28 of 2002) (MPRDA), as amended to the Competent Authority (CA) on 05 September 2022. The CA acknowledged receipt of the application on 19 September 2022.

Licence Block 11B/12B is located offshore the southern cape coast, South Africa and the application area is approximately 12 000 km2 (Figure 1.1). The north-eastern point of the Block 11B/12B application area is approximately 75 km offshore Cape St Francis and the north-western point is approximately 120 km offshore Mossel Bay.

Exploration activities in Block 11B/12B commenced in 2012 and ended in 2020. Drilling efforts focused on the south-west section of the Block, the Production Development Area, where the drilling of the Brulpadda – 1AX exploration well was completed in February 2019 and the drilling of the Luiperd – 1X exploration well was completed in October 2020. Extensive 3D seismic survey data was acquired between 2019 and 2020. This exploration programme led to an important gas discovery and, after further completion of technical and feasibility studies, the commercial viability of the gas and associated condensates resources was confirmed. TEEPSA is planning to develop Block 11B/12B if a PR is granted and if commercial agreements for the sale of the gas onto the domestic market can be achieved.

The development of Block 11B/12B will involve the drilling of five production wells, with the option of drilling a sixth well, in the Project Development Area. In this area, the wells will be connected via subsea infrastructure to a multiphase pipeline carrying both gas and associated condensates to the existing F-A Platform located approximately 40 km northwest of Block 11B/12B. Owned and operated by PetroSA, the F-A Platform was constructed in the early 1990’s and processed gas and condensate from the Block 9 gas fields to supply the PetroSA Gas-to-Liquid (GTL) plant located outside Mossel Bay. The Platform was placed in care and maintenance mode in November 2020 and it is intended that this facility will be used to process gas and condensate from Block 11B/12B. The processed products will be conveyed from the Platform to shore via existing subsea pipelines.

No exploratory drilling has been conducted to date in the east-northeast area of Block 11B/12B, the Exploratory Priority Area where crude oil is possibly the main hydrocarbon. TEEPSA intends to conduct an exploration drilling campaign of up to four exploration and appraisal wells in this area with the objective to further define the resource.

Survey works (sonar, coring, etc.) will possibly be conducted at specific locations within Block 11B/12B to support activities within the Project Development Area and the Exploratory Priority Area.

Assessed here are drilling discharges from two locations 4 and 5, deemed representative of proposed drilling operations in the proposed production development area within Block 11B/12B.

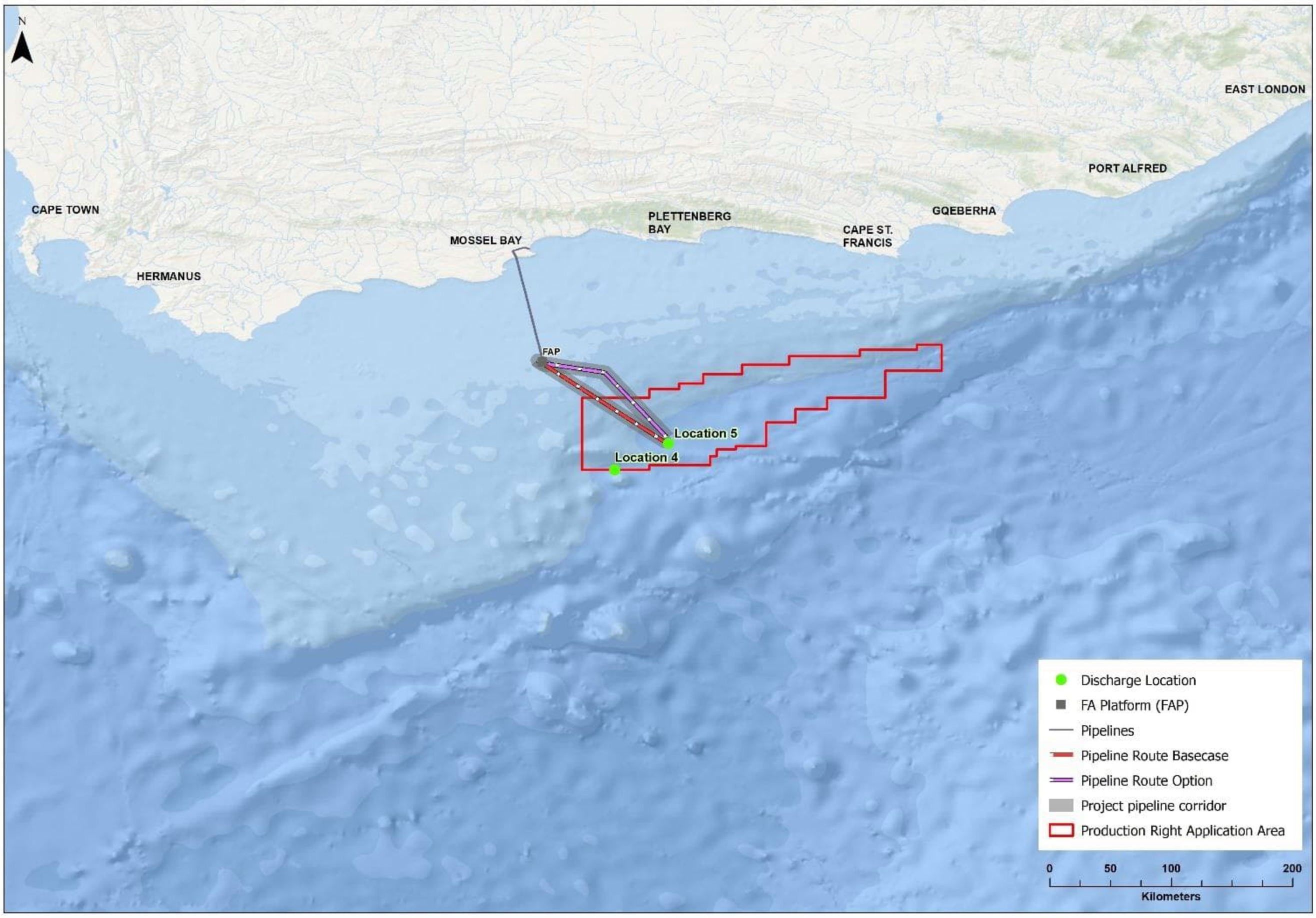

Figure 1.1 Base map showing the locations 4 and 5.

SINTEF Ocean has used the DREAM model to assess deposition, spreading and potential environmental risks (and the associated EIF values) for the water column and the sediment caused by the planned drilling operation. The present report shows the results from the calculations.

The top hole sections 42” and 26" have been discharged directly on the seabed.
The deeper drilling sections 12.25” and 8.5” have been discharged from the rig 10 meters below sea surface.

Simulations for drilling discharges from Block 11B/12B, (location 4 and location 5), have been performed with currents and wind data for four different months during the year, summer, autumn, winter and spring. The details for the different seasons are described in chapter 6.

All chemical input data was provided by TotalEnergies EP South Africa B.V. (TEEPSA).

The model versions used in the present study are MEMW 14.1 dated 22.11.2022 (Fates and MEMW.exe).

We note that the simulations in this report do not include resuspension and transport of sediments by currents. In areas with significant resuspension, this gives a conservative estimate of risk and duration of risk for burial and grain size change for discharged matter that reaches the sediments, since these are not redistributed after the initial impact.

The present report comprises the following sections:

- Description of the DREAM model and the EIF concept (Section 2).
- Details of model setup and input data. Drilling location and drilling sections. The mud package composition for each drilling section (Section 5).
- Ambient conditions such as currents and stratification (Section 6).
- Results from the DREAM modelling of discharges and fates, including EIF results for both the water column and sediment. Presentation and discussion of results (Section 7 to Section 9).
- Summary of results and discussion (Section 10).
- References are included in Section 11.

2 The DREAM model and the EIF concept

In 1996 the Norwegian government issued a White Paper requiring the Norwegian oil industry to reach the goal of 'zero harmful discharge' for the marine environment by 2005. To achieve this goal the Norwegian oil and gas industry initiated the Zero Discharge Program for produced water discharges. The 'Zero Discharge Program' made the oil industry responsible for showing and documenting achievements towards the goal of 'zero harmful discharges.

To quantify and document the potential risk to the marine environment from substances in produced water, SINTEF, together with the Norwegian oil and gas industry, started the development of DREAM (Dose-related Risk and Effects Assessment Model) in 1998. Since 2002, DREAM is being used by all operators on the Norwegian Continental Shelf as a modelling platform for calculating the Environmental Impact Factor for produced water discharges (EIF_{PW}). The EIF_{PW} is an indicator of environmental risk from produced water discharges. By reducing the EIF_{PW}, operators reduce the likelihood of adverse effects which might occur because of operational discharges.

DREAM and the EIF_{PW} concept for produced water were well received by the Norwegian authorities and the ERMS (Environmental Risk Management System) joint industry program was established to further develop the DREAM model (see Figure 2.1) as a basis for calculation of a similar EIF for drilling discharges (EIF_{DD}).

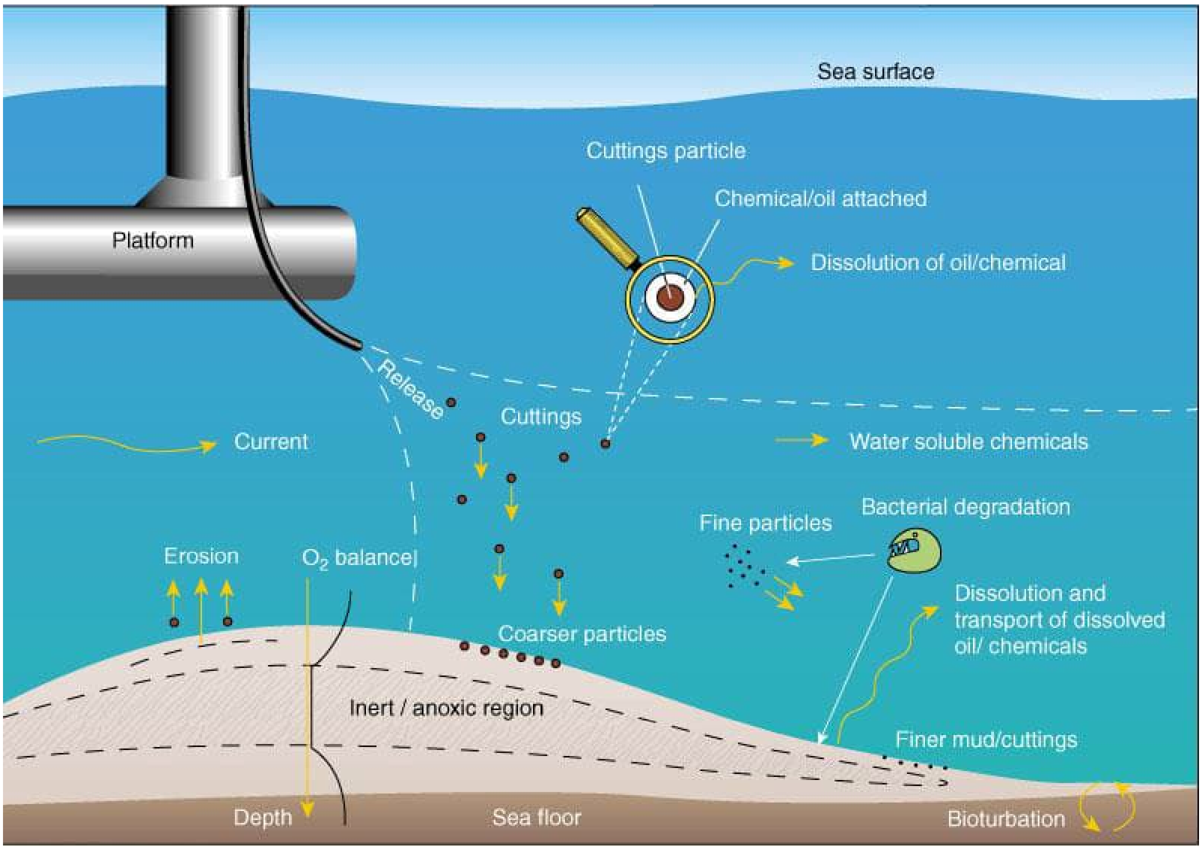

Figure 2.1 Sketch of processes in the DREAM model. In the water column the model accounts for attached chemicals which might dissolve into the water column as well as stress from particles during the simulation period. At the end of the simulation period, the sediment module will compute processes in the sediment compartment. See text for details.

DREAM was enhanced by a sediment module which simulates processes in the sediment to account for stressors like change through introduced sediments, burial, oxygen demand from biodegradation in addition to toxicity of the sedimented chemicals[1].

2.1 The Environmental Impact Factor for drilling discharges

The EIF methodology follows the generic concept for environmental risk assessment as described by the United States' Environmental Protection Agency (USEPA, 1993) and the European Commission (EC, 2003). The EIF method is based on a PEC/PNEC approach, in which the predicted environmental concentration (PEC) for each discharged compound or stressor is compared to a predicted no-effect concentration (PNEC) for that same compound / stressor. When the PEC exceeds the PNEC, it is not unlikely that adverse effects occur as a result of exposure to that compound / stressor. In the following sections, the PEC and PNEC are briefly described as well as the risk principles behind the EIF calculation. More details can be found in Johnsen *et al*. (2000) and Smit *et al*. (2011) as well as Altin *et al* (2008), Rye H, *et al* (2008), Singsaas *et a*l (2008) and Durgut *et al.* (2015).

The EIF_{DD} considers stresses in the water column and stresses in the sediment. Stresses in the water column are relatively short-term which are only computed for the simulation period (10-30 days), while stresses in the sediment are considered long term and are calculated by a dedicated sediment module during the restitution period (10-30 years).

The following stresses are included in the EIF_{DD} (summarized in Figure 2.2 and Figure 2.3):

Water column stresses:

1. Toxicity from dissolved non-PLONOR[2] compounds or chemicals. Exposure is represented by the dissolved chemical concentration in the water column. Typically, contributions come from compounds with high solubility. Often, these compounds have a logPow < 3 and as so are classified as not-attached. However, attached chemicals with high enough solubility may also contribute toward water column stress from the fraction that dissolves during the sinking phase toward the seabed.

2. Particle stress from suspended barite, bentonite and other types of particles present in the water column.

For the sediment, four stresses are calculated:

1. Toxicity caused by deposited metals and chemicals with a logPow ≥ 3. These are assumed not to dissolve in the water column but to attach to particles and to be transported to the sediment where the chemical will eventually biodegrade. The exposure concentration is represented by the average concentration of chemical compounds in the upper 3 cm of the sediment (assuming equilibrium partitioning between pore water and sediment concentrations). DREAM considers organic chemicals (*e.g*. as part of the mud formulation) as well as heavy metals *(e.g*. as impurities in barite). Heavy metals may add to toxicity in the sediment but do not contribute to oxygen depletion as they will not biodegrade.

2. Oxygen depletion in the sediment layer is caused by the consumption of oxygen by biodegradation of the deposited chemicals that can biodegrade. The oxygen content in the sediment and is computed over the vertical extent of the active bioturbation layer (default is 10 cm). The exposure to reduced oxygen is represented by the % reduction of oxygen in the oxygenated layer

3. Deposition of particle matter on the sea floor (primarily cuttings and clay) might result in burial of benthic fauna as the deposited material will cause an extra layer on the seafloor (accumulation). Bioturbation and

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[1] All reports from the ERMS program can be found at www.sintef.no/ERMS.

[2] PLONOR = Pose Little Or NO Risk to the Environment as defined by OSPAR Agreement 2013-06

resuspension might reduce the thickness of that layer. Exposure is represented by the thickness of the deposited layer.

4. A change in median sediment grain size caused by deposited particle matter on the sea floor constitutes a change in benthic habitats and might result in a change of benthic communities. Exposure related to grain size change is defined as the change of the median grain size in the sediment, averaged over the upper three cm of the sediment layer (including the added sediment).

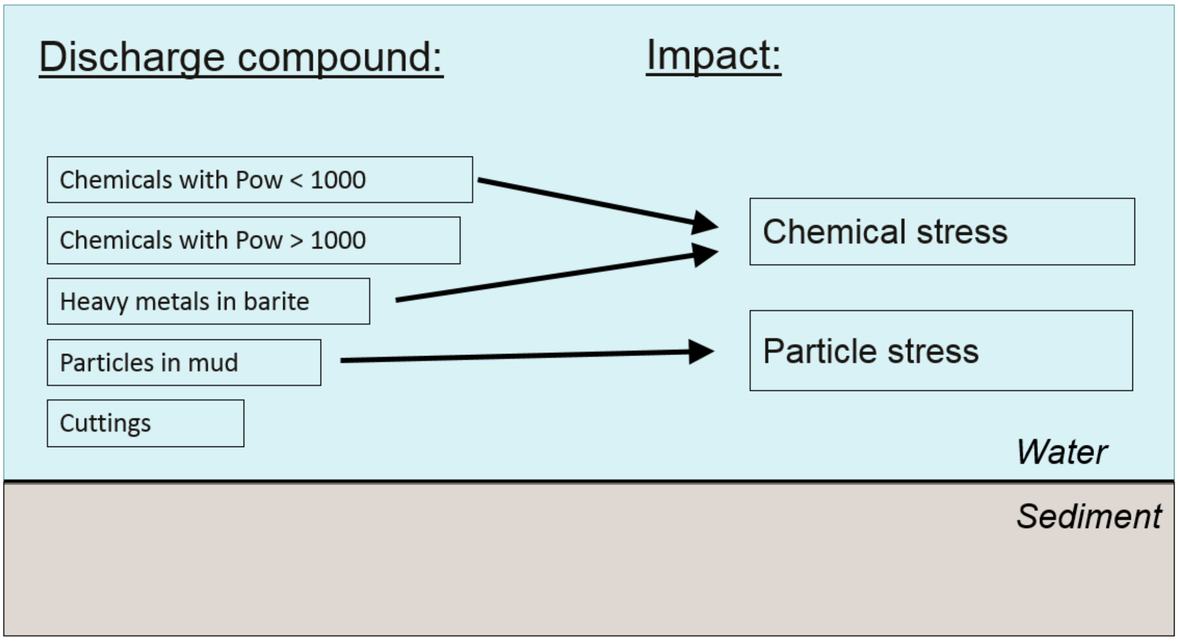


Figure 2.2 Water column impacts from drilling discharges.

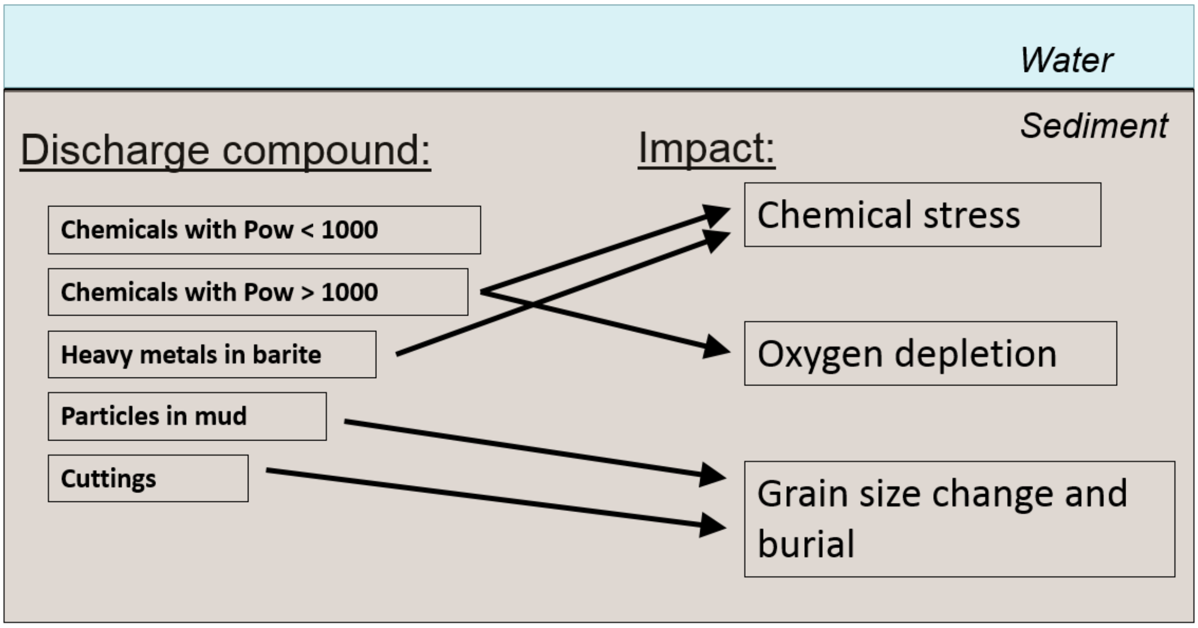


Figure 2.3 Sediment impacts from drilling discharges.

2.2 Computation of PEC

The way the PEC (Predicted Environmental Concentration) is calculated depends on the compartment and the stress factor. In the water column, PEC is represented by the three-dimensional and time variable concentration in the recipient of compounds present in the discharge. DREAM calculates the PEC for all compounds with a log Pow < 3 and for particles that are defined in the discharge profile, under the influence of ambient currents, vertical and horizontal transport and mixing, evaporation at the sea surface, biodegradation, and adsorption-desorption dynamics.

Site-specific meteorology and hydrodynamics are used as input for model simulations. The ocean current field applied in the DREAM model is usually imported from outputs generated by 3-dimensional and time-variable hydrodynamic models. It is also possible to apply observed ocean current profiles generated from measurements at a specific location.

The model concept applied in DREAM is a “particle”, or Lagrangian approach. The model generates numerical particles at the discharge point, which are transported with the currents and turbulence in the sea. Different properties, such as the mass of various compounds, densities and sinking velocities, are associated with each particle to represent the characteristics of a discharged compound. Model particles can also represent different states or phases, such as bubbles, droplets, dissolved matter and solid matter.

The formulas applied for calculating the spreading in the water column are given in Reed and Hetland (2002). The fates calculations for dissolved compounds in drilling discharges are described by Rye *et al*. (2008) and are mainly based on recommendations from the European Commissions’ technical guidance document on environmental risk assessment (EU-TGD) (EC, 2003). For the four stresses in the sediment compartment PEC is represented by the chemical concentration in the porewater, the % oxygen depletion in the oxygenated layer, the layer thickness of the deposited layer and the change in the medium sediment grainsize, respectively. After deposition, the level of exposure to these four stresses are calculated by diagenetic equations as described by Rye *et al.* (2006) and Durgut *et a*l. (2015).

Discharges from a drilling rig to the sea are rather intermittent and time variable, with various composition and amounts of the mud discharged from each drilling section. This causes corresponding time variability in the recipient concentrations.

2.3 Computation of PNEC

For toxicity, the PNEC (*Predicted No Effect Concentration*) for a chemical compound is the concentration in either water or sediments below which it is unlikely that adverse effects to the environment will occur because of exposure to that compound. This PNEC is usually derived from results of laboratory toxicity tests and must be provided for each compound to be considered in the discharge. Guidelines on how the PNEC for water and sediment are derived from laboratory toxicity test results are available from the EU (ECHA, 2008; EC, 2011). Further details on how to derive PNECs for added chemicals in the water column can be found in Johnsen *et al.* (2000), while Altin *et al*. (2015) provides an overview for the calculation of the PNEC for sediments.

As for toxicity levels, also for the non-toxic stressors, there are levels where it is unlikely that adverse effects to the environment will occur below that level. Based on effect levels from laboratory studies, Smit *et al*. (2006a) derived species sensitivity distributions for suspended clays, burial and grainsize change that were used as a basis for PNECs for non-toxic stress. Based on this work, the PNEC for or burial was set to a deposited layer of 0.65 cm. The PNEC for the change in oxygen content was set to 20% reduction of oxygen (in terms of mg $O2/m^2$ sediment surface) based on Thorne Schaaning And Bakke (2006), NIVA Report no. 5188-2006, by considering the effect of reduced redox potential on the diversity of the benthic fauna.

The PNECs for the sediment stressors are included in DREAM’s sediment module directly, while PNECs for chemical components follow as input data with these components.

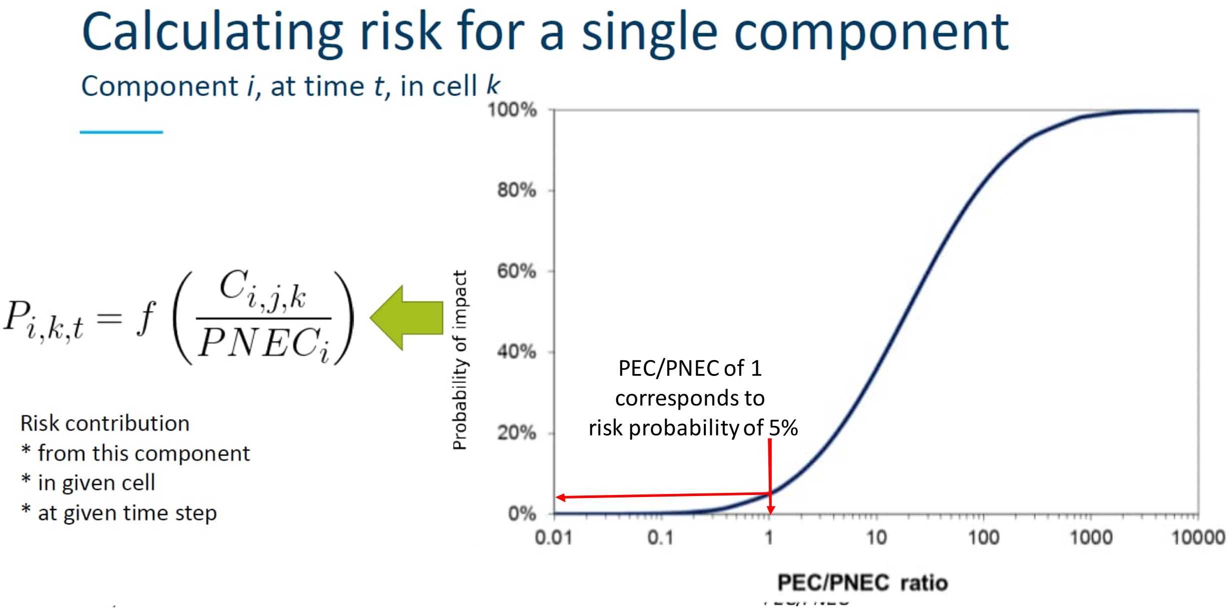
PNEC values: Currently used PNEC values for non-toxic stressors are (ERMS project):

- Burial: 6.5 mm
- Change of median grain size: 0.0461 mm change over the upper 3 cm of sediment
- Oxygen depletion in sediment: >20 % reduction of pore water free oxygen content

2.4 Environmental risk and the EIF

The output from the transport and fate calculations in DREAM is a time- dynamic representation of the exposure in the receiving environment. For calculating an EIF, the exposure concentrations (PEC) are translated to a risk probability. This risk probability can be explained as the probability that a randomly selected species in the environment is exposed to concentrations exceeding its chronic no-effect concentration (NOEC). A risk probability of 5% is often used as a cut-off criterion assuming that risk is unacceptable if more than 5% of the species are exposed above their chronic NOEC (Smit *et al*., 2006b). Therefore, it has been suggested that the concentration at which the risk probability is 5% corresponds to the PNEC. This implies that when the PEC/PNEC equals 1, the risk probability equals 5%. Figure 2.4 shows the relation between the PEC/PNEC ratio and the risk probability as published by Karman *et. Al*. (1994).

PNEC values can be found from EC50, LC50, or NOEC data from the HOCNF form (OSPAR (2020), ECHA (2008)).



Calculating risk for a single component

Component *i*, at time *t*, in cell *k*

$$P_{i,k,t} = f\left(\frac{C_{i,j,k}}{PNEC_i}\right)$$

Risk contribution
* from this component
* in given cell
* at given time step

PEC/PNEC of 1 corresponds to risk probability of 5%

Figure 2.4 Relation between the PEC/PNEC ratio and the risk probability (in %) as presented by Karman et. Al. (1994) and further described in Karman and Reerink (1997).
PEC/PNEC = 1 corresponds to a 5% risk probability (5% of the species are exposed above their chronic NOEC).

For each chemical compound in the modelled discharge, the modelled concentration field is calculated into a risk (impact probability) field from risk curves. For each sediment stressor, the modelled stress is calculated into a risk field (Smit *et al.*, 2008, Durgut 2015).

The overall risk from several different chemical compounds and stressors, is calculated as the sum of independent impact probabilities using equation 1:

$$P(A+B) = P(A) + P(B) - P(A) * P(B) \qquad (1)$$

where P(A) is the impact probability for compound A and P(B) is the impact probability for compound B. For small risks (that is, P(A) and P(B) are both small), or risks from chemicals which are toxicologically similar in their activity, the risks can be considered to be linearly additive. This method does not account for interactions among chemicals or stressors.

The overall risk for the sediment results from all compounds from the drilling discharge that ended up in the sediment and all non-toxic stressors is calculated by the DREAM model in space and time within the model domain. The maximum sea floor area where the overall impact probability exceeds 5% during the simulation period (sediment module) is used to derive the EIF_{DD}. While the selected unit for the EIF in the water column is the water volume of 100m x 100m x 10m (100,000 m^3), the unit for the sediment is the sea floor area of 100m x 100m (10,000 m^2). Therefore, a sediment EIF of 10 represents a sea floor area of 100,000 m^2.

Due to time-varying wind and current conditions, the plume and corresponding water volume with an overall risk probability exceeding 5% varies over time. Due to the rather intermittent and time variable discharges from a drilling rig to the sea, the corresponding EIF_{DD} is time-variable as well. This is expressed in terms of presenting the EIF_{DD} as a time function, with the risk contributions shown as a function of time as well.

The figures below give an example of both, water column (Figure 2.5) and sediment (Figure 2.6) EIF development over time.

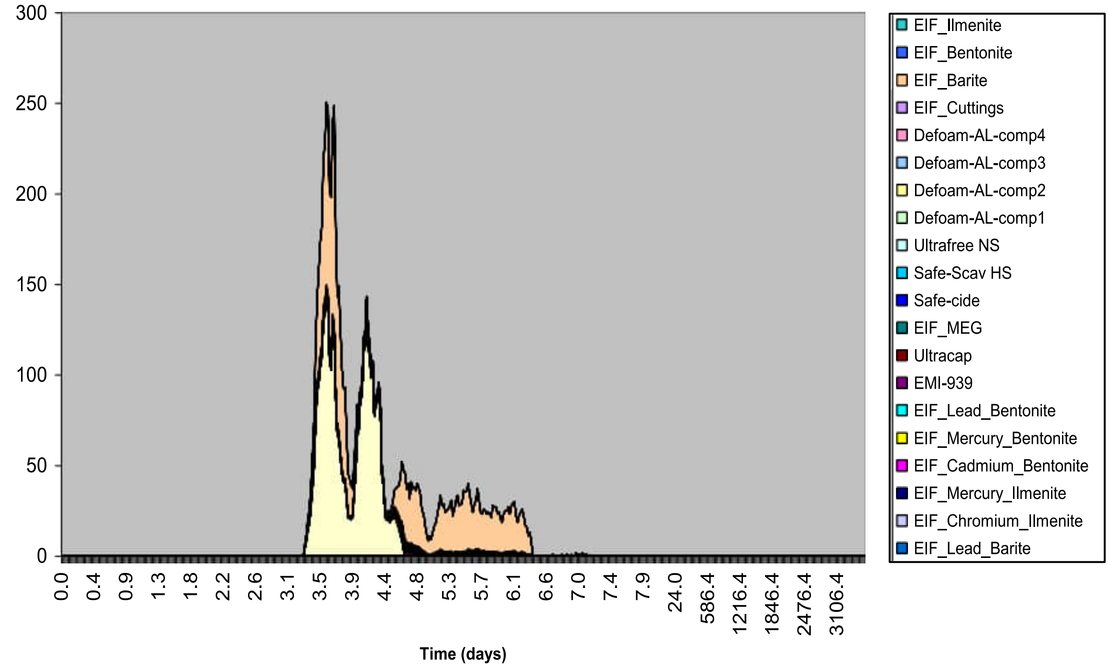


Figure 2.5 Time series development of the water column EIF for a drilling discharge. The values are cumulative. Risks are time-varying with the discharges from the different drilling sections. The main contribution in this case is from barite and one of the added chemicals. The duration of the impact is limited to between day 3 and 7. Toward the end of the impact-period, barite carries near 100 % of the risk.

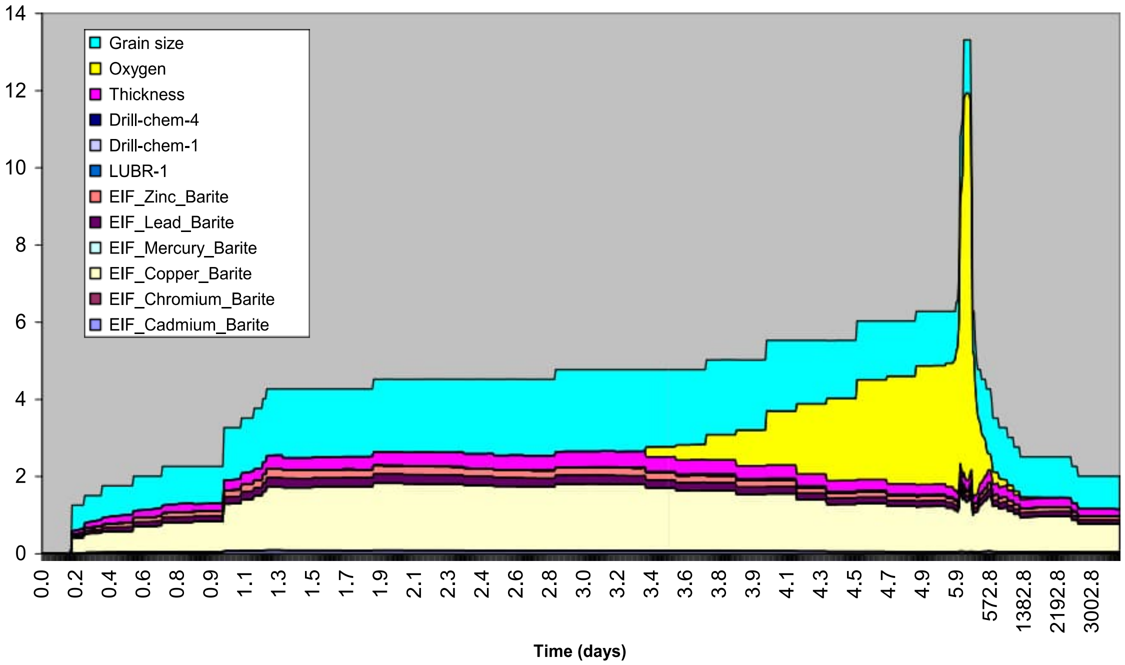


Figure 2.6 The time development of the sediment EIF caused by drilling discharges. The values are cumulative. Note that although the discharge is lasting for some days only, the impact on the sediment layer is extending over a period of more than 7 years. The oxygen depletion (yellow contribution) is lasting of order one year before the biodegradable chemicals have been biodegraded. Other significant contributions to the sediment stress are change of grain size (introduction of "exotic" sediment) and burial (denoted "Thickness" in the legend). In addition, heavy metals present in barite (Cu in particular) contribute to toxicity in the sediment.

2.5 Presentation of results and risk management

The results of a DREAM simulation can be presented as shown in Figure 2.7 (snapshot in time).

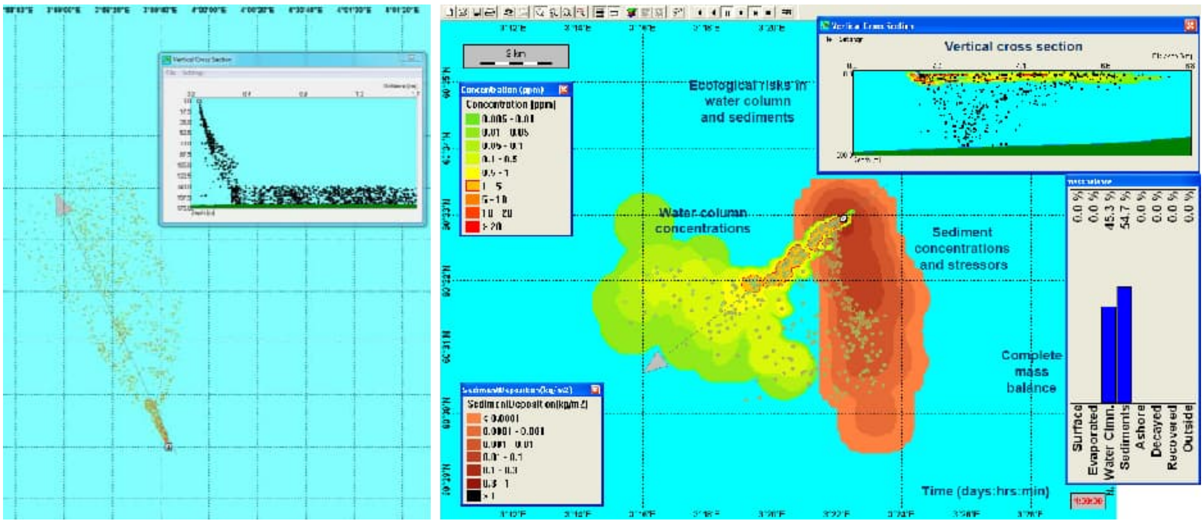


Figure 2.7 Example of a DREAM calculation showing spreading of the numerical particles by ocean currents (left) and the resulting concentration fields (right), as a snapshot in time of both the horizontal and vertical plume extent.

Calculation of risk and the corresponding EIF_{DD} is a post-processing of the simulation results (PEC).
An attractive feature of the EIF approach is that the method enables the quantification of the contribution of the various compounds in the discharge (toxicity) and the non-toxic stressors to the overall environmental risk. An example from another study of the contribution to risk in the water-column and for the sediment attributed to the different compounds in a release is shown in Figure 2.8 and Figure 2.9.
This enables the identification of the highest risk contributors in the discharge and facilitates the definition and selection of cost-effective risk mitigation measures based on best available technology. These can for instance be the selection of additional effluent treatment technologies or the substitution of harmful compounds from added chemicals.

The contribution to risk for each compound is calculated as an average of the contributions each timestep. Thus, the reported contribution of risk considers the time duration and the relative contribution compared with other compounds. For example, if compound A is released early in the simulation and carries a risk above 5 %, it will contribute to 100 % of the risk if there are no other compounds. Later in the simulation, two compounds, B and C are additionally released for a short period of time. Both B and C may both have a higher total release volumes and lower PNECs than A, but A might still be reported as having the largest contribution to risk, since it carried 100 % of the risk for a much longer period. In this report, this can be seen in Table 8.1, where the time-averaged total contribution to risk is different than the area under the risk-curves in Figure 8.1.

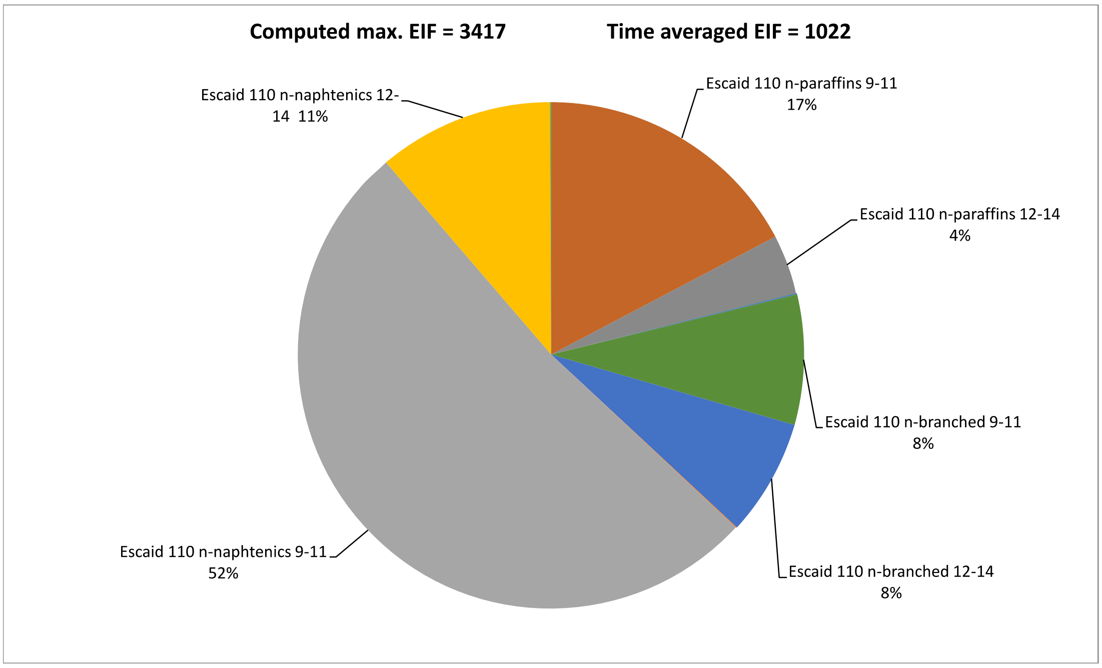


Figure 2.8 Distribution of the contribution to risk in water column from the different stressors from an example EIF_{DD} calculation. In this example case the Escaid 110 n-naphtenics 9-11 contributes with 52% to the overall environmental risk in the water column.

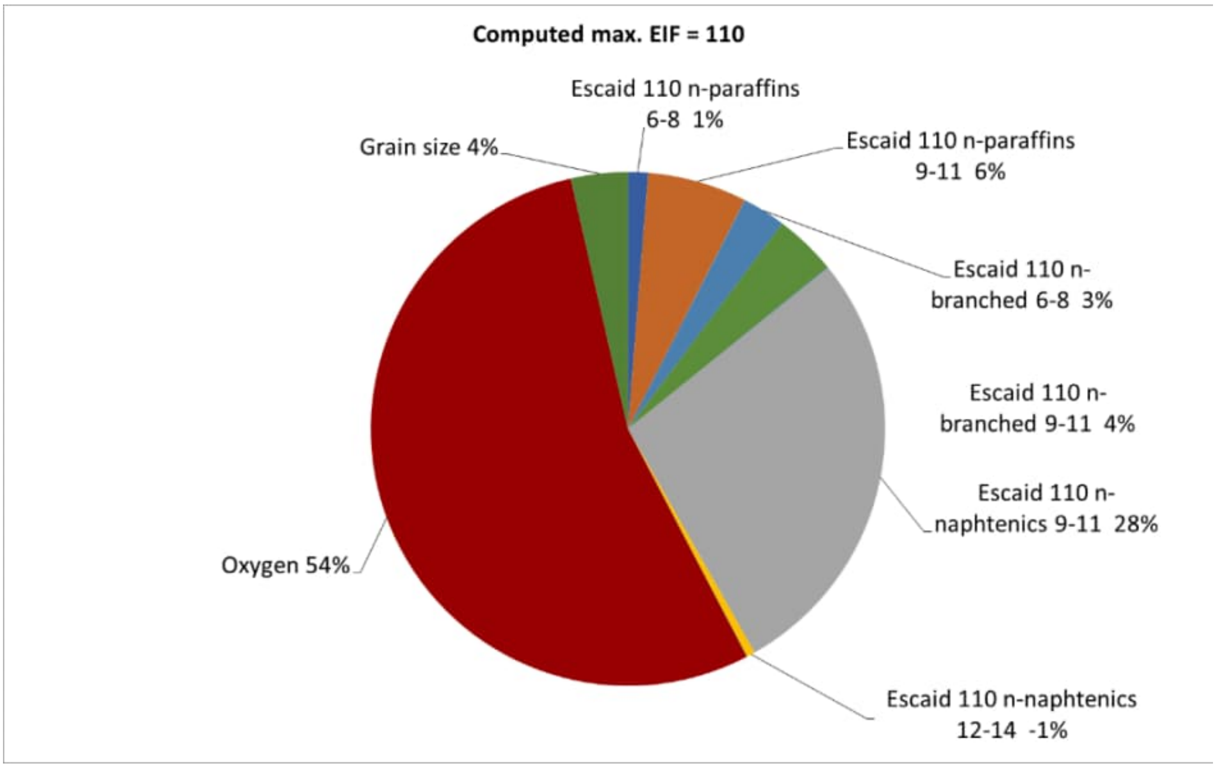


Figure 2.9 Distribution of the contribution to risk in the sediment from the different stressors from an example EIF_{DD} calculation. In this example case, stress from exceeded oxygen demand contributes 54% to the overall environmental risk. Other contributors are grain size change from the introduced particle matter and chemical toxicity.

3 Model validation

SINTEF has developed a dose-related risk and effects assessment model (DREAM) for transport (dispersion, advection, settling) and fate (biodegradation) modelling of drilling discharges. The model accounts for chemical and particle stress in the water column and chemical and non-chemical stress in the receiving sediments, where the non-chemical stress is through oxygen demand from biodegradation, burial, and change in sediment grain size. Environmental risk is quantified through the Environmental Impact Factor (EIF) based on which quantifies harm within a reference water volume or sea floor area. The EIF methodology for drilling discharges in DREAM has been developed by SINTEF and the operators on the Norwegian continental shelf for managing discharges and environmental risk. 1 EIF is the unit for the reference water volume or sea floor area where the risk for an effect on the most sensitive species exceeds 5% (more than 5% of the most sensitive species are at risk). 1 EIF equates to 100x100x10 m^3 in the water column, 1 EIF equates to 100x100 m^2 on the sea floor (*i.e.* 100 EIF = 1 km^2).

Each individual scenario is manually constructed by expert users to ensure stable and consistent results. This includes the chosen number of numerical particles representing the discharge which is adjusted according to release duration and released amounts, the computational time step which is adjusted according to desired results (short-term vs. long-term simulations, EIF) and the model area which is supposed to capture the discharged and deposited matter in sufficient resolution.

Several studies have been carried out to validate the model. An overview of completed studies that have been published is listed below:

G. Kjeilen-Eilertsen (Total EP Norge AS), T. Merzi, M. Burgos (Total SA), U. Brönner (Sintef), 2016: TRL (Technology Readiness Level) Assessment of DREAM (Dose-related Risk and Effects Assessment Model) to Qualify its Use for Modelling of Produced Water and Drilling Discharges. SPE-179217-MS.

Durgut, I., Rye, H., Reed, M., Smit, M., Ditlevsen, M.K., 2015: Dynamic modeling of environmental risk associated with drilling discharges to marine sediments. Marine Pollution Bulletin 99, page 240-249.

H. Rye, U. Brönner, M.K. Ditlevsen, T.K. Frost, E. Furuholt, G. Kjeilen-Eilertsen, R. Nepstad, P. Page, J.E. Paulsen, R. Ramos, P. Rønningen and S.E. Sørstrøm, 2014: Use of the DREAM Model for Control and Prediction of Concentrations and Environmental Risks Associated with Regular Discharges to Sea: Experiences and Challenges. SPE paper 170763-MS. SPE Annual Technical Conference and Exhibition held in Amsterdam, The Netherlands, 27–29 October 2014. Copyright 2014, Society of Petroleum Engineers.

Frost, T.K., Myrhaug, J.L., Ditlevsen, M.K., Rye, H., 2014: Environmental Monitoring and Modelling of Drilling Discharges at a Location with Vulnerable Seabed Fauna: Comparison between Field Measurements and Model Simulations. SPE 168328.

Rye, H., Ditlevsen, M.K., Jannecke A. Moe, Morten Løkken, 2012: Simulation of Concentrations and Depositions of Particle Matter Caused by Drilling Discharges. Comparison Between Field Measurements and Simulation Results at Coral Locations. SPE-156775.

4 Quality Control

SINTEF OCEAN maintains a certified management system that meets the requirements of the international standard ISO 9001 Quality management systems – Requirements. The project is carried out in compliance with our internal procedures for project management and quality assurance of project work. One or more quality assurors is always designated in the project to ensure that the project is conducted in accordance with recognized scientific principles, and to perform technical/scientific check of the delivery.

5 Input data

5.1 General

As illustrated in Figure 2.2 and Figure 2.3, the risks associated with discharges of drill cuttings and mud to sea, are related to impacts both in the water column and the sediment. The calculation of environmental risks for the water column includes two types of “stressors”:

- Dissolved non-PLONOR compounds or chemicals. These are calculated as dissolved chemicals in the water column. Only compounds with a logPow < 3 are included, because these are assumed to dissolve in the water column and thus appear in a bioavailable form. Compounds with a log Pow ≥ 3 are assumed to “attach” to particles, sink down with the particles, and thus enter the sediment layer on the sea floor. Here they may contribute to environmental risks in the sediment (see below).

- Particle stress from barite, bentonite and other types of particles present in the water column.

For the sediment layer, four stresses are calculated:

- Toxicity caused by chemicals in the sediment layer. Only compounds with a logPow ≥ 3 are included. These are assumed not to dissolve in the water column but attach to particles and enter the sediment layer. Here they will biodegrade and therefore contribute to oxygen depletion in the sediment layer. Stresses in the sediment caused by heavy metals in particle matter are included as well. These may cause toxicity in the sediment but does not contribute to oxygen consumption.

- Excessive oxygen consumption in the sediment layer due to biodegradation of organic chemicals.

- Thickness of deposited matter due to deposition of particle matter on the sea floor.

- Stresses originating from change of grain size in the sediment layer caused by the particle depositions.

To calculate these stressors, a variety of input information must be made available. This section describes the information that has been applied as input to the DREAM calculations.

A variety of input information is required to calculate the stressors that are included in the EIF. This section describes the input to the DREAM model for the drilling discharge computations. All input data were provided by or agreed on with the client.

5.2 Location

Drilling discharges have been assessed for two locations 4 and 5, deemed representative of proposed drilling operations in the proposed production development area within Block 11B/12B. Discharge location 5 was selected as a representative location for drilling occurring both to the east and the west of this location, i.e., a central location within the proposed production development area. The point is in close proximity to the previously drilled explorations well Luiperd-1X upon which the oil spill characteristics for the study are based. Drilling location 4 has been selected due to its close proximity to a marine protected area and critical biodiversity areas located immediately to the southwest of this location.

The location of the drilling case for discharge location 4 and discharge location 5 are shown in Figure 5.1. The coordinates for the drilling locations are:

Discharge location 4:
Lon: 22° 44’ 43.9515” E
Lat: 35° 46’ 58.4526” S
Discharge location 5:
Lon.: 23° 8’ 27.6914” E
Lat.: 35° 35’ 17.3071” S

MEMW database was used for the bathymetry. The water depth for the drilling locations is 1191 meters for discharge location 4 and 1805 meters for discharge location 5.

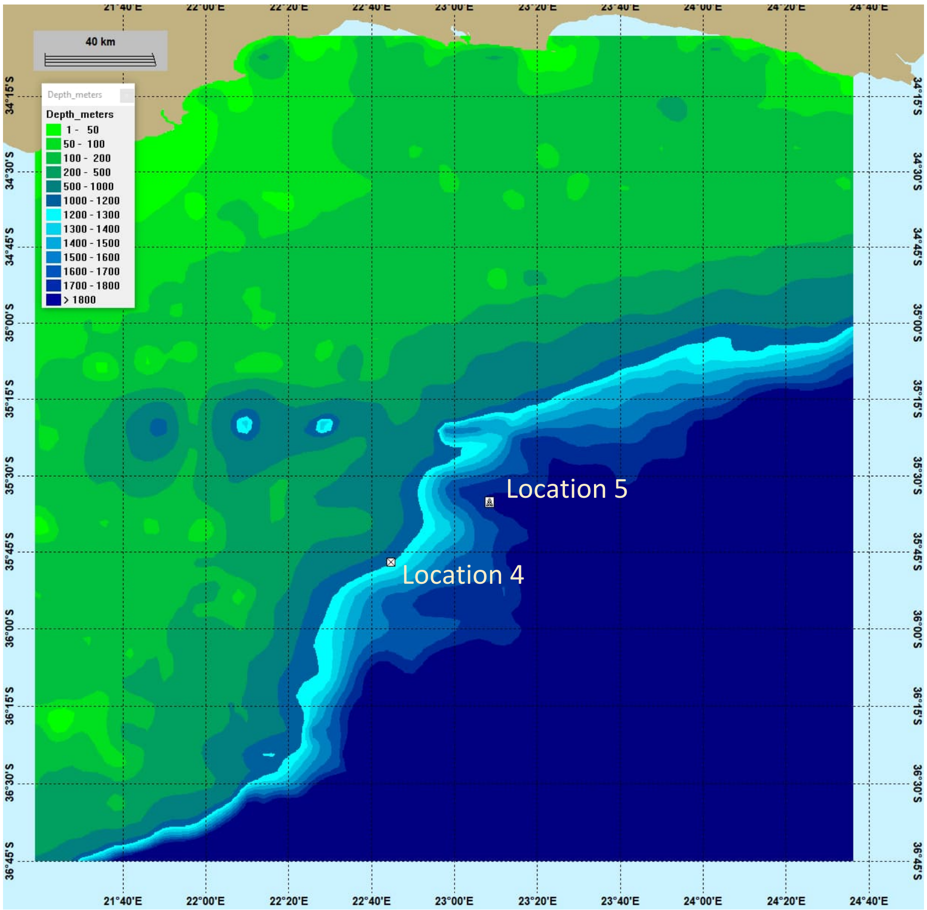


Figure 5.1 Location of the drilling discharge location 4 and 5, offshore South Africa.

MEMW comes with a built-in coastline and world map. This is derived from the United States Defense Mapping Agency's digital chart of the world (DCW). This has similar coastal resolution as high resolution version of the GSHHG dataset1. GSHHG is a good source of global map data for when the built-in map is not of sufficient resolution.

The built-in bathymetry database is made from the SeaTopo dataset version 8.2 and the IBCAO database for the arctic region.

5.3 Water temperature and salinity data

Ambient water temperature and salinity for the field used in the simulations are detailed in Table 5.1 and Figure 2.1 shows the ambient temperature profile. These values were obtained from the client (Appendix 1 – Service Request Form).

Table 5.1 Environmental data.

	Summer	Autumn	Winter	Spring
Upper water column temperature (°C)	22.6	22.7	19.5	18.6
Mid water temperature (°C)	7.4	6.0	6.4	5.2
Lower water temperature (°C)	3.1	3.1	3.1	3.1
Air temperature (°C)	21.5	21.2	17.6	16.9
Salinity, ppt: Surface (0 meter): Mid (700 meter): Bottom (2000 meter):	35.4 34.9 34.7	35.4 34.9 34.7	35.4 34.9 34.8	35.4 34.9 34.8
Seawater oxygen content (mg/l) Surface (0 meter): Mid (1000 meter): Bottom (2000 meter):	 7.68 6.08 6.88	 7.68 6.08 6.88	 7.68 6.08 6.88	 7.68 6.08 6.88
Median Grain Size (mm)	0.350			
Suspended sediment (mg/l)	0			

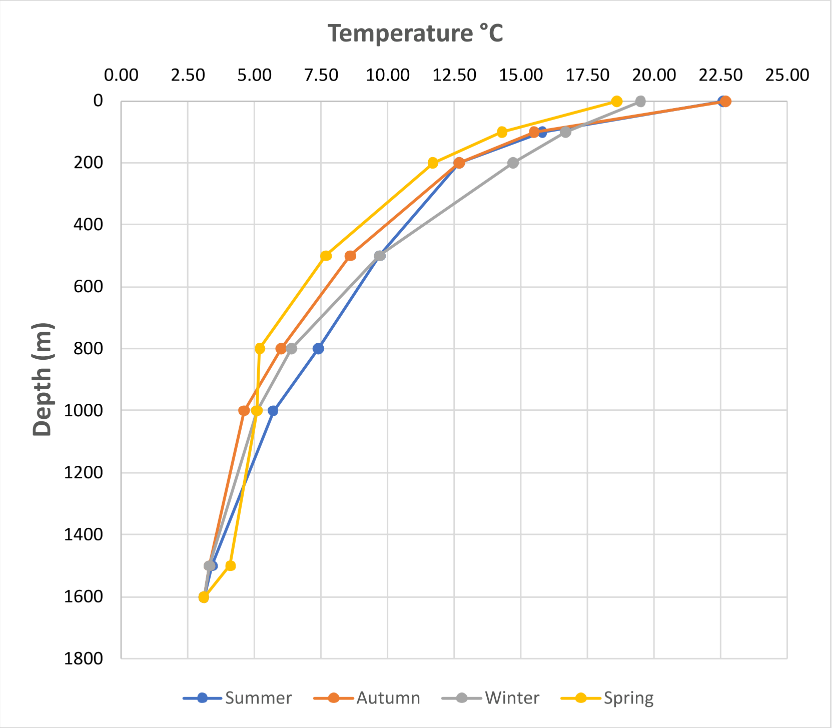


Figure 5.2 Ambient temperature used in the simulations for discharge location 4 and 5.

5.4 DREAM discharge, fate & transport model setup

DREAM operates with a gridded model area that represents the area of interest. The model area has a horizontal grid resolution of 50 metres on the sea floor and 200 metres in the water column. The EIF, a measure for environmental risk, is a reference volume of 100x100x10 m^3 in the water column and a reference area of 100x100 m^2 for the sea floor.

The discharge is represented by numerical particles, where each numerical particle carries the respective amount of chemicals and particulate material. The numerical particles are transported with the currents and sink due to their density. There are different numerical particle classes for dissolved (chemicals) and particulate matter (undissolved chemicals, mud and cuttings).

The simulation itself is performed with two different modules in DREAM, the first being the transport and fate module, that computes dissolution and degradation in the water column and settling on the sea floor. The second module, the sediment module, computes long-term processes on the sea floor and is run for 10 years.

Table 5.2 Summary of model setup.

Variable	Value
Random seed	same for all scenarios to ensure comparability
Grid resolution used for sediment	50 meters (*i.e.* one cell will contribute with ¼ EIF)
Grid resolution used for water column	200 meters
Vertical grid resolution	10 meters
Simulation periods	35 days
Sediment module simulation period	10 years
Solid and dissolved particles	30 000
Water-column:	
Modelling area	166 x 190 km
Model timestep	10 minutes
Model output interval	3 hours
Sediment:	
Modelling area	6.5 x 5.5 km
Model timestep	15 minutes
Model output interval	1 hours

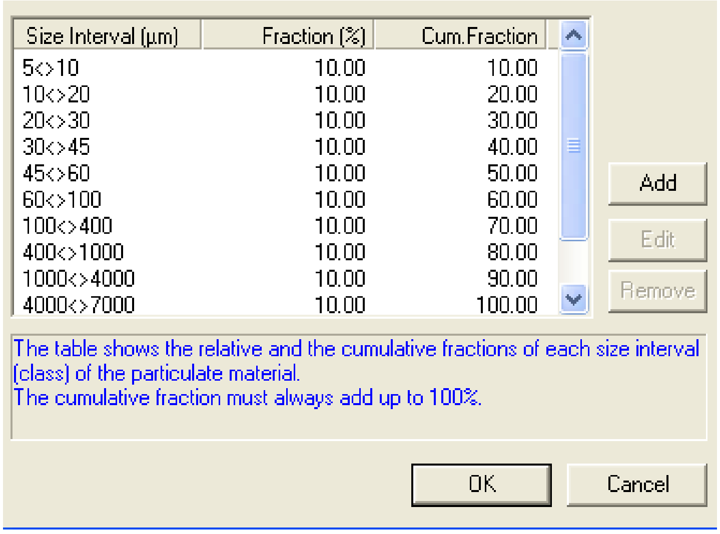
5.5 DREAM sediment module

The DREAM model calculates the stresses caused by the deposition of grains with sizes that are different from the natural grain sizes on the actual location. Therefore, the actual natural grain size on the location must be input to the sediment model. The median diameter of the natural grain size on site is measured to be 0.35 mm based on information from the operator (see Appendix 1 – Service Request Form).

Stress caused by oxygen demand through biodegradation of dissolved chemicals in the sediment pore water as well as chemicals attached to deposited particles are computed and related to the oxygen levels before exposure. To calculate oxygen depletion, an initial gradient of pore water oxygen levels is calculated. This gradient starts with a default value of 9 mg/L at the sediment surface and ends with a default value of 0.01 mg/L at 10 cm depth.

The discharges consist to a large extent of particles (cuttings, barite, bentonite, and cement). To compute sinking behaviour, we must assume a size distribution for these different materials. These distributions are often unavailable, and the DREAM model contains data from previous studies in that are used in these cases.
The grain size of cuttings particles used in the study has been investigated by Saga (1994). A typical distribution found by them is given in Table 5.3.

Table 5.3 Grain size distributions of cuttings particles measured during an exploration drilling in the Barents Sea. From Saga (1994). Density of cuttings 2600 kg/m3. Copied from the DREAM model interface.

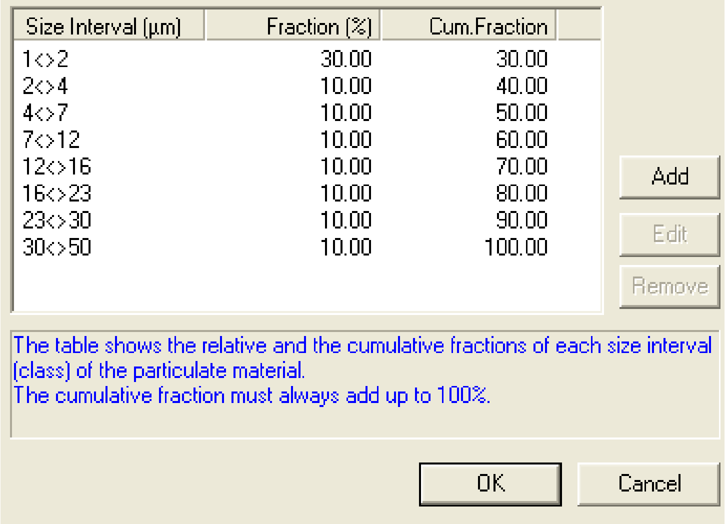


Size Interval (µm)	Fraction (%)	Cum.Fraction
5<>10	10.00	10.00
10<>20	10.00	20.00
20<>30	10.00	30.00
30<>45	10.00	40.00
45<>60	10.00	50.00
60<>100	10.00	60.00
100<>400	10.00	70.00
400<>1000	10.00	80.00
1000<>4000	10.00	90.00
4000<>7000	10.00	100.00

The table shows the relative and the cumulative fractions of each size interval (class) of the particulate material.
The cumulative fraction must always add up to 100%.

Other particle ingredients in the discharge include barite as the weighting material. A particle size distribution found by Saga (1994) for barite particles is shown in Table 5.4.

Table 5.4 Grain size distributions of barite particles measured during an exploration drilling in the Barents Sea (Saga 1994). The sampling of the barite is taken at the shaker, after the particles have been through the drill pit. Copied from the DREAM model interface.



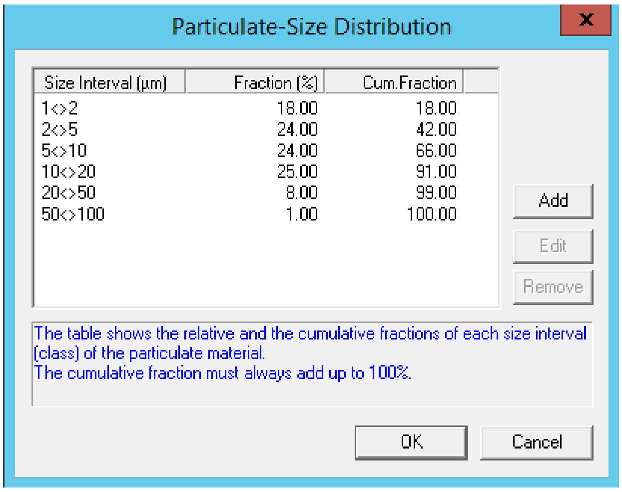
Size Interval (µm)	Fraction (%)	Cum.Fraction
1<>2	30.00	30.00
2<>4	10.00	40.00
4<>7	10.00	50.00
7<>12	10.00	60.00
12<>16	10.00	70.00
16<>23	10.00	80.00
23<>30	10.00	90.00
30<>50	10.00	100.00

The table shows the relative and the cumulative fractions of each size interval (class) of the particulate material.
The cumulative fraction must always add up to 100%.

Bentonite is also planned to be used for the top hole drilling section. Since the particle size distribution for the bentonite is not known, it is assumed to be similar to barite (Table 5.4).

Generally, bentonite is a clay-like material with individual particle sizes of order smaller than about 2 µm. However, experience has shown that this material flocculates to a large extent when discharged to the sea. The flocculation process causes the formation of larger particles. This process therefore justifies the use of larger particles sizes for bentonite in the discharge calculations.

Table 5.5 Grain size distributions of Baracarb particles used in the simulations. Data from DREAM database.



Size Interval (µm)	Fraction (%)	Cum.Fraction
1<>2	18.00	18.00
2<>5	24.00	42.00
5<>10	24.00	66.00
10<>20	25.00	91.00
20<>50	8.00	99.00
50<>100	1.00	100.00

The table shows the relative and the cumulative fractions of each size interval (class) of the particulate material.
The cumulative fraction must always add up to 100%.

5.6 PNECs for discharged particulate matter

Particle groups. The PNEC values for the particle barite and bentonite in the water column have been provided by the operator. The PNECs used in the calculations for these particles are given in Table 5.6.

Cuttings is considered a non-toxic material, and no PNEC values are available. To ensure that cuttings do not contribute toward the EIF for water column toxicity, a PNEC value of 100 ppm is used, which is the default in DREAM’s database.

Table 5.6 PNEC’s for various particle groups given by the operator (see Appendix 1 – Service Request Form).

Particle/component	PNEC, ppm
Barite:	
Barium sulfate	0.115
Chrystalline silica, quartz	0.440
Bentonite	0.170

5.7 Discharge configurations

The fate of a discharge to the sea is in part dependent on the discharge configuration. The top hole sections 42” and 26" will be drilled (without help from the rig) and the cuttings will be discharged directly at the sea floor. The coarser part of the particle content in the discharges will deposit on the sea floor rather immediately, while the finer particles and dissolved chemicals will be transported along the sea floor with the ambient currents.

The discharges from the deeper drilling sections 12 1/4” and 8.5” will be drilled from the rig using WBM. For these sections, discharges from the drilling rig will occur at 10 m below sea surface.

5.8 Discharge setup for the various drilling sections

Table 5.7 gives an overview of each drilling section implemented in the MEMW DREAM model. Table 5.8 gives a summary of cuttings and mud volumes, and Figure 5.3 gives an overview of the drilling schedule for both discharge locations.

Table 5.7 Discharge setup for each drilling section.

Input data for discharge location 4 and 5.	Drilling section:	42" drilling	42" Displacement	26" drilling	26" Displacement	12 1/4" drilling	8.5" drilling	8.5" Log
Start of discharge, **days**[1)]		0	4	0	5	0	3	3
Section length, m:		122	-	510		1392	418	-
Drilling rate m/h		20	-	30		25	15	-
Discharge depth, m		Seabed	Seabed	Seabed	Seabed	10 m below sea surface	10 m below sea surface	10 m below sea surface
Diameter of outlet opening (m)		1.0668	42"Open hole	0.66	26"Open hole	0.305	0.305	0.305
Orientation of outlet opening		Upwards	Upwards	Upwards	Upwards	Downwards	Downwards	Downwards
Duration, **hours** :		5	12	25	12	110	70	20
		Cuttings,Seawater+ Gel/Polymer Sweeps	KCL/Polymer Mud	Seawater+Gel/ Polymer Sweeps	KCL/Polymer Mud	Cuttings + HPWBM	Cuttings + HPWBM	HPWBM
	Compound	Amount	Amount	Amount		Amount	Amount	
Components	in discharge	tonnes	tonnes	tonnes		tonnes	tonnes	
Particles	Cuttings	433	0	694	0	421	57	
Particles	Bentonite	20	0	56	0	0		
Particles	Barite	0	70		280	900	450	450
Chemical	Barazan-D	2	1.2	5.6	4.8	12	6	6
Chemical	Soda Ash	0.25	0.2	0.7	0.8	2	1	1
Chemical	Caustic Soda	0.25	0.2	0.7	0.8	2	1	1
Chemical	Pottasium Chloride		14		56	140	70	70
Chemical	Starcide		0.1		0.4			
Chemical	Sodium Chloride					80	40	40
Chemical	GEM GP					2	1	1
Chemical	Clayseal Plus					1.4	0.7	0.7
Chemical	Clay Grabber					1.15	0.575	0.575
Chemical	Clay Sync II					10	5	5
	Bore HIB					10	20	20
	Dextrid E					40	8	8
	Pac-L					16	8	8
Particles	Baracarb 150						25	25
Particles	Baracarb 50						25	25
	Sum MUD	270	260	756	1040	1200	500	1200

[1)] Start of discharge is time elapsed before starting discharge for this section (i.e. time passed after the previous discharge ends). Unit in days.

Table 5.8 Summary of cuttings and mud volumes.

Wellbore diameter (")	Mud type	Section length (m)	Drilling rate (m/h)	Drilling/ operation (Hours)	Discharge duration (Hours)	Time before next operation (days)	Discharged cuttings (T)	Quantity of mud discharged (T)	Discharge depth	Diameter of outlet opening (m)
42"	Cuttings+ seawater+ Gel/Polymer Sweeps	122	20	5	5	4	433	270	Seabed	1.0668
42" Displacement	1.3sg KCL/Polymer Mud			12	12	0	0	260	Seabed	1.0668
26"	Cuttings+seawater+ Gel/Polymer Sweeps+KCl Mud	510	30	25	25	5	694	756	Seabed	0.66
26" Displacement	1.3sg KCL/Polymer Mud			12	12	0	0	1040	Seabed	0.66
12 1/4"	Cuttings+HPWBM	1392	25	96	110	3	421	1200	10 m below surface	0.305
8.5"	Cuttings+HPWBM	418	15	50	70	3	57	500	10 m below surface	0.305
8.5"	HPWBM			0	20	0	0	1200	10 m below surface	0.305

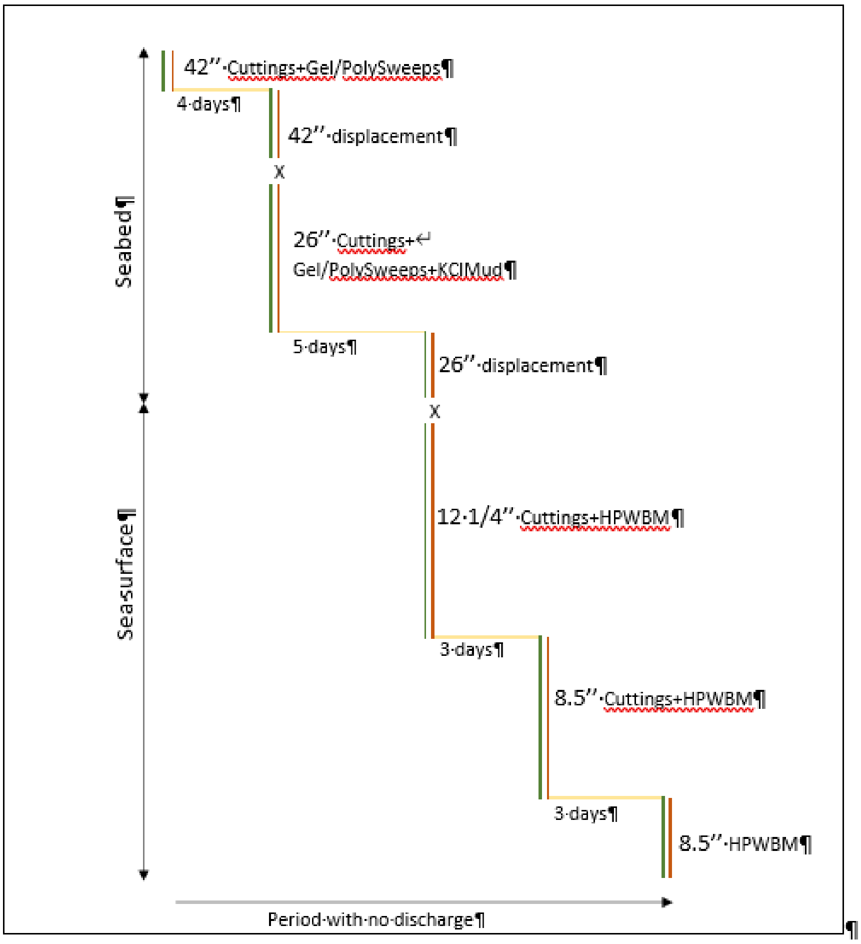
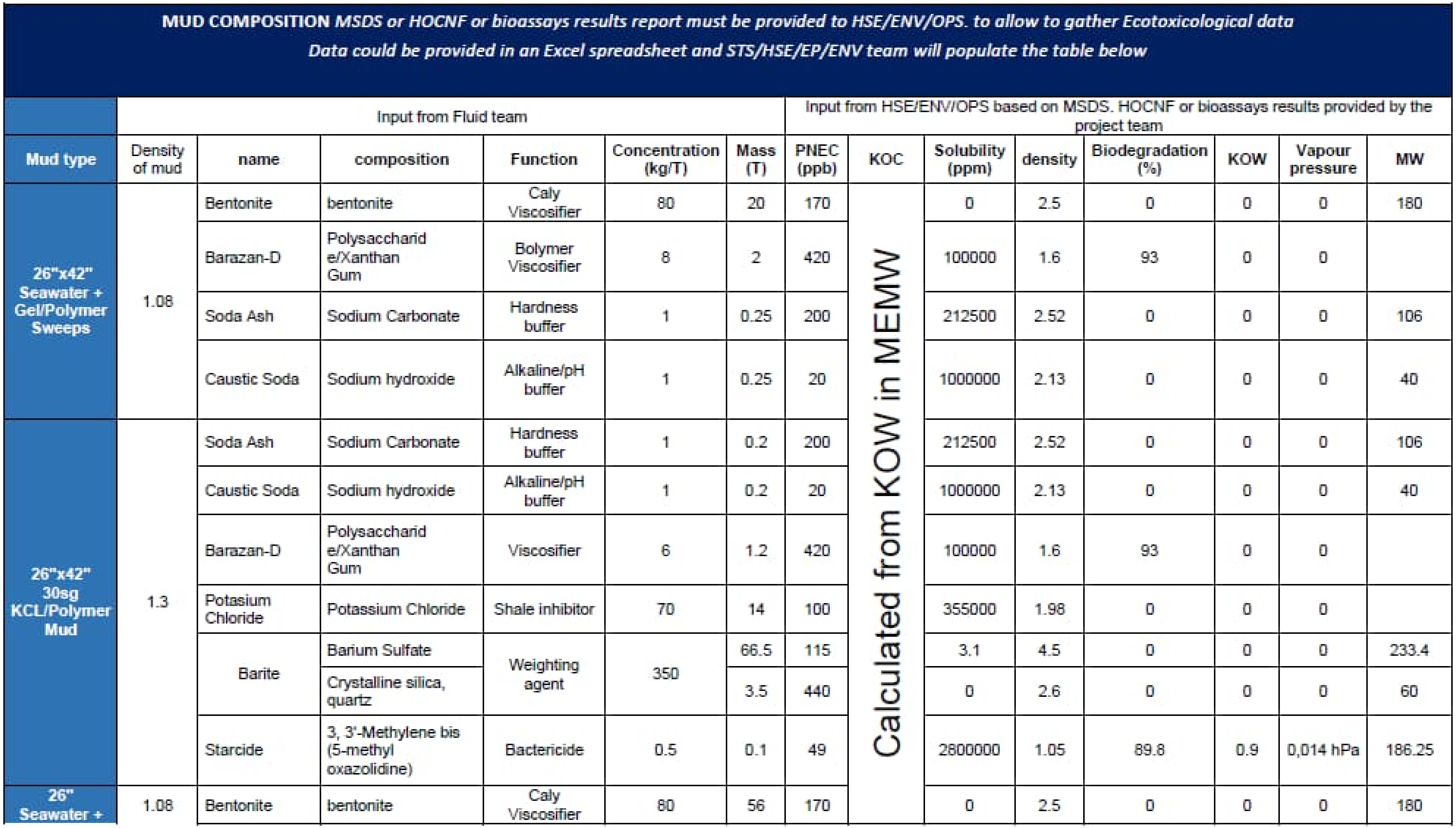


Figure 5.3 Drilling schedule for both discharge locations.

5.9 Mud composition

The mud composition presented in this report is provided by the TEEPSA Fluid team (see Table 5.9). Several types of drilling fluid will be used for drilling operations with different compositions and densities (details provided in Service Request Form).

Table 5.9 Composition of the muds used in the simulations for discharge location 4 and 5.



MUD COMPOSITION *MSDS or HOCNF or bioassays results report must be provided to HSE/ENV/OPS. to allow to gather Ecotoxicological data Data could be provided in an Excel spreadsheet and STS/HSE/EP/ENV team will populate the table below*														
	Input from Fluid team						Input from HSE/ENV/OPS based on MSDS. HOCNF or bioassays results provided by the project team							
Mud type	Density of mud	name	composition	Function	Concentration (kg/T)	Mass (T)	PNEC (ppb)	KOC	Solubility (ppm)	density	Biodegradation (%)	KOW	Vapour pressure	MW
26"x42" Seawater + Gel/Polymer Sweeps	1.08	Bentonite	bentonite	Caly Viscosifier	80	20	170	Calculated from KOW in MEMW	0	2.5	0	0	0	180
		Barazan-D	Polysaccharide/Xanthan Gum	Bolymer Viscosifier	8	2	420		100000	1.6	93	0	0	
		Soda Ash	Sodium Carbonate	Hardness buffer	1	0.25	200		212500	2.52	0	0	0	106
		Caustic Soda	Sodium hydroxide	Alkaline/pH buffer	1	0.25	20		1000000	2.13	0	0	0	40
26"x42" 30sg KCL/Polymer Mud	1.3	Soda Ash	Sodium Carbonate	Hardness buffer	1	0.2	200		212500	2.52	0	0	0	106
		Caustic Soda	Sodium hydroxide	Alkaline/pH buffer	1	0.2	20		1000000	2.13	0	0	0	40
		Barazan-D	Polysaccharide/Xanthan Gum	Viscosifier	6	1.2	420		100000	1.6	93	0	0	
		Potasium Chloride	Potassium Chloride	Shale inhibitor	70	14	100		355000	1.98	0	0	0	
		Barite	Barium Sulfate	Weighting agent	350	66.5	115		3.1	4.5	0	0	0	233.4
			Crystalline silica, quartz			3.5	440		0	2.6	0	0	0	60
		Starcide	3, 3'-Methylene bis (5-methyl oxazolidine)	Bactericide	0.5	0.1	49		2800000	1.05	89.8	0.9	0,014 hPa	186.25
26" Seawater +	1.08	Bentonite	bentonite	Caly Viscosifier	80	56	170		0	2.5	0	0	0	180

Gel/Polymer Sweeps		Barazan-D	Polysaccharide/Xanthan Gum	Bolymer Viscosifier	8	5.6	420		100000	1.6	93	0	0	
		Soda Ash	Sodium Carbonate	Hardness buffer	1	0.7	200		212500	2.52	0	0	0	106
		Caistic Soda	Sodium hydroxide	Alkaline/pH buffer	1	0.7	20		1000000	2.13	0	0	0	40
26" 30sq KCL/Polymer Mud	1.3	Soda Ash	Sodium Carbonate	Hardness buffer	1	0.8	200		212500	2.52	0	0	0	106
		Caistic Soda	Sodium hydroxide	Alkaline/pH buffer	1	0.8	20		1000000	2.13	0	0	0	40
		Barazan-D	Polysaccharide/Xanthan Gum	Viscosifier	6	4.8	420		100000	1.6	93	0	0	1000000
		Potasium Chloride	Potassium Chloride	Shale inhibitor	70	56	100		355000	1.98	0	0	0	74.55
		Barite	Barium Sulfate	Weighting agent	350	266	115		3.1	4.5	0	0	0	233.4
			Crystalline silica, quartz			14	440		0	2.6	0	0	0	60
		Starcide	3, 3'-Methylene bis (5-methyl oxazolidine)	Bactericide	0.5	0.4	49		2800000	1.069	90	0.9	0,014 hPa	186.25
12-1/4" HPWBM	1	Soda Ash	Sodium Carbonate	Hardness buffer	1	2	200		212500	2.52	0	0	0	106
		Caistic Soda	Sodium hydroxide	Alkaline/pH buffer	1	2	20		1000000	2.13	0	0	0	40
		Barazan-D	Polysaccharide/Xanthan Gum	Bolymer Viscosifier	6	12	420		100000	1.6	93	0	0	
		Potasium Chloride	Potassium Chloride	Shale inhibitor	70	140	100		355000	1.98	0	0	0	
		Barite	Barium Sulfate	Weighting agent	350	855	115		3.1	4.5	0	0	0	233.4
			Crystalline silica, quartz			45	440		0	2.6	0	0	0	60
		Sodium Chloride	NaCl	Shale inhibitor	40	80	1E+06		317000	2.17	100	0	0	
		GEM GP	Polyethylene glycol butyl ether	Shale inhibitor	1	2	188		989000	0.989	69	2.75	0	

		Clayseal Plus	Triethylenetetramine, polymer with oxirane	Shale inhibitor	2	1.2	562.3		500000	1.0411	100	0		
			Hydrochloric acid			0.2	0.45		500000	1.27	100	0	45.6	
		Clay Grabber	Hydrotreated light petroleum distillate	Shale inhibitor	2.5	1	9.8		12	0.798	58.6	1E+07	0.03	
			Ethoxylated branched C13 alcohol			0.15	1.31		1000	1	60	10	0	228.42
		Clay Sync II	?	Shale inhibitor	5	10	1160		500000	1.04	2.8	0	0	
		Bore HIB	Silicic acid, potassium salt	Fluid loss reducer	20	10	146		0	1.43	na	na	0	
		Dextrid E	Complex carbohydrate	Fluid loss reducer	8	40	1000		500000	1.5	70	0	0	
		PAC-L	Polyanionic Cellulose	Fluid loss reducer	8	16	87.26		500000	1.6	60	na	0	263
8/1/2" HPWBM	1	Soda Ash		Hardness buffer	1	1	200		212500	2.52	0	0	0	106
		Caistic Soda		Alkaline/pH buffer	1	1	20		1000000	2.13	0	0	0	40
		Barazan-D		Viscosifier	6	6	420		100000	1.6	93	0	0	
		Potasium Chloride		Shale inhibitor	70	70	100		355000	1.98	0	0	0	
		Barite	Barium Sulfate	Weighting agent	350	427.5	115		3.1	4.5	0	0	0	233.4
			Crystalline silica, quartz			22.5	440		0	2.6	0	0	0	60
		Sodium Chloride		Shale inhibitor	40	40	1E+06		317000	2.17	100	0	0	
		GEM GP		Shale inhibitor	1	1	188		989000	0.989	69	2.75	0	
		Clayseal Plus	Triethylenetetramine, polymer with oxirane	Shale inhibitor	2	0.6	562.3		500000	1.0411	100	0		
			Hydrochloric acid			0.1	0.45		500000	1.27	100	0	45.6	
		Clay Grabber	Hydrotreated light petroleum distillate	Shale inhibitor	2.5	0.5	9.8		12	0.798	58.6	1E+07	0.03	

			Ethoxylated branched C13 alcohol			0.075	1.31		1000	1	60	10	0	228.42
		Clay Sync II	?	Shale inhibitor	5	5	1160		500000	1.04	2.8	0	0	
		Bore HIB	Silicic acid, potassium salt	Fluid loss reducer	20	20	146		0	1.43	na	na	0	
		Dextrid E	Complex carbohydrate	Fluid loss reducer	8	8	1000		500000	1.5	70	0	0	
		PAC-L	Polyanionic Cellulose	Fluid loss reducer	8	8	87.26		500000	1.6	60	na	0	263
		BARACARB 150	Barium Sulfate	Loss Control Material/LCM	25	25	115		3.1	4.5	0	0	0	233.4
		BARACARB 50	Barium Sulfate	Loss Control Material/LCM	25	25	115		3.1	4.5	0	0	0	233.4

6 Ambient ocean currents conditions

Identical discharge scenarios for discharge location 4 and discharge location 5 have been simulated for 4 seasons to capture any seasonal variability in the discharge fate. The specific start end of the seasons have been provided by the client. The start times (corresponding to the time stamps in the SATOCEAN dataset) for the discharge location 4 simulations in each season are:

Summer (Dec-Jan-Feb)	2015-12-26 15:00
Autumn (Mar-Apr-May)	2013-03-12 09:00
Winter (Jun-Jul-Aug)	2016-08-14 09:00
Spring (Sep-Oct-Nov)	2014-10-19 12:00

Selected start date/times for the simulations at discharge location 5 are:

Summer (Dec-Jan-Feb)	2015-12-24 03:00
Autumn (Mar-Apr-May)	2013-03-12 09:00
Winter (Jun-Jul-Aug)	2015-08-12 00:00
Spring (Sep-Oct-Nov)	2015-10-15 03:00

For detailed information see the Metocean report delivered by WSP in Appendix 2:
ANALYSIS OF METOCEAN DATA FOR OIL SPILL AND DRILLING DISCHARGE MODELLING FOR BLOCK 11B/12B, WSP Ref.No.: 41105306.

7 Presentation of results

This chapter presents the results from the simulated drilling operations together with their computed Environmental Impact Factor (EIF). The DREAM model first simulates the discharge and its fate and behaviour for a simulation period of 35 days. It then starts the sediment module, which simulates the restitution processes in the sediment compartment (toxicity, oxygen change, grain size change and burial). The sediment module was run for 10 years and is independent of environmental data like currents. This means that resuspension of sediments and subsequent redistribution is not simulated. This is a conservative assumption.

The results are presented as figures. The following figures are shown:

For the water column:

- Table and pie chart for the risk contributors
- Time series of EIF value
- Instantaneous risk calculated for the instant with maximum risk in the water column, including vertical cross section
- Concentration field for the component with the max. contribution to the environmental risk, including vertical cross section

For the sediment:

- Table and pie chart for the risk contributors
- Time series of EIF value
- Accumulated risk calculated for the whole simulation period
- Total deposition in mm (burial), including a cross section through the pile
- Change of grain size in the sediment
- Oxygen change in the sediment

This chapter presents the results for drilling discharges from discharge location 4 and 5 simulated with environmental data for the different periods of a year as defined in Chapter 6. See the attached Metocean report Appendix 2, Chapter 2 and 3.

The results from simulations for discharge location 4 are shown in chapter 8.1 - 8.4 (EIF for the water column and sediment), chapter 8.5 (Risk in the water column), chapter 8.6 (Risk in the sediment), chapter 8.7 (deposition on the seafloor), chapter 8.8 (Sediment thickness at the sea floor from cuttings), 8.9 (grainsize change) and 8.10 (Oxygen change in the sediment).

The results from simulations for discharge location 5 are shown in chapter 9.1 - 9.4 (EIF for the water column and sediment), chapter 9.5 (Risk in the water column), chapter 9.68.6 (Risk in the sediment), chapter 9.7 (deposition on the seafloor), chapter 9.8 (Sediment thickness at the sea floor from cuttings), 9.9 (grainsize change) and 9.10 (Oxygen change in the sediment).

The tables show all chemical components of the discharge together with their associated PNEC value. The PNEC values for the mud composition is provided by the TEEPSA Fluid team see Table 5.9.
The column 'Contribution to risk' shows the relative fraction of the chemical component or stressor (thickness, oxygen demand and grain size change) of the EIF value, the column 'Contribution EIF' is the absolute fraction of the chemical component or stressor to the EIF value. Both columns show the values for the time where the EIF is at its maximum.

Note: EIF = 1 is the area of 100x100x10 m^3 where the risk for environmental effects exceeds 5%. This is defined as more than 5% of the species are potentially being affected as they are exposed above a chronic no-effect level.

8 Results for drilling discharges from location 4

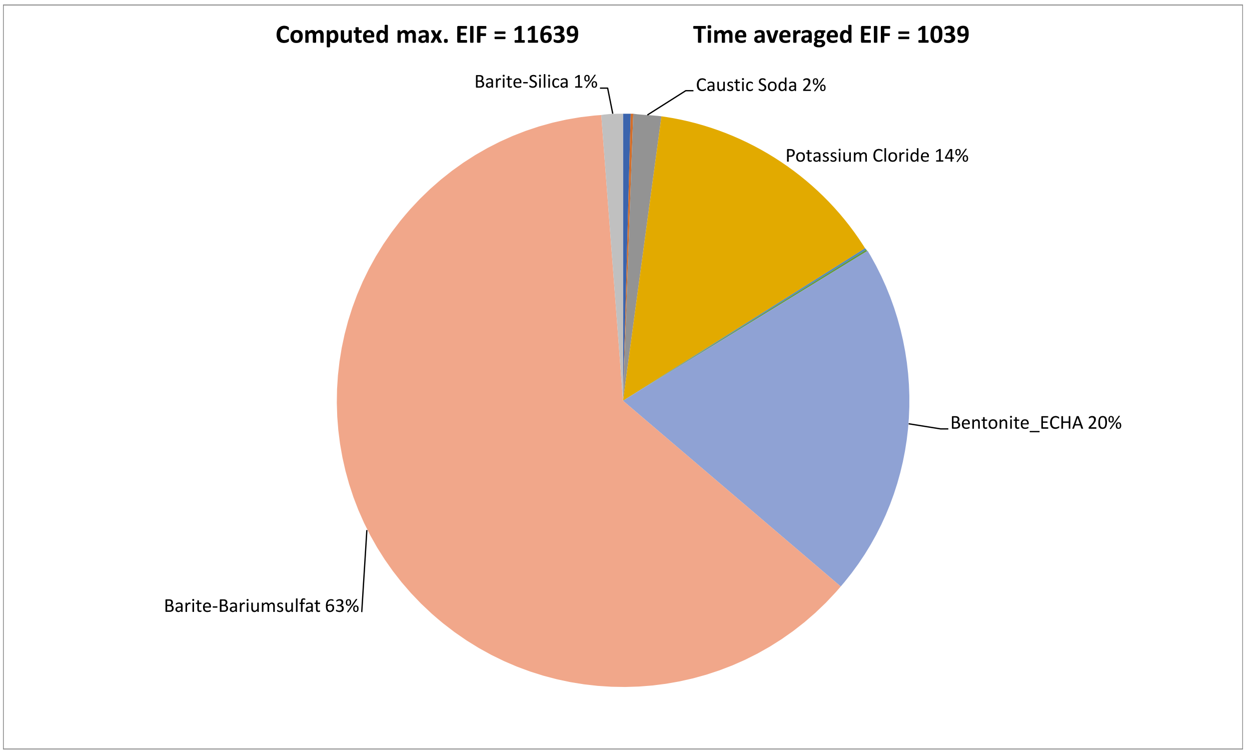
8.1 EIF results for discharge location 4, Summer

8.1.1 Discharge location 4 - Lower water-column – Summer

The maximum EIF (water volume 100x100x10 m^3) in the lower water-column 1100 - 1300 meters for discharge location 4, was 11639, while the time average EIF was 1039. The contributions of the components of the discharge are listed in the table below (risk in % of EIF).

Table 8.1 Table and pie-chart with EIF results for the lower water column, 1100 - 1300 meters, discharge location 4 - Summer.

Computed max. EIF:	**11639**				
Time averaged EIF:	1039				
Components	Product	PNEC ppb	Contribution to risk %	Contribution max EIF	Contribution time averaged EIF
Total					
Barazan D		420	0.43	50.0478	4.4685
Soda Ash		200	0.12	13.9668	1.2470
Caustic Soda		20	1.58	183.8964	16.4190
Potassium Cloride		100	13.91	1618.9865	144.5500
Starcide		49	0.12	13.9668	1.2470
Cuttings		100000	0.08	9.3112	0.8313
Bentonite_ECHA		170	20.01	2328.9662	207.9400
Barite-Bariumsulfat		115	62.58	7283.6935	650.3190
Barite-Silica		440	1.17	136.1764	12.1584



Barium sulfate is dominating the risk with 63% for the lower water column. This is caused by the amount of Barite that will be discharged on the seafloor from the displacement sections released after drilling of the 42” and 26” sections, together with Bentonite discharged during drilling.

Figure 8.1 shows the time development for the EIF in water-column. It shows the duration of risk during the discharges on the sea floor and that the risk in the water column disappears immediately afterwards.

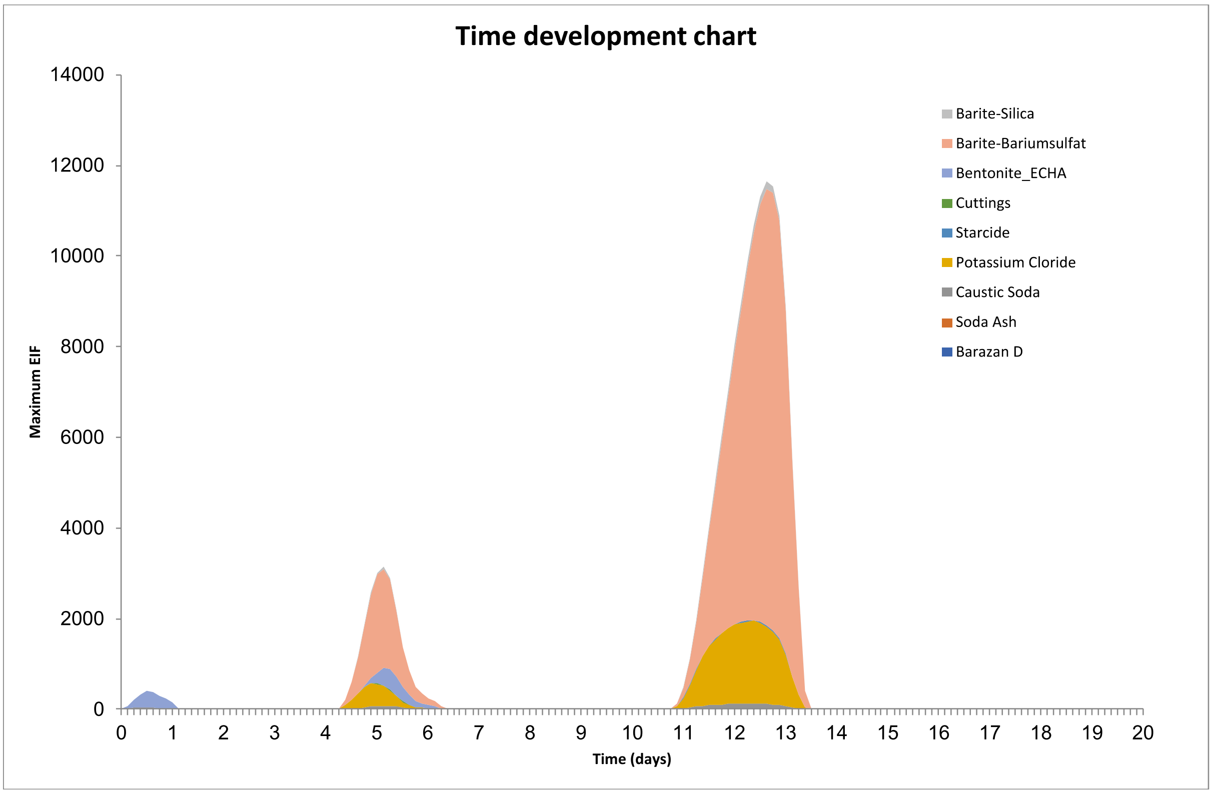


Figure 8.1 Time development of the EIF for the lower water column, discharge location 4 - Summer.

Figure 8.2 shows the time instant with maximum EIF for the lower water column due to discharges from the top hole sections, while Figure 8.4 shows the maximum cumulative risk (foot-print) throughout the lower water column at any time during the drilling operation with discharges from the top hole sections. The discharge is advected offshore into deeper water, which is the reason why the seabed is not seen as close to the discharge in the cross-section.

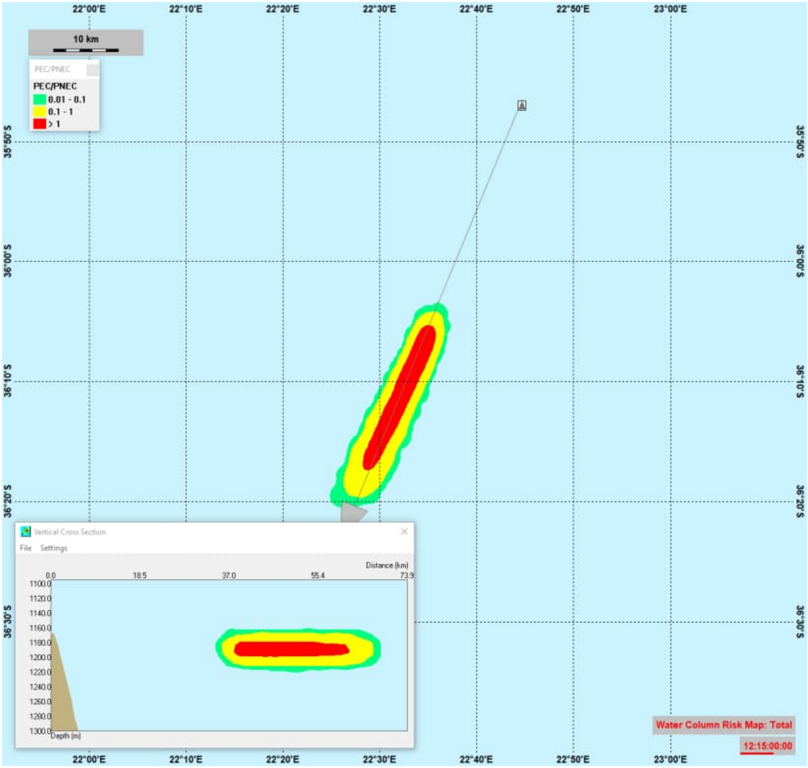


Figure 8.2 *Snapshot showing the time instant with maximum EIF for the lower water column at 1100 - 1300 meters. Snapshot at day 12.5, at the end of discharges from the top hole sections on the sea floor. The vertical cross section shows the PEC/PNEC ratio along the grey arrow, discharge location 4 - Summer.*

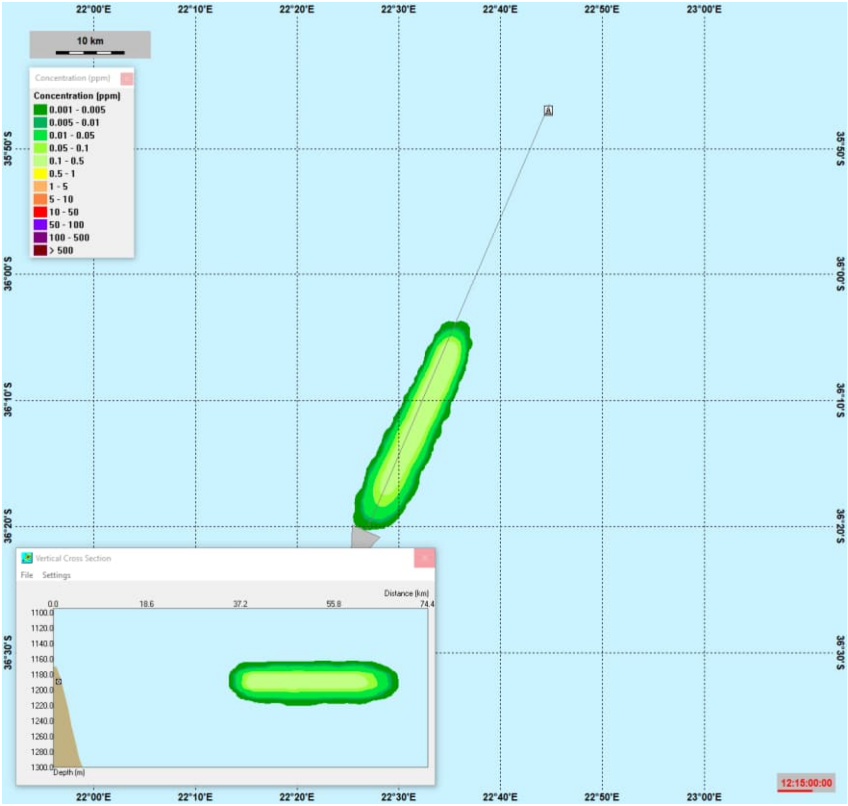


Figure 8.3 *Concentration field for the component that gave the largest contribution to the environmental risk, namely the particle group barite, at the same time-step as for maximum EIF. A cross-section of the plume is shown in the smaller panel, discharge location 4 - Summer.*

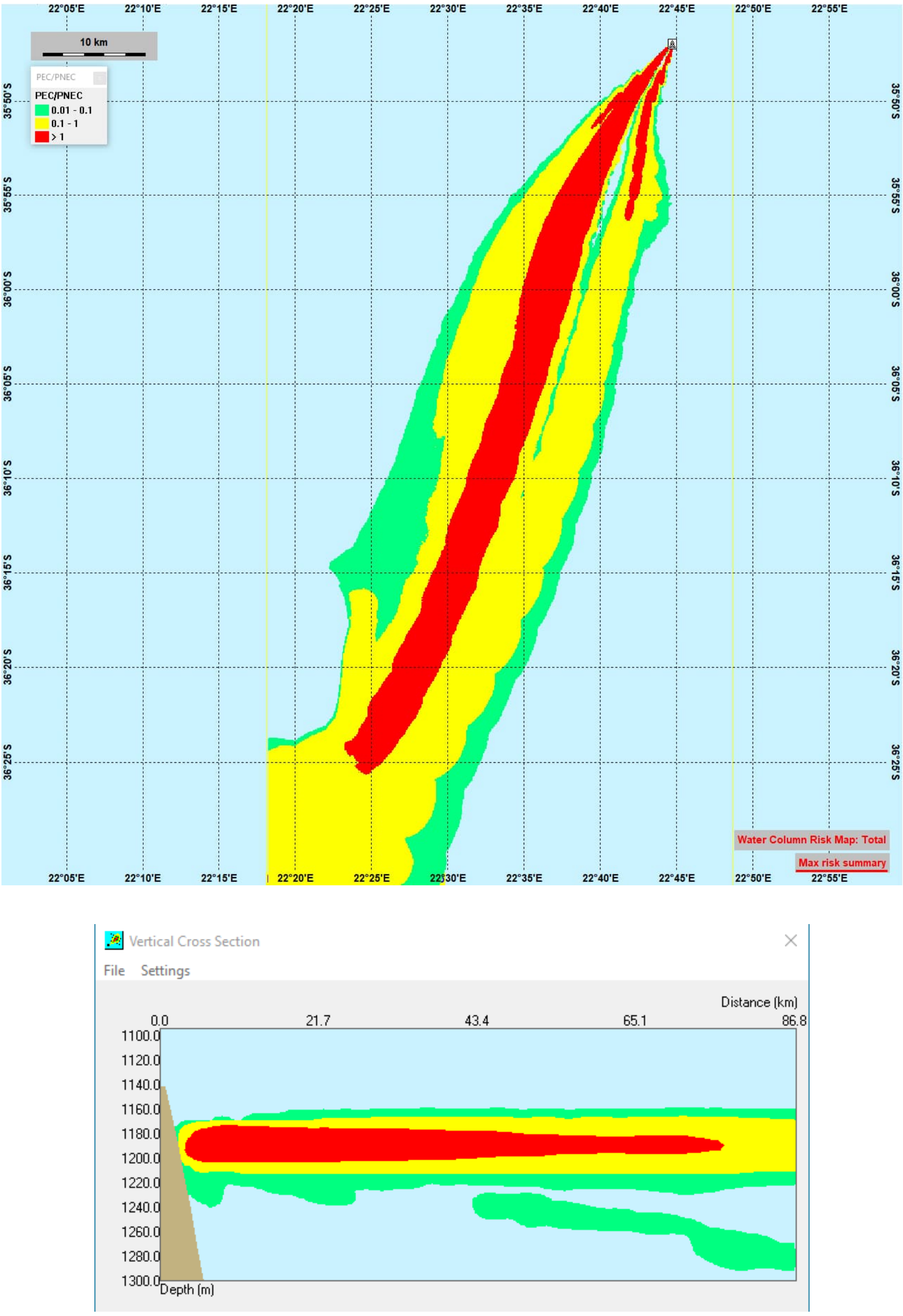


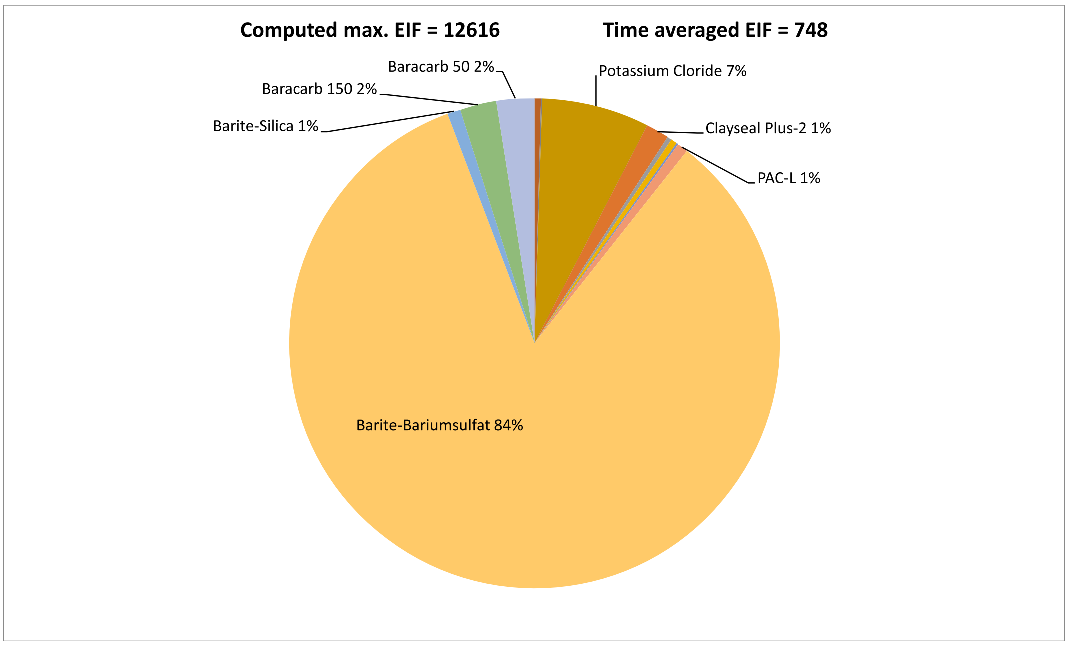
Figure 8.4 Maximum cumulative risk of drilling operations throughout the lower water column at any time for discharge location 4 (Start time December 26) Discharge at the seafloor. Discharge location 4 – Summer.

8.1.2 Discharge location 4 - Upper water-column – Summer

The maximum EIF (water volume 100x100x10 m^3) in the upper water-column 0-100 meter for discharge location 4, Summer, was 12616, while the time average EIF was 748. The contributions of the components of the discharge are listed in the table below (risk in % of EIF).

Table 8.2 Table and pie-chart with EIF results for the water column, upper 100 meter for discharge location 4, Summer.

Computed max. EIF:	**12616**				
Time averaged EIF:	748				
Components	Product	PNEC ppb	Contribution to risk %	Contribution max EIF	Contribution time averaged EIF
Total					
Soda Ash		200	0.03	3.7848	0.2244
Caustic Soda		20	0.36	45.4175	2.6928
Barazan D		420	0.08	10.0928	0.5984
Potassium Cloride		100	7.14	900.7796	53.4081
Sodium Chloride		1000000	0	0	0
GEM GP		188	0.03	3.7848	0.2244
Clayseal Plus		562.3	0	0	0
Clayseal Plus-2		0.45	1.48	186.7162	11.0706
Clay Grabber		9.8	0.33	41.6327	2.4684
Clay Grabber-2		1.31	0.41	51.7254	3.0669
Clay Sync II		1160	0.02	2.5232	0.1496
Bore HIB		146	0	0	0
Dextrid E		1000	0.08	10.0928	0.5984
PAC-L		87.26	0.69	87.0501	5.1613
Cuttings		100000	0	0	0
Barite-Bariumsulfat		115	83.58	10544.4198	625.1895
Barite-Silica		440	0.86	108.4973	6.4329
Baracarb 150		115	2.46	310.3526	18.4011
Baracarb 50		115	2.46	310.3526	18.4011



The results show that for the upper water column, effects caused by discharges of particle matter (essentially Barium sulfate 84%) are dominating the risk in the affected water volume. During the time of maximum EIF, the discharge is released from the rig 10 meters below sea-surface and sinks down to about 40 meters in the water-column, where the discharge plume reached neutral buoyancy. The reason why barium remains for some time at this depth is due to the fine particles, it is having 50 % of the size distribution below 7 micrometers, see Table 5.4.The discharge is driven by the currents in S/SW direction.

Figure 8.5 shows the time development for the EIF in water-column. It shows that the time duration with environmental risk occurs in intervals lasting some days after.

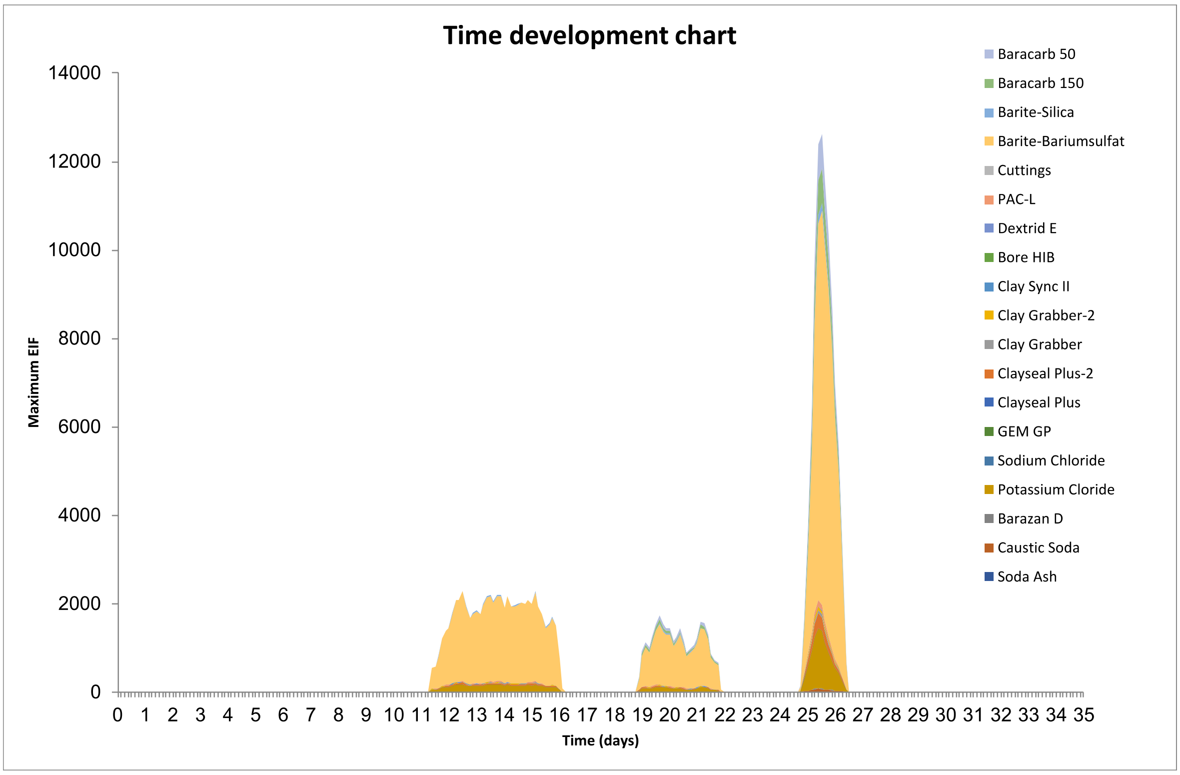


Figure 8.5 Time development of the EIF for the upper water column, for discharge location 4 - Summer.

Figure 8.6 shows the time instant with maximum EIF for the upper water column due to discharges from rig 10 m below sea surface, while Figure 8.8 shows the maximum cumulative risk (foot-print) throughout the upper water column at any time during the drilling operation with discharges from the rig.

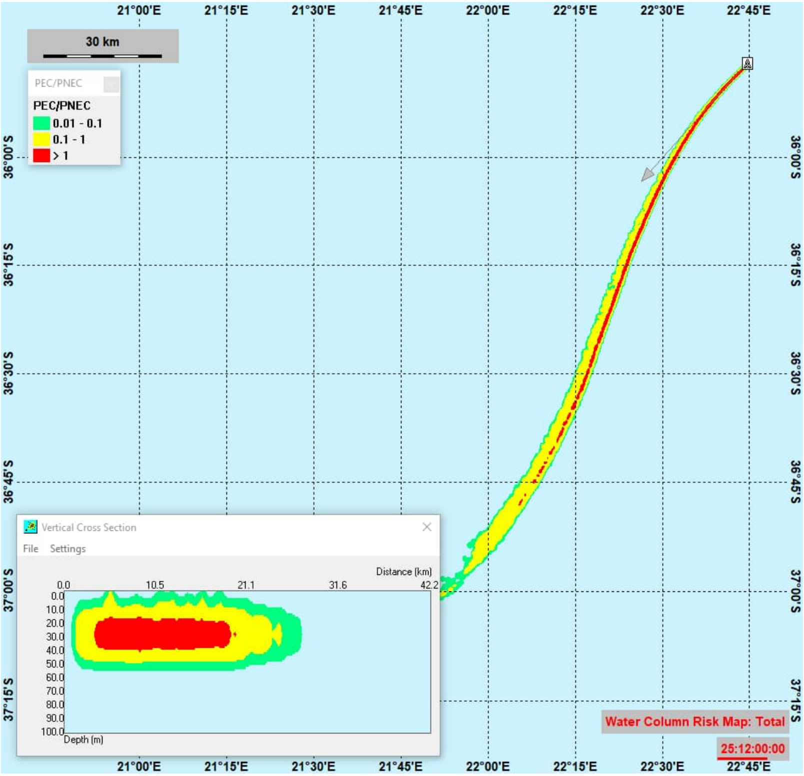


Figure 8.6 *Snapshot showing the time instant with maximum EIF for the upper water column between 0-100 meters. Snapshot from 25.5 days after start, when the discharge is released from the rig. The vertical cross section shows the PEC/PNEC ratio in the water column along the grey arrow. Discharge location 4 - Summer.*

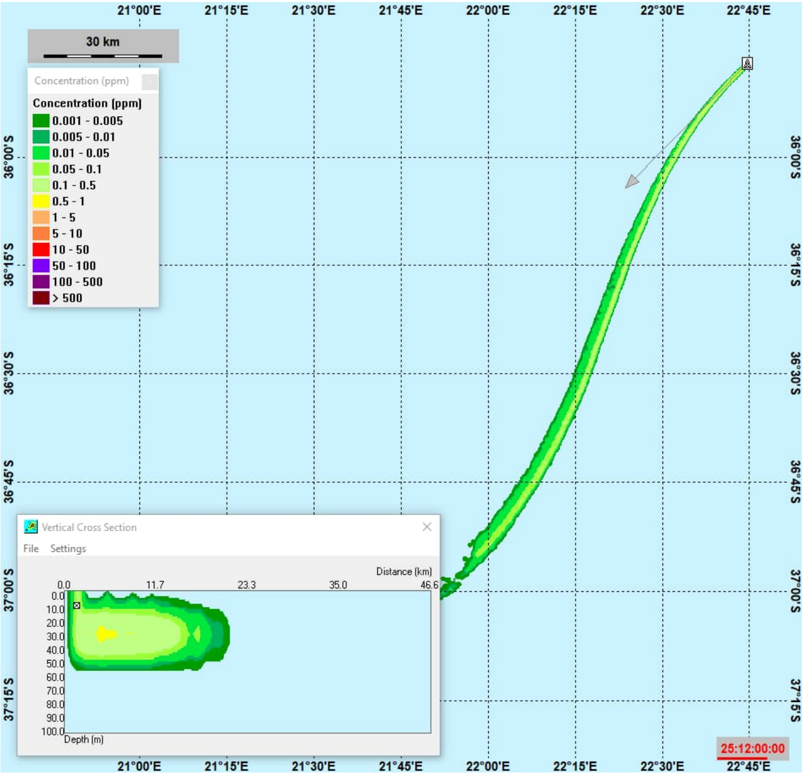


Figure 8.7 *Concentration field for the component that gave the largest contribution to the environmental risk, namely the particle group Barium sulfate, at the same time-step as for maximum EIF. The discharge is spread in the upper 40 meters in the water column driven by the currents. Concentrations up to 1 ppm. A cross section of the plume is shown in the smaller panel. Discharge location 4 - Summer.*

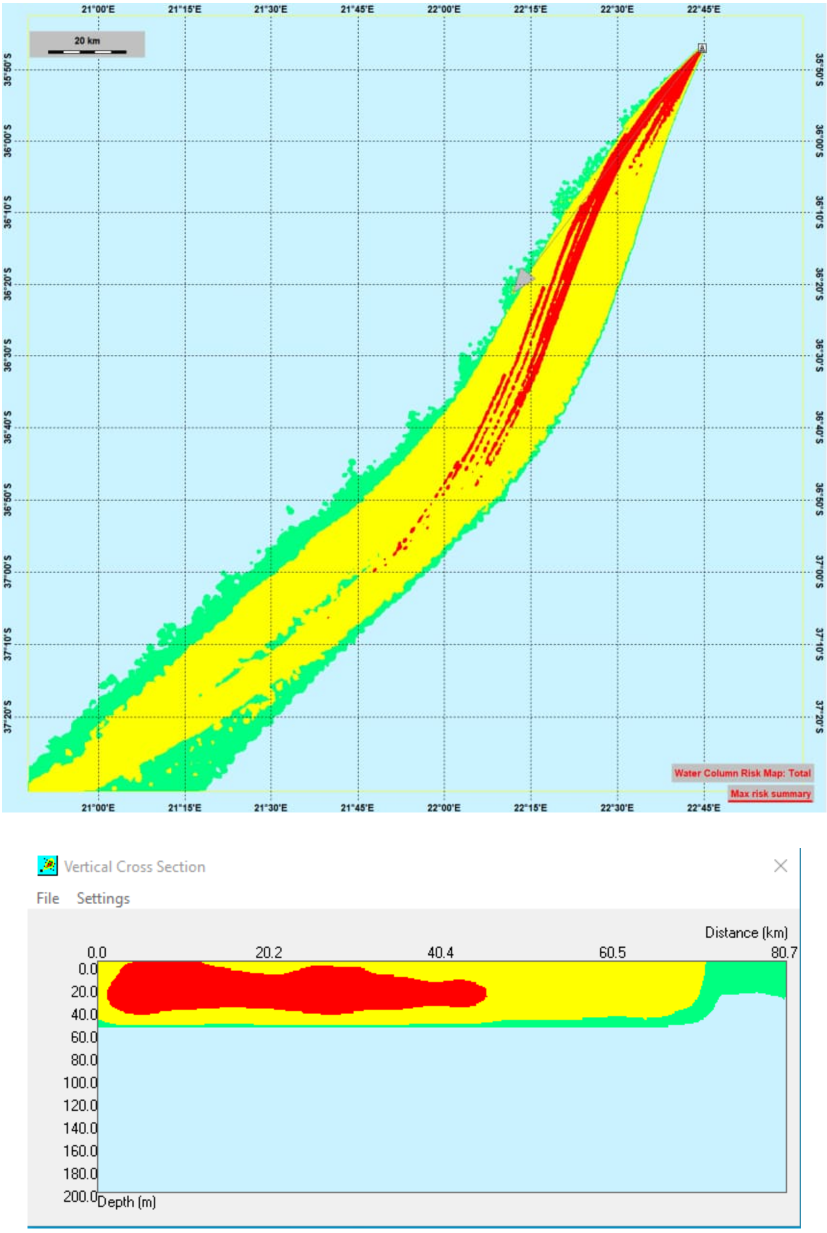


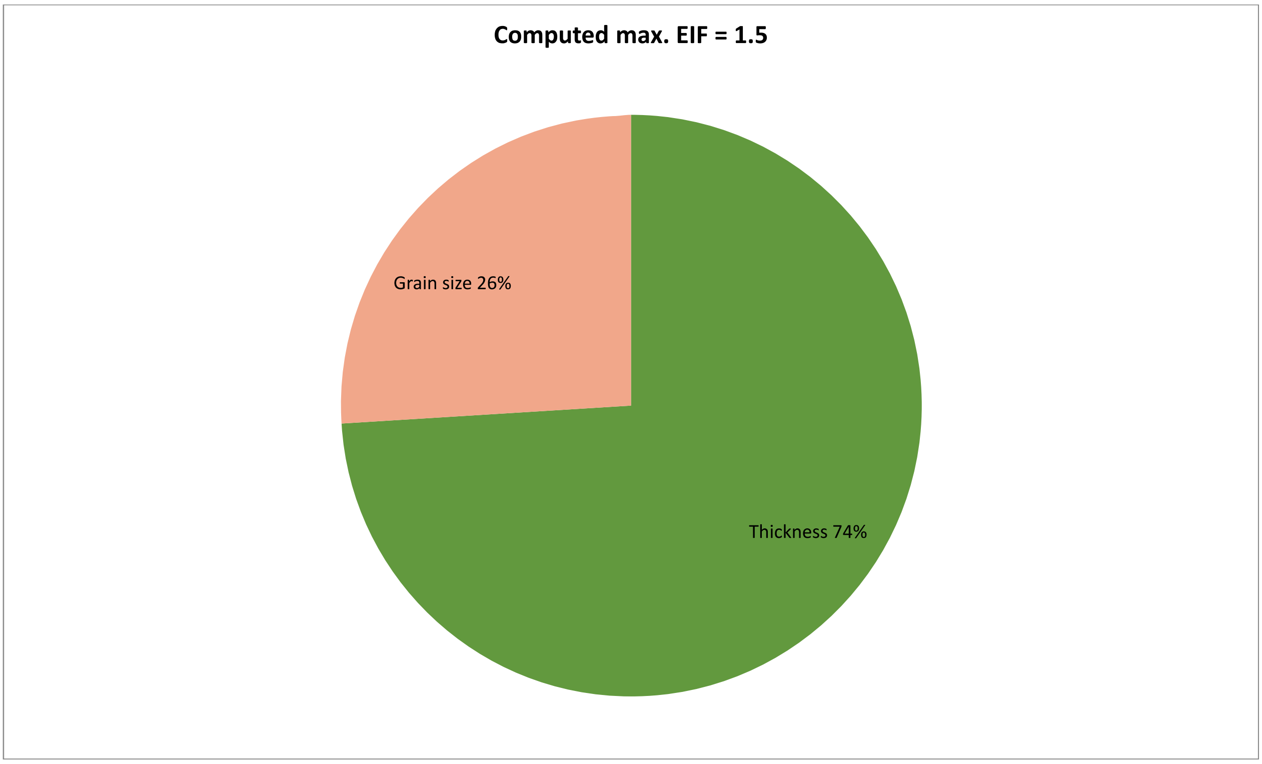
Figure 8.8 *Maximum cumulative risk of drilling operations throughout the upper water column at any time for discharge location 4 (Start time December 26), discharge from rig 10 m below sea surface. Discharge location 4 – Summer.*

8.1.3 Discharge location 4 - EIF results for the sediment – Summer

The maximum EIF (sea floor area100x100 m^2) is computed to 1.5 impacted by the top hole discharge, Figure 8.10 and with 1.25 impacted by discharge from the rig, Figure 8.12. The contributions of the components of the discharge are listed in Table 8.3 for the top hole sections, and Table 8.4 for the discharge from rig (risk in % of EIF). The factor affecting the EIF from the discharge from rig is essentially only due to grain size change. This holds true for the other seasons and for location 4 as well, so the equivalent to Table 8.4 is not shown for these scenarios. Most of the affected area on the sea floor is caused by the top hole discharges. The impact is largest at the end of the transport and fate simulation, shortly after the sediment module starts. After that the sea floor will start the restoration process and the affected area (EIF) then decreases.

Table 8.3 Table and pie-chart shows contributions to EIF from the components discharged from the top hole sections to the sediment for location 4 – Summer.

Simulated instantaneous EIF:	**1.5**				
Components	Product	PNEC ppb	Contribution to risk %	Contribution max EIF	Contribution time averaged EIF
Total					
Barazan D		420	0	0	0
Soda Ash		200	0	0	0
Caustic Soda		20	0	0	0
Potassium Cloride		100	0	0	0
Starcide		49	0	0	0
Thickness		0	74.05	1.11075	1.11075
Oxygen		0	0	0	0
Grain size		0	25.95	0.38925	0.38925



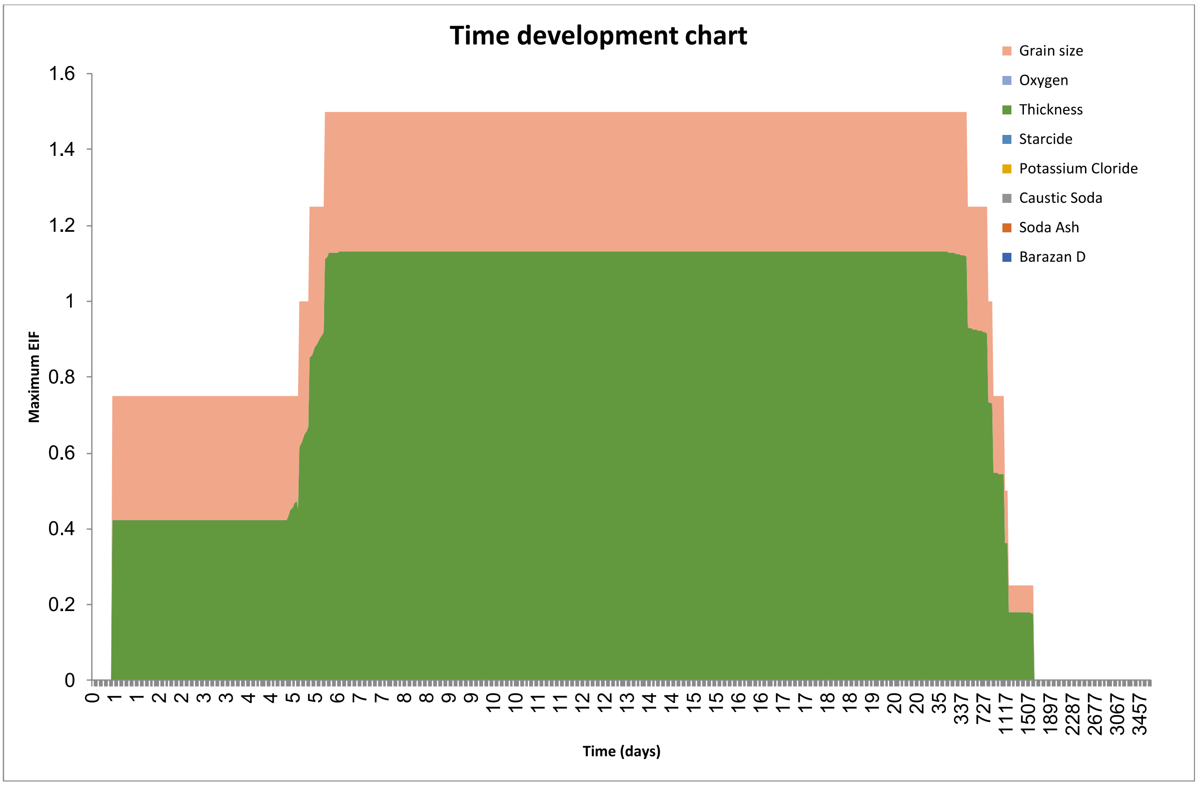


Figure 8.9 Time development of EIF for the sediment for discharges from the top hole sections, location 4 – Summer.

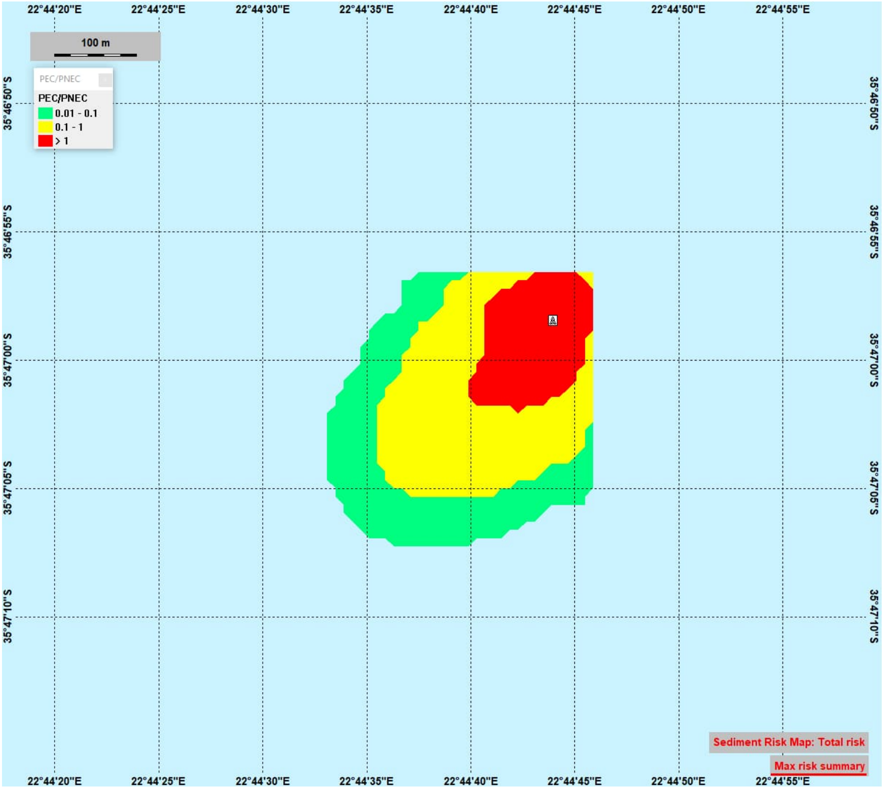
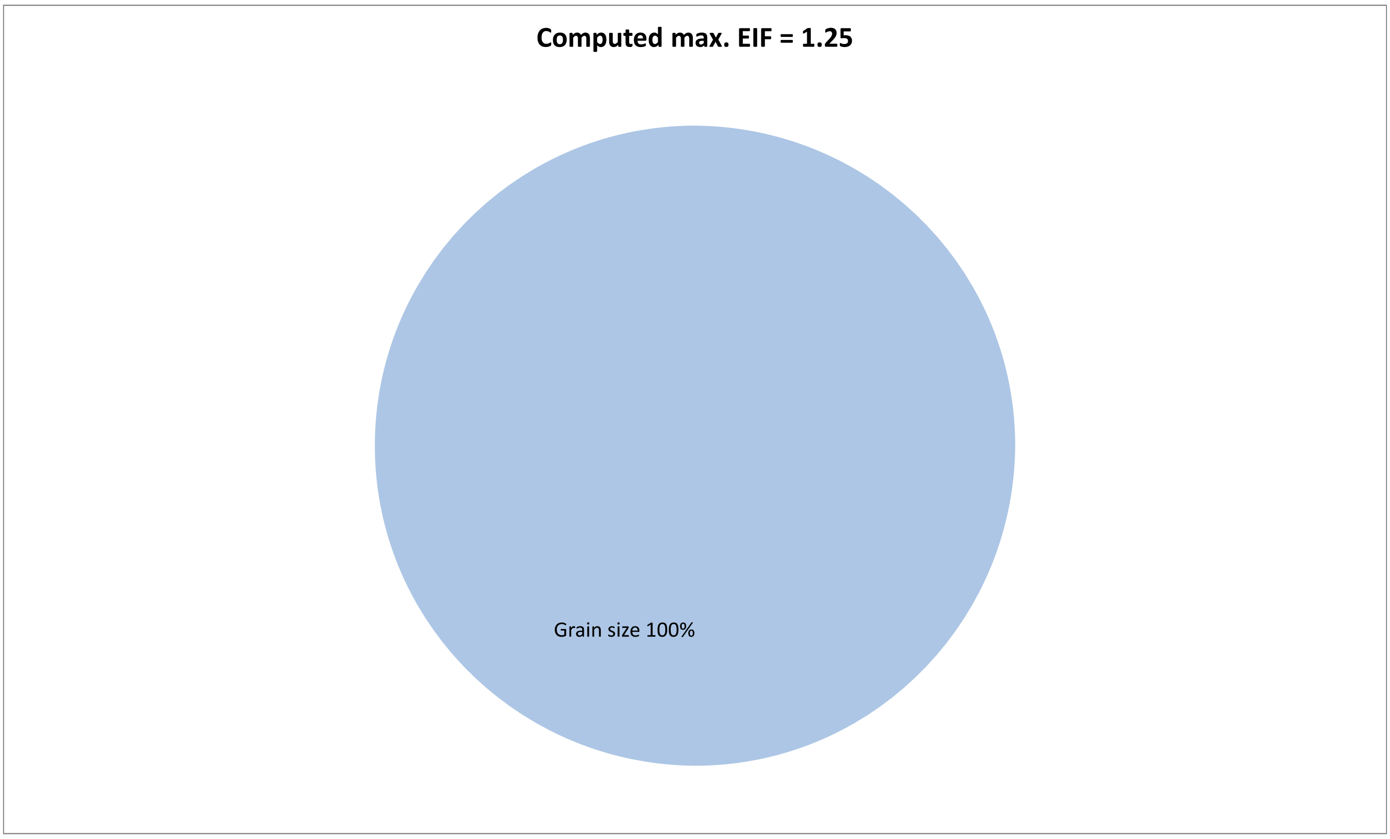


Figure 8.10 The total maximum EIF for the sediment (highest value at each location over simulation period) for discharge from the top hole drilling. (The straight edges in this figure is an artifact of smoothing).

Table 8.4 Table and pie-chart shows contributions to EIF from the components discharged from the rig to the sediment for location 4 – Summer.

Simulated instantaneous EIF:	**1.25**				
Components	Product	PNEC ppb	Contribution to risk %	Contribution max EIF	Contribution time averaged EIF
Total					
Soda Ash		200	0	0	0
Caustic Soda		20	0	0	0
Barazan D		420	0	0	0
Potassium Cloride		100	0	0	0
Sodium Chloride		1000000	0	0	0
GEM GP		188	0	0	0
Clayseal Plus		562.3	0	0	0
Clayseal Plus-2		0.45	0	0	0
Clay Grabber		9.8	0	0	0
Clay Grabber-2		1.31	0	0	0
Clay Sync II		1160	0	0	0
Bore HIB		146	0	0	0
Dextrid E		1000	0	0	0
PAC-L		87.26	0	0	0
Thickness		0	0.01	0.000125	0.000125
Oxygen		0	0	0	0
Grain size		0	99.99	1.249875	1.249875



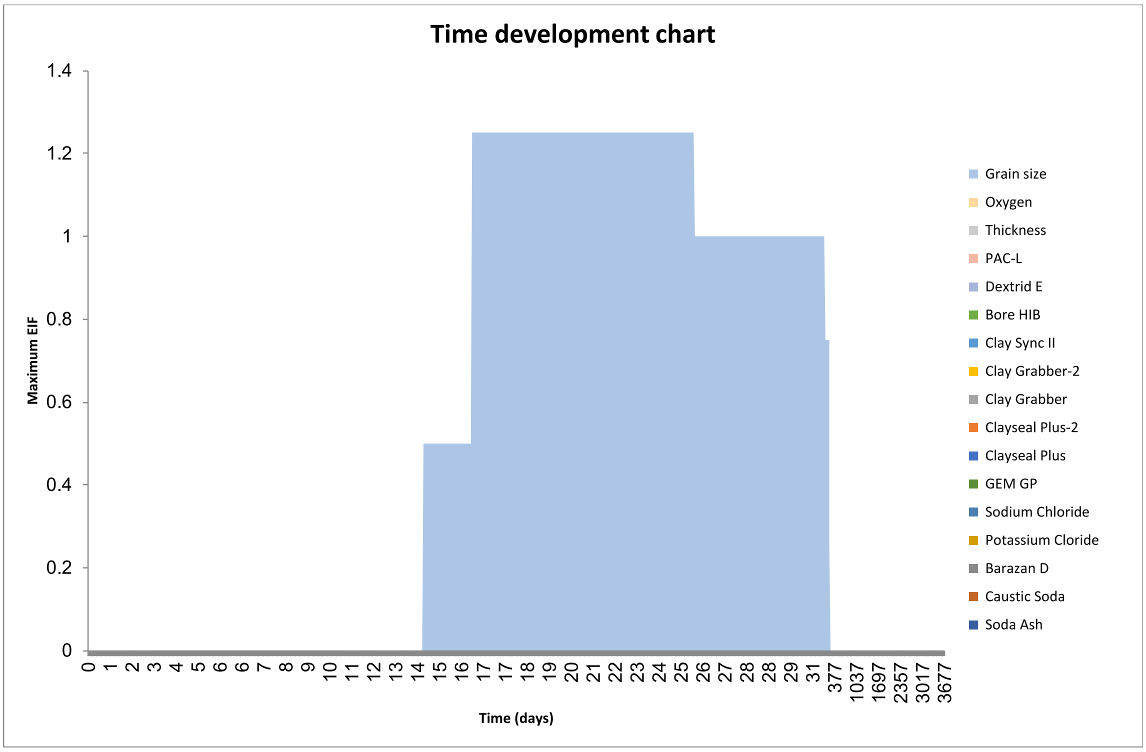


Figure 8.11 Time development of EIF for the sediment for discharges from the rig, location 4 – Summer.

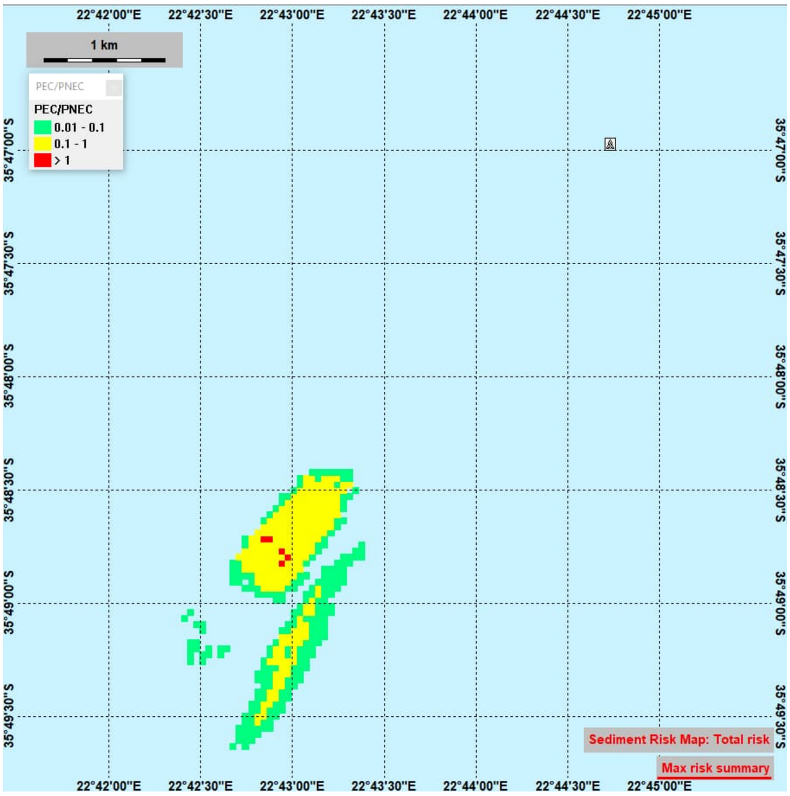


Figure 8.12 The total maximum EIF for the sediment (highest value at each location over simulation period) for discharge from the rig. The figure shows impact 3.5 km away from the release-point. Discharge location 4 – Summer (Un-smoothed results).

Simulations show that impact on the sediment caused by discharge from rig are negligible for all seasons, with EIF < 1. Therefore, only results showing impact from the top hole discharge are presented for the further scenarios.

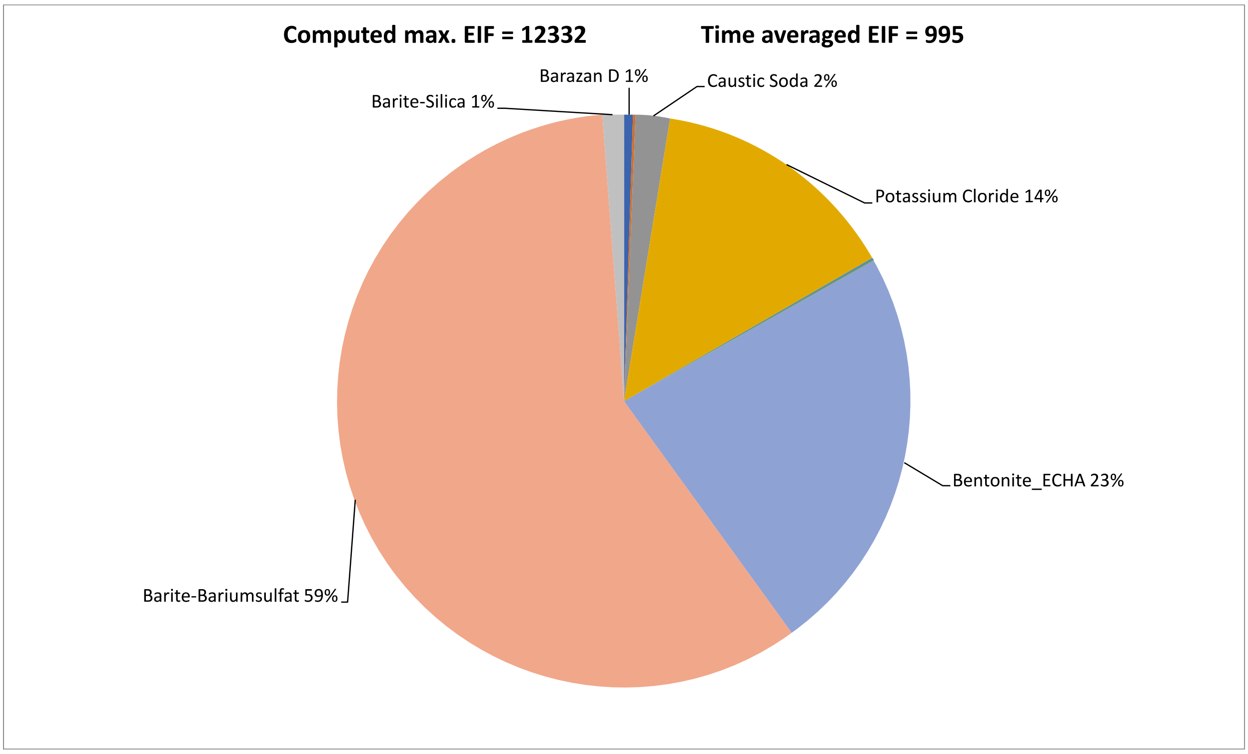
8.2 EIF results for discharge location 4, Autumn

8.2.1 Discharge location 4 - Lower water-column – Autumn

The maximum EIF (water volume 100x100x10 m^3) in the lower water-column 1100 - 1300 meters for discharge location 4, Autumn, was 12332, while the time average EIF was 995. The contributions of the components of the discharge are listed in the table below (risk in % of EIF).

Table 8.5 Table and pie-chart with EIF results for the lower water column, 1100 - 1300 meters. Discharge location 4 – Autumn.

Computed max. EIF:	**12332**				
Time averaged EIF:	995				
Components	Product	PNEC ppb	Contribution to risk %	Contribution max EIF	Contribution time averaged EIF
Total					
Barazan D		420	0.52	64.1265	5.1732
Soda Ash		200	0.14	17.2648	1.3928
Caustic Soda		20	1.9	234.3085	18.9020
Potassium Cloride		100	14.1	1738.8157	140.2729
Starcide		49	0.12	14.7984	1.1938
Cuttings		100000	0.08	9.8656	0.7959
Bentonite_ECHA		170	23.18	2858.5637	230.6047
Barite-Bariumsulfat		115	58.73	7242.5990	584.2716
Barite-Silica		440	1.23	151.6839	12.2366



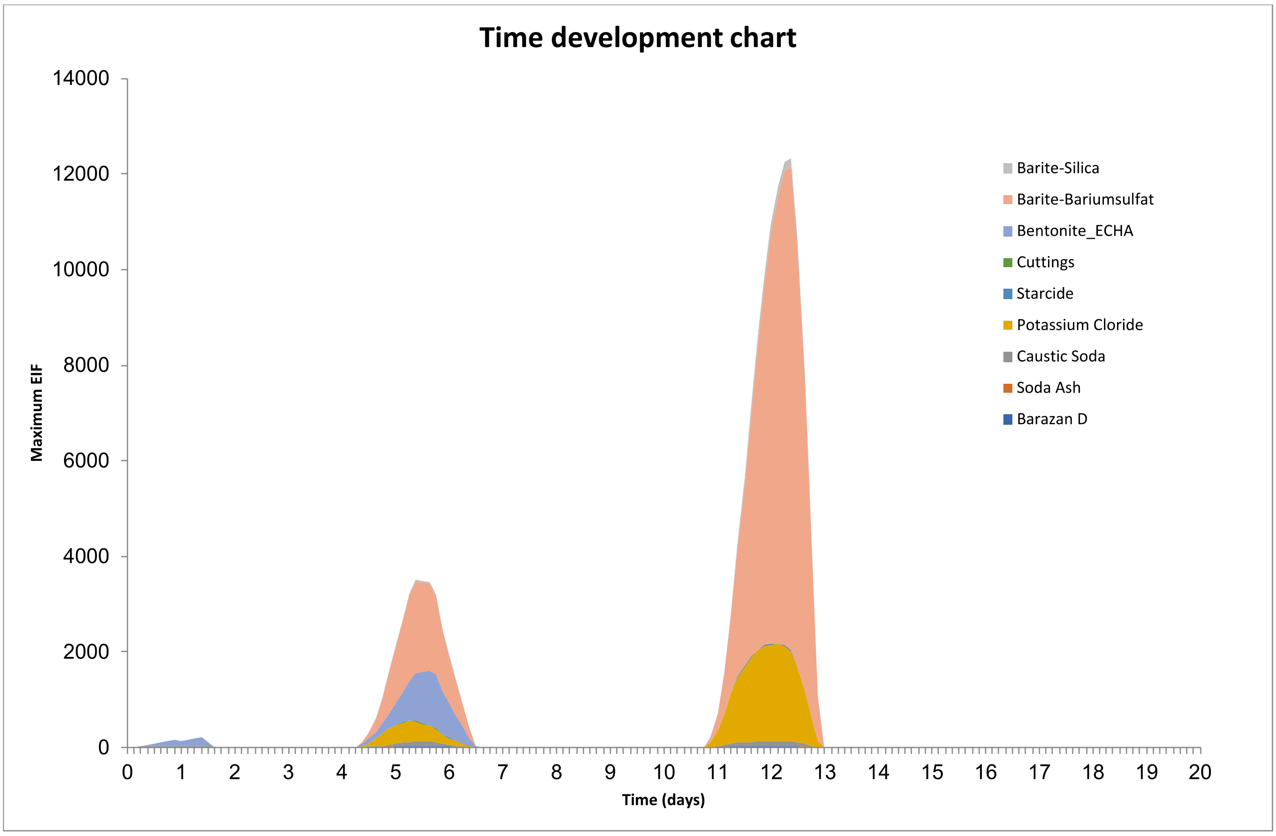


Figure 8.13 Time development of the EIF for the lower water column. Discharge location 4 – Autumn.

Figure 8.14 shows the time instant with maximum EIF for the lower water column due to discharges from the top hole sections, while Figure 8.16 shows the maximum cumulative risk (foot-print) throughout the lower water column at any time during the drilling operation with discharges from the top hole sections.

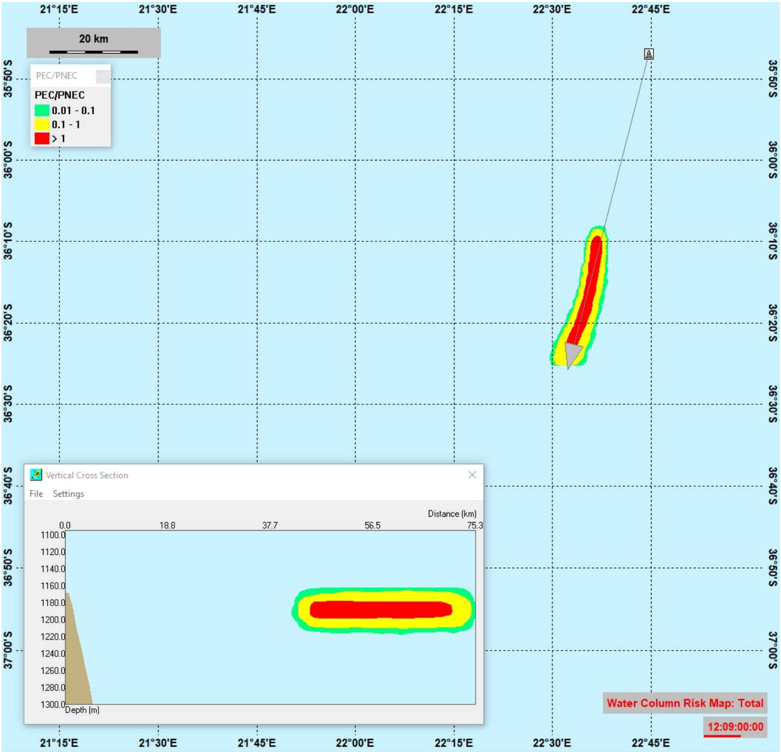


Figure 8.14 Snapshot showing the time instant with maximum EIF for the lower water column at 1100 - 1300 meters. Snapshot at day 12.75, when the discharge is from the top hole sections on the sea floor. The vertical cross section shows the PEC/PNEC ratio along the grey arrow. Discharge location 4 – Autumn.

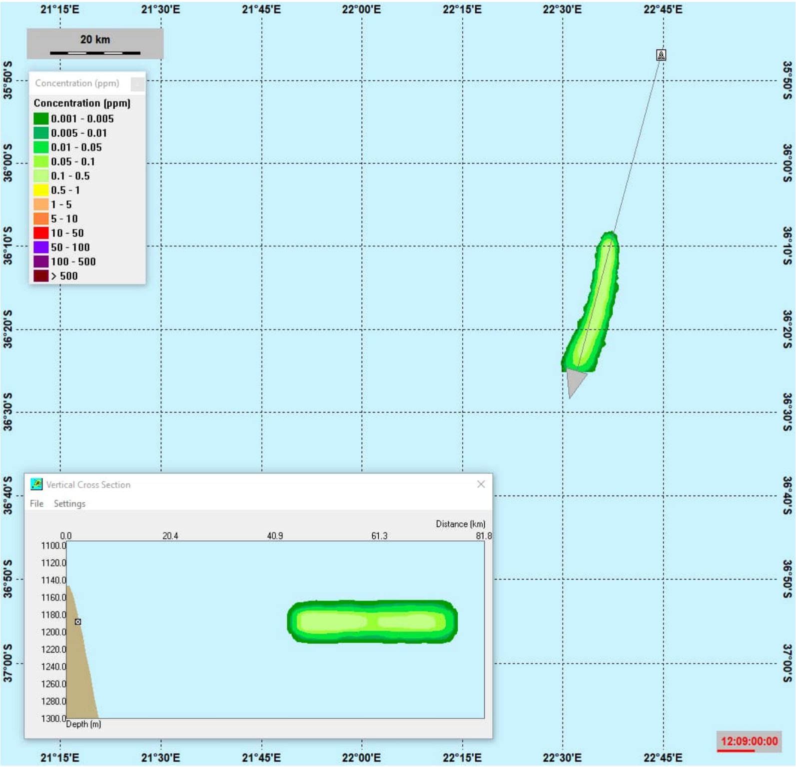


Figure 8.15 Concentration field for the component that gave the largest contribution to the environmental risk, namely the particle group barite, at the same time-step as for maximum EIF. A cross-section of the plume is shown in the smaller panel. Discharge location 4 – Autumn.

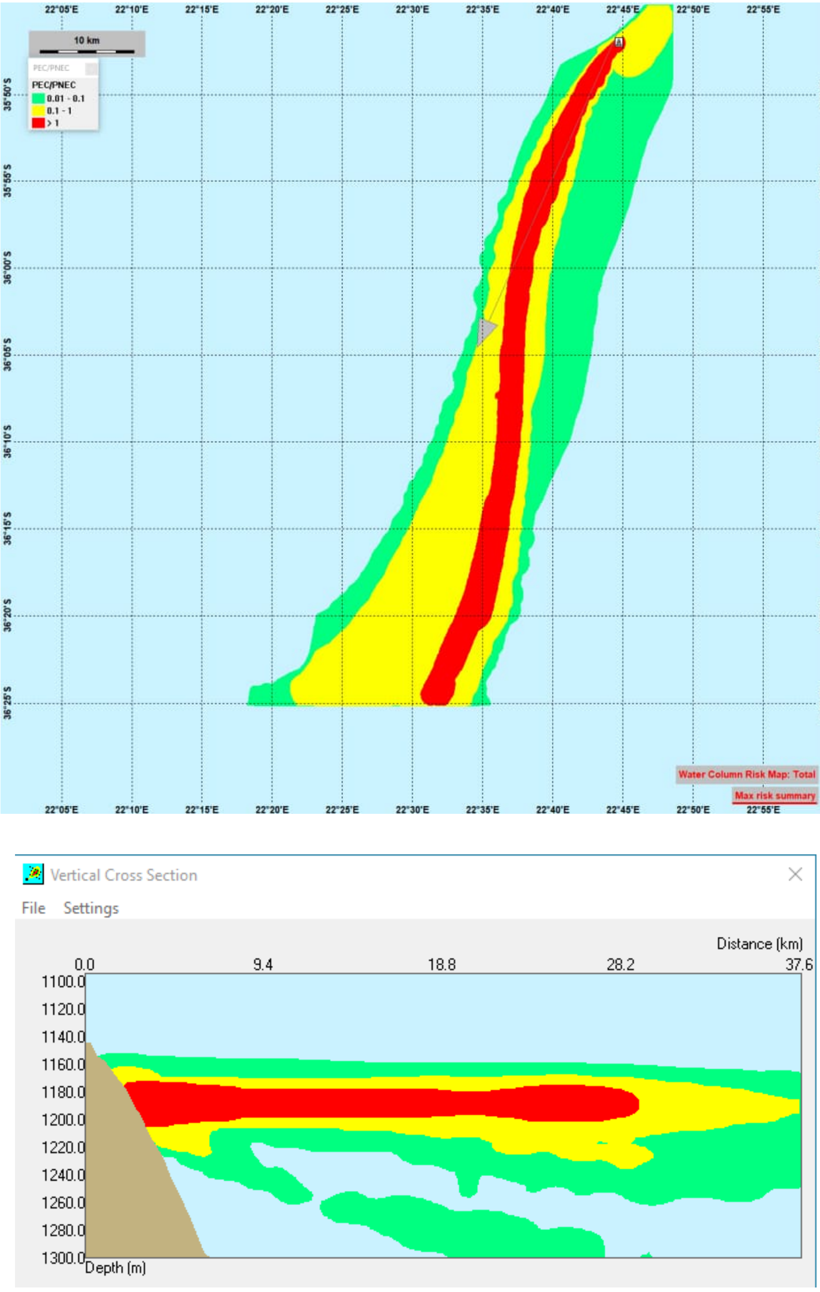


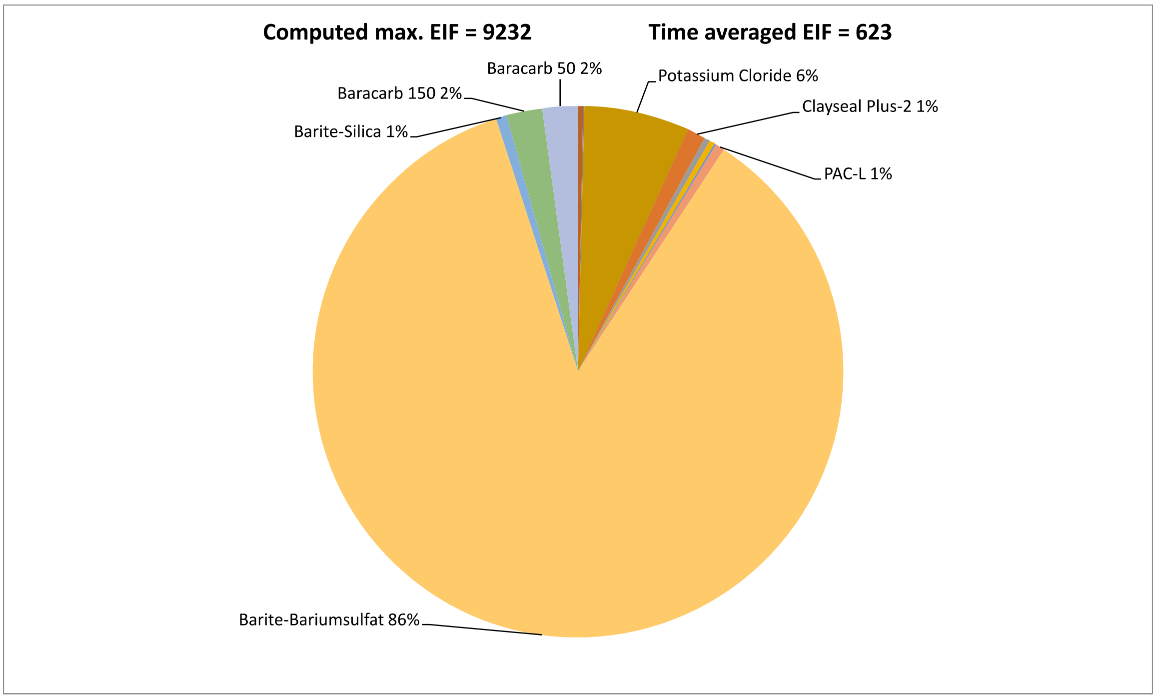
Figure 8.16 Maximum cumulative risk of drilling operations throughout the lower water column at any time for discharge location 4 (Start time March 12) Discharge at the seafloor. Discharge location 4 – Autumn.

8.2.2 Discharge location 4 - Upper water-column – Autumn

The maximum EIF (water volume 100x100x10 m^3) in the upper water-column 0-100 meter for discharge location 4, Autumn, was 9232, while the time average EIF was 623. The contributions of the components of the discharge are listed in the table below (risk in % of EIF).

Table 8.6 Table and pie-chart with EIF results for the water column, upper 100 meter for discharge location 4, Autumn.

Computed max. EIF:	**9232**				
Time averaged EIF:	623				
Components	Product	PNEC ppb	Contribution to risk %	Contribution max EIF	Contribution time averaged EIF
Total					
Soda Ash		200	0.02	1.8464	0.1246
Caustic Soda		20	0.32	29.5423	1.9934
Barazan D		420	0.07	6.4624	0.4360
Potassium Cloride		100	6.37	588.0766	39.6802
Sodium Chloride		1000000	0	0	0
GEM GP		188	0.02	1.8464	0.1246
Clayseal Plus		562.3	0	0	0
Clayseal Plus-2		0.45	1.15	106.1677	7.1636
Clay Grabber		9.8	0.29	26.7727	1.8065
Clay Grabber-2		1.31	0.35	32.3119	2.1802
Clay Sync II		1160	0.02	1.8464	0.1246
Bore HIB		146	0	0	0
Dextrid E		1000	0.07	6.4624	0.4360
PAC-L		87.26	0.6	55.3918	3.7375
Cuttings		100000	0	0	0
Barite-Bariumsulfat		115	85.72	7913.6456	533.9696
Barite-Silica		440	0.65	60.0078	4.0490
Baracarb 150		115	2.18	201.2570	13.5797
Baracarb 50		115	2.17	200.3338	13.5174



The results show that for the upper water column, effects caused by discharges of particle matter (essentially Barium sulfate 86%) are dominating the risk in the affected water volume. During the time of maximum EIF, the discharge is being released from the rig 10 meters below sea-surface and sinks down in the water-column.

Figure 8.17 shows the time development for the EIF in water-column. It shows that the duration with high environmental risk lasts some days for each discharge.

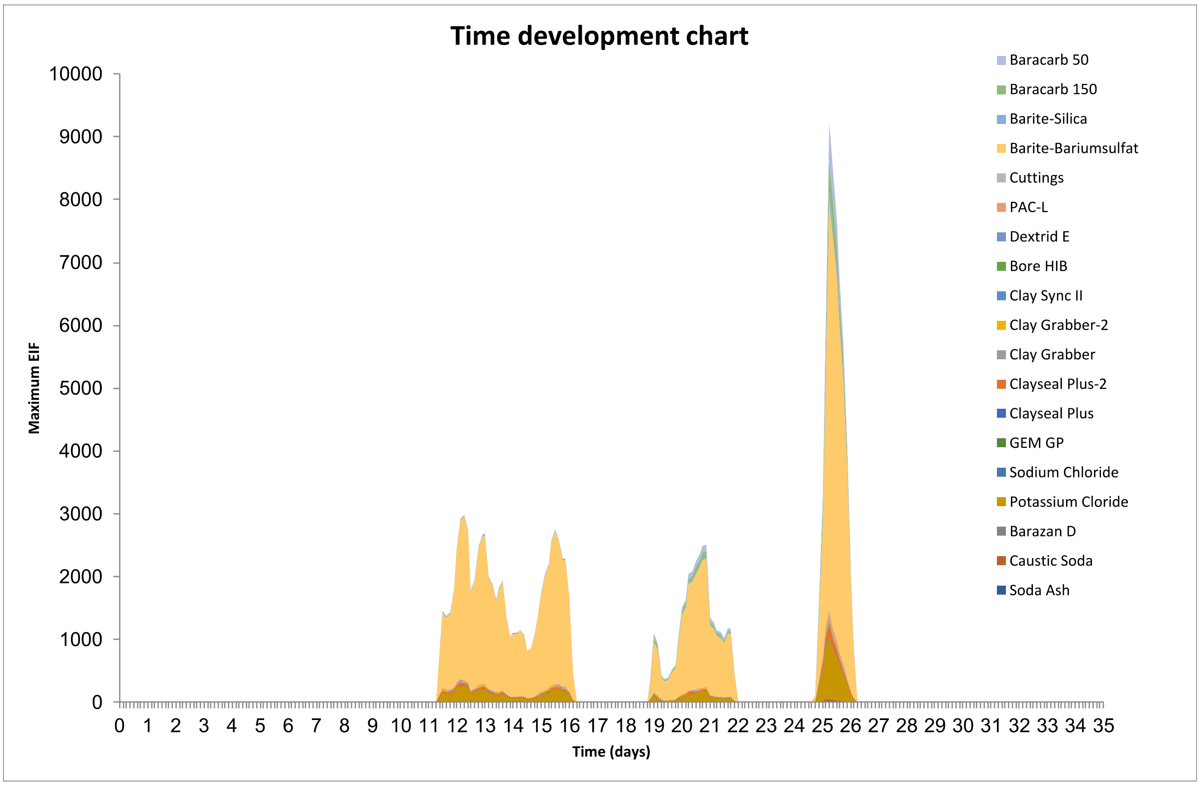


Figure 8.17 Time development of the EIF for the upper water column, for discharge location 4 Autumn.

Figure 8.18 shows the time instant with maximum EIF for the upper water column due to discharges from rig 10 m below sea surface, while Figure 8.20 shows the maximum cumulative risk (foot-print) throughout the upper water column at any time during the drilling operation with discharges from the rig.

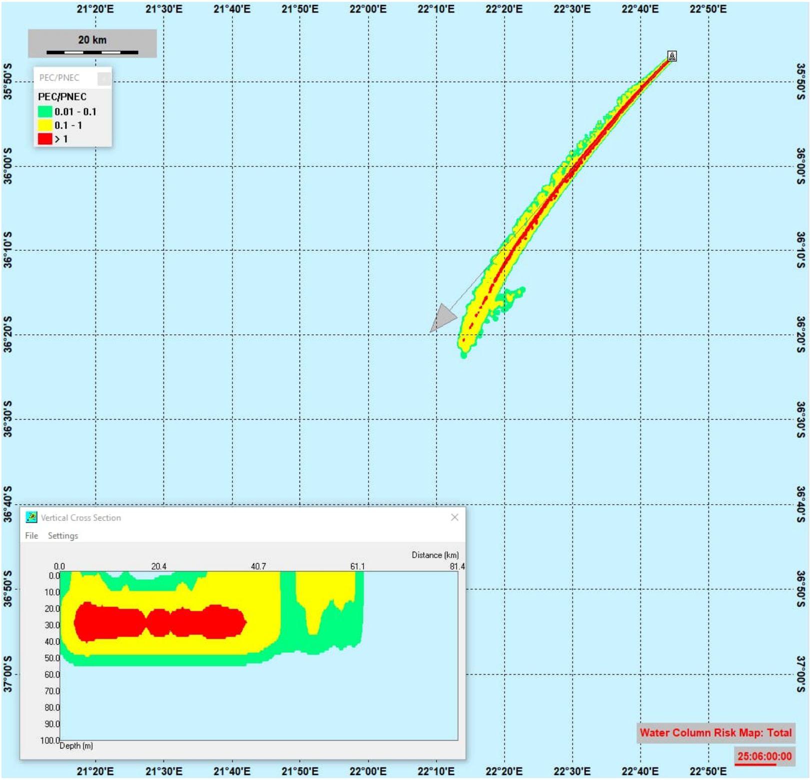


Figure 8.18 *Snapshot showing the time instant with maximum EIF for the upper water column between 0-100 meters. Snapshot from 25.25 days after start, for the discharge released from the rig. The vertical cross section shows the PEC/PNEC ratio in the water column along the grey arrow. Discharge location 4 – Autumn.*

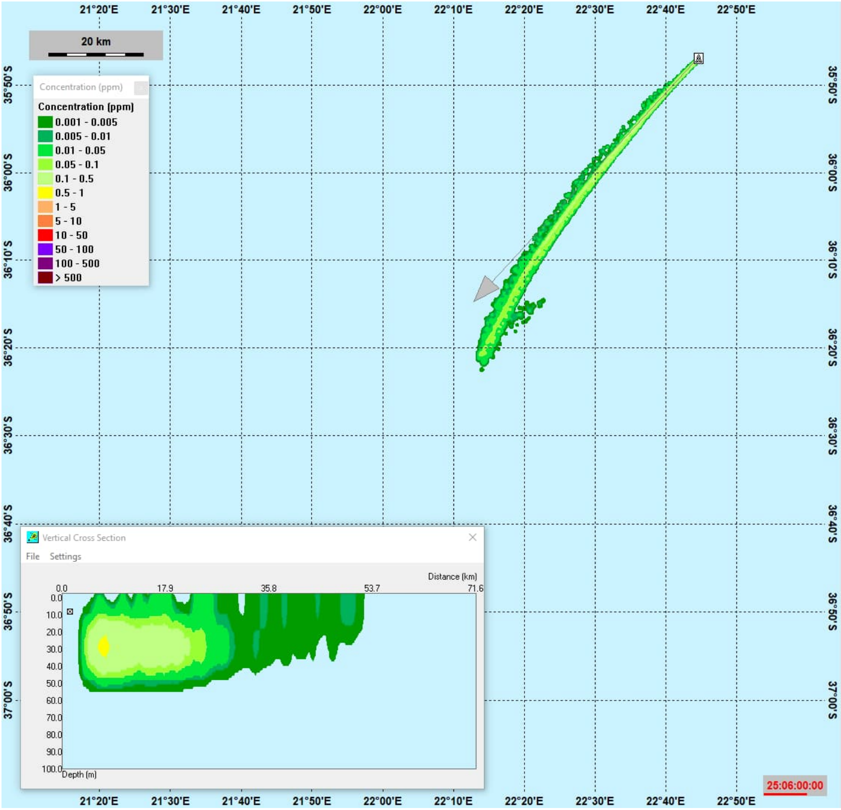


Figure 8.19 *Concentration field for the component that gave the largest contribution to the environmental risk, namely the particle group Barium sulfate, at the same time-step as for maximum EIF. Discharge location 4 – Autumn.*

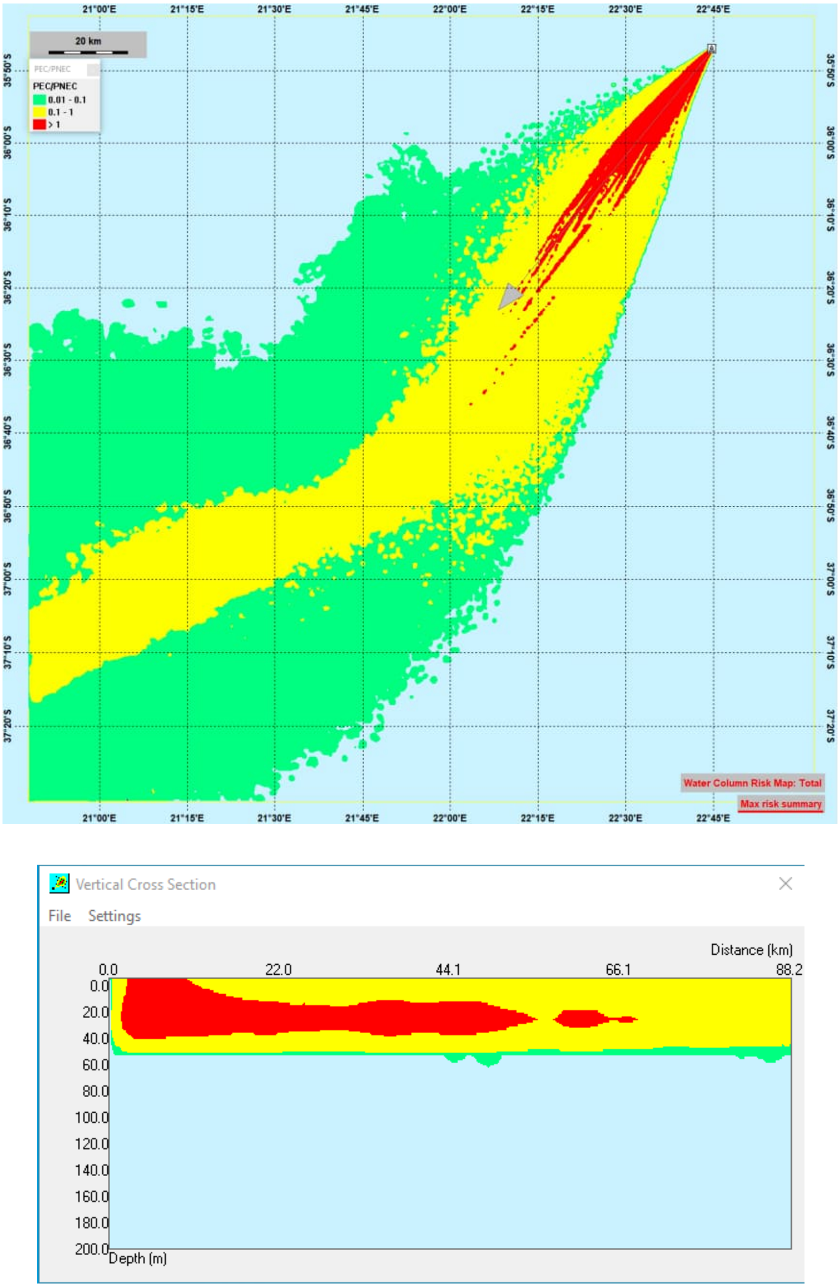


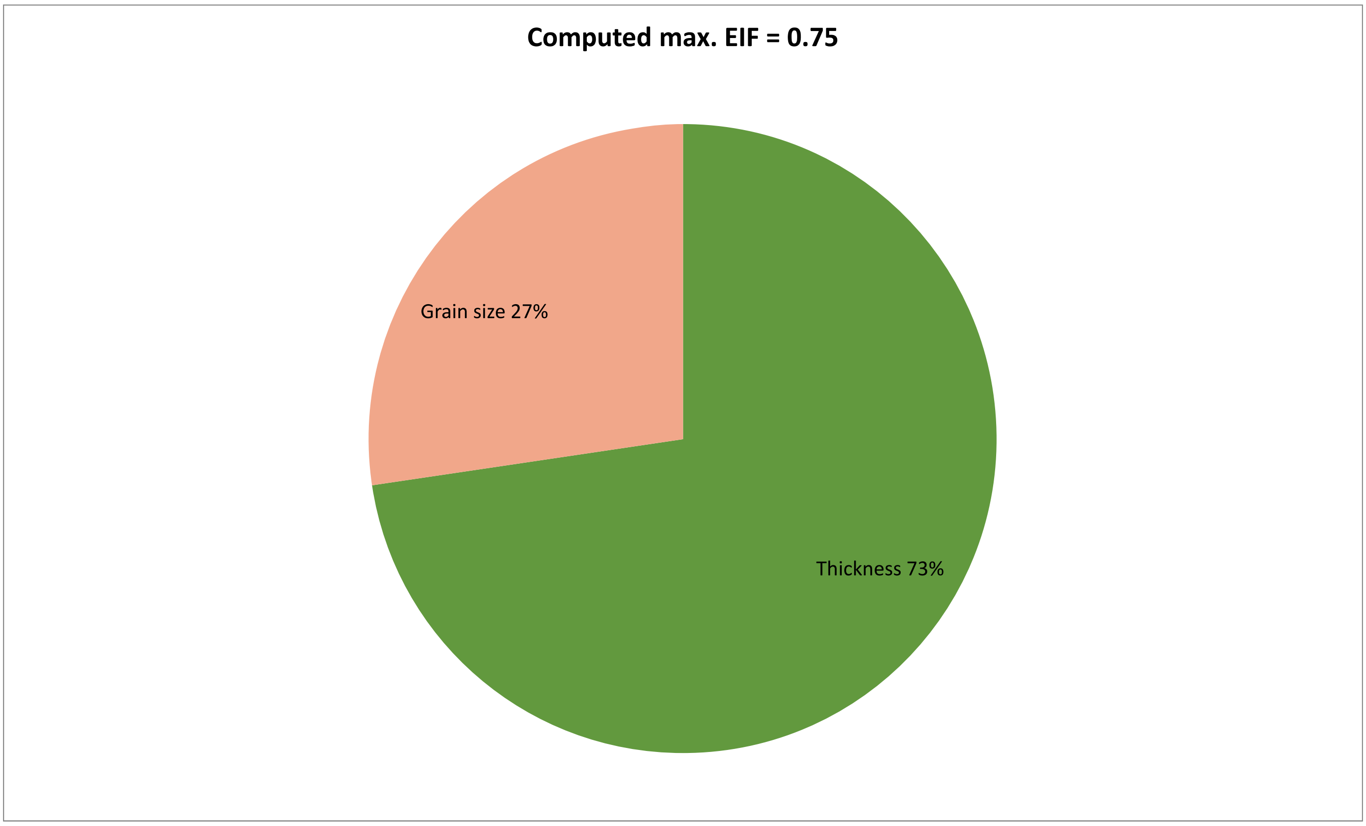
Figure 8.20 Maximum cumulative risk of drilling operations throughout the upper water column at any time for discharge location 4 (Start time March 12), discharge from rig 10 m below sea surface. Discharge location 4 – Autumn.

8.2.3 Discharge location 4 - EIF results for the sediment – Autumn

The maximum EIF (sea floor area 100x100 m^2) is computed with 1.5 impacted by discharge from the rig, and 0.75 impacted by the top hole discharge. The contributions of the components of the discharge are listed in the table below (risk in % of EIF). The affected area on the sea floor is largest at the end of the transport and fate simulation, shortly after the sediment module starts. After that the sea floor will start to restore and the impacted area (EIF) will get smaller. The factor affecting risk for the rig discharge is only grain size as for discharge location 4, Summer.

Table 8.7 Table and pie-chart shows contributions to EIF from the components discharged from the top hole sections to the sediment for location 4 – Autumn.

Simulated instantaneous EIF:	**0.75**				
Components	Product	PNEC ppb	Contribution to risk %	Contribution max EIF	Contribution time averaged EIF
Total					
Barazan D		420	0	0	0
Soda Ash		200	0	0	0
Caustic Soda		20	0	0	0
Potassium Cloride		100	0	0	0
Starcide		49	0	0	0
Thickness		0	72.64	0.5448	0.5448
Oxygen		0	0	0	0
Grain size		0	27.36	0.2052	0.2052



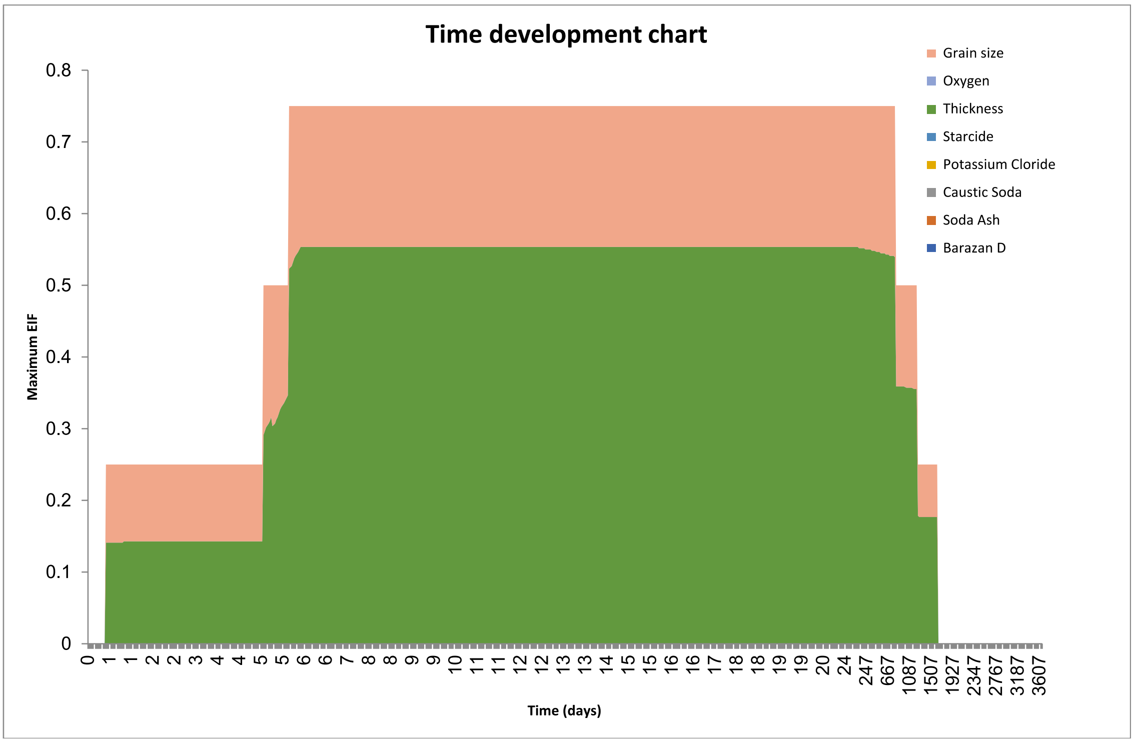


Figure 8.21 Time development of EIF for discharge from the top hole sections for the sediment for discharge location 4 – Autumn.

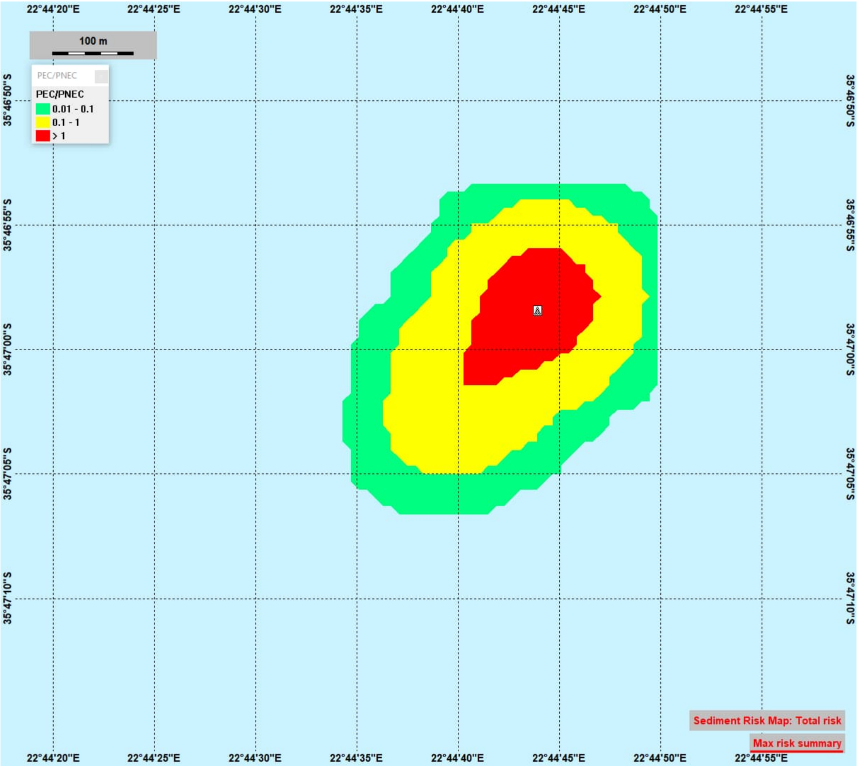


Figure 8.22 The total maximum EIF for the sediment (highest value at each location over simulation period) for discharge location 4 – Autumn.

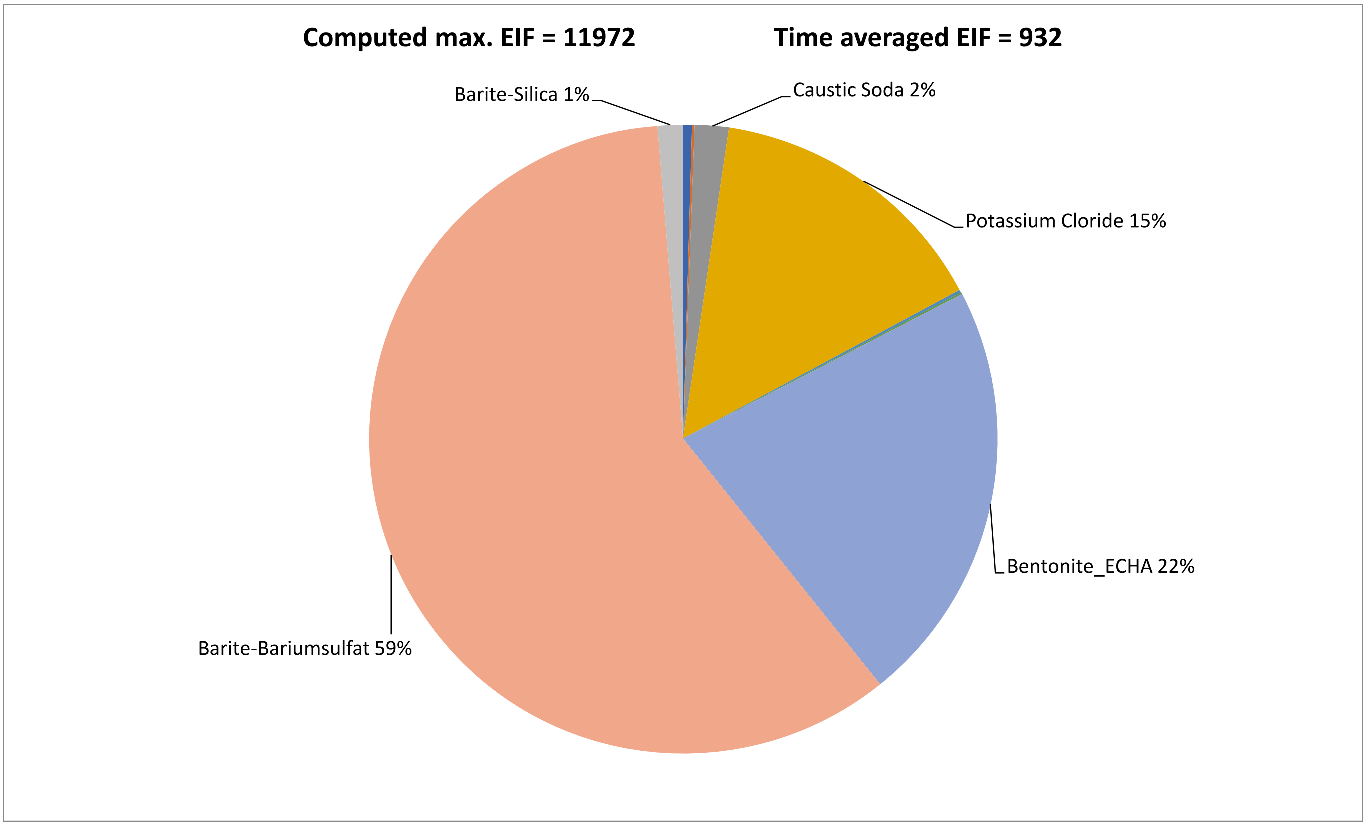
8.3 EIF results for discharge location 4, Winter

8.3.1 Discharge location 4 - Lower water-column – Winter

The maximum EIF (water volume 100x100x10 m^3) in the lower water-column 1100 - 1300 meters for discharge location 4, Winter, was 11972, while the time average EIF was 932. The contributions of the components of the discharge are listed in the table below (risk in % of EIF).

Table 8.8 Table and pie-chart with EIF results for the lower water column, 1100 - 1300 meters. Discharge location 4 – Winter.

Computed max. EIF:	**11972**				
Time averaged EIF:	932				
Components	Product	PNEC ppb	Contribution to risk %	Contribution max EIF	Contribution time averaged EIF
Total					
Barazan D		420	0.48	57.4657	4.4735
Soda Ash		200	0.13	15.5636156	1.2116
Caustic Soda		20	1.75	209.51021	16.3095
Potassium Cloride		100	14.79	1770.660575	137.8389
Starcide		49	0.13	15.5636156	1.2116
Cuttings		100000	0.1	11.972012	0.9320
Bentonite_ECHA		170	21.86	2617.081823	203.7294
Barite-Bariumsulfat		115	59.48	7120.952738	554.3377
Barite-Silica		440	1.29	154.4389548	12.0225



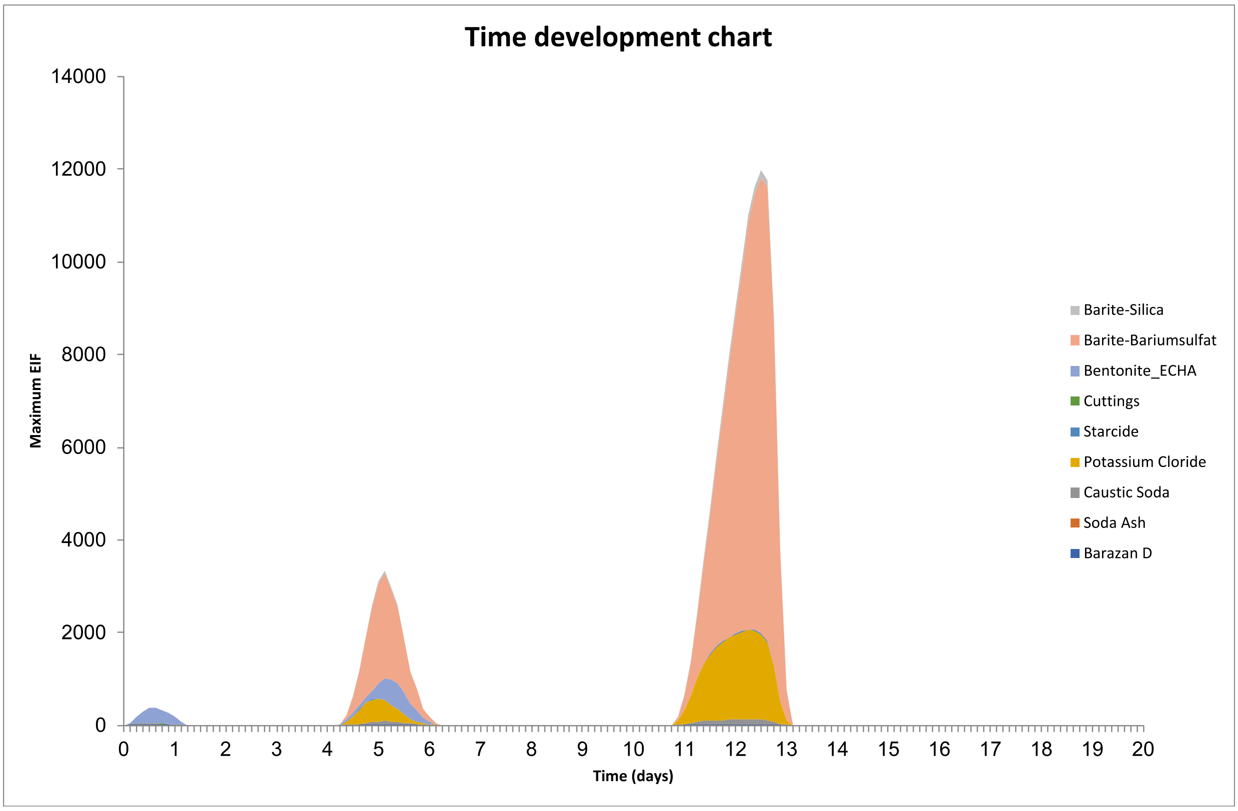


Figure 8.23 Time development of the EIF for the lower water column. Discharge location 4 – Winter.

Figure 8.24 shows the time instant with maximum EIF for the lower water column due to discharges from the top hole sections, while Figure 8.26 shows the maximum cumulative risk (foot-print) throughout the lower water column at any time during the drilling operation with discharges from the top hole sections.

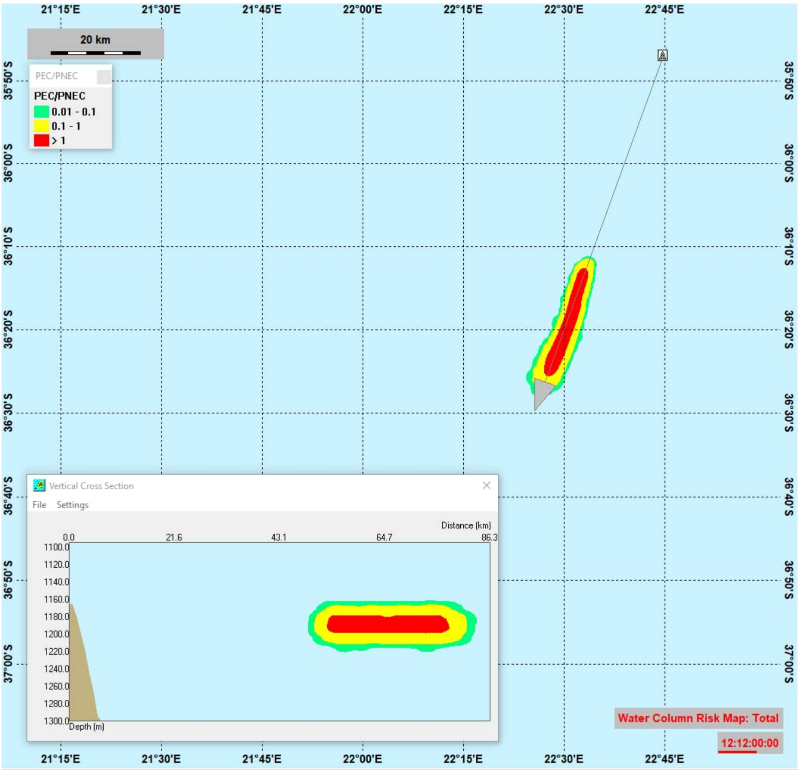


Figure 8.24 *Snapshot showing the time instant with maximum EIF for the lower water column at 1100 - 1300 meters. Snapshot at day 14.5, when the discharge is from the top hole sections on the sea floor. The vertical cross section shows the PEC/PNEC ratio along the grey arrow. Discharge location 4 – Winter.*

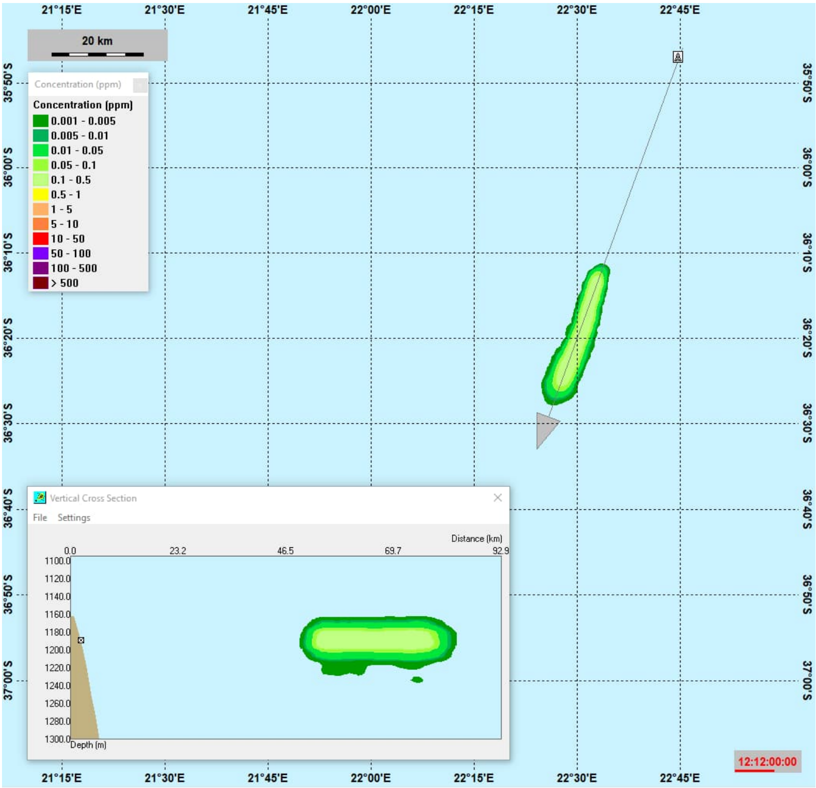


Figure 8.25 *Concentration field for the component that gave the largest contribution to the environmental risk, namely the particle group barite, at the same time-step as for maximum EIF. A cross-section of the plume is shown in the smaller panel. Discharge location 4 – Winter.*

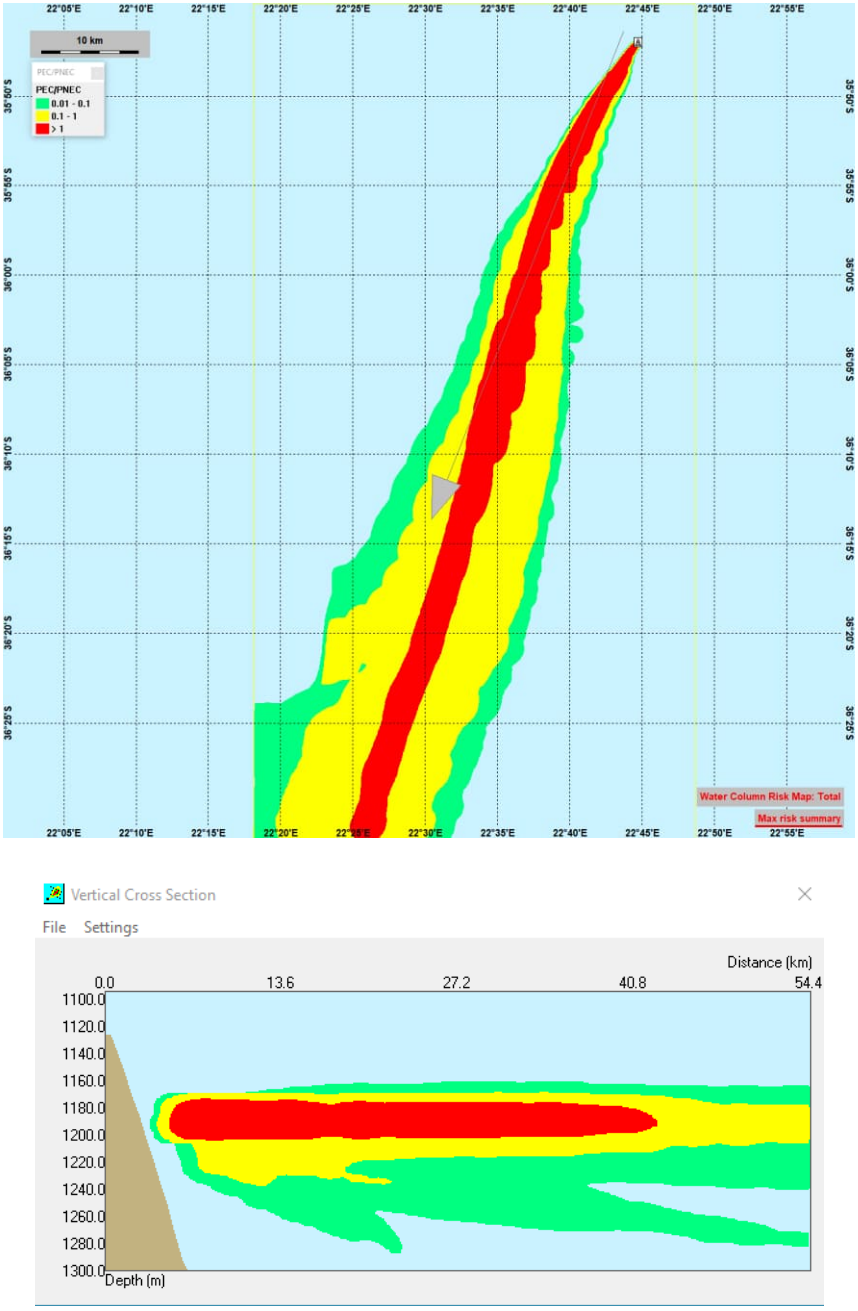


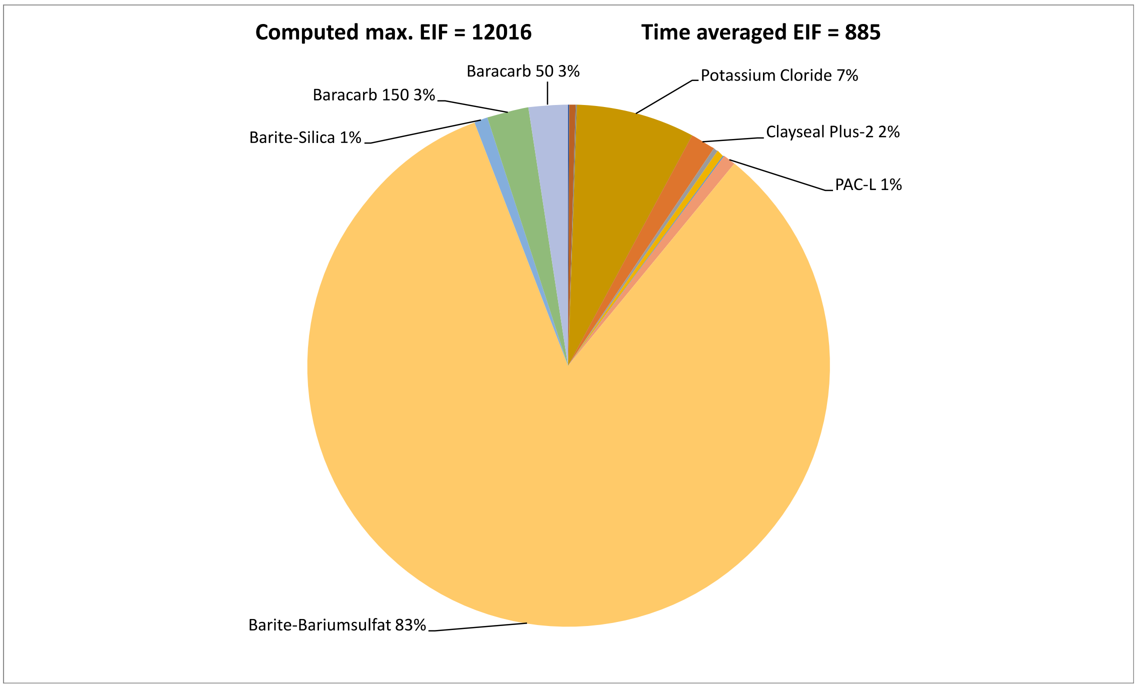
Figure 8.26   Maximum cumulative risk of drilling operations throughout the lower water column at any time for discharge location 4 (Start time August 14) Discharge at the seafloor. Discharge location 4 – Winter.

8.3.2 Discharge location 4 - Upper water-column – Winter

The maximum EIF (water volume 100x100x10 m3) in the upper water-column 0-100 meter for discharge location 4, Winter, was 12016, while the time average EIF was 885. The contributions of the components of the discharge are listed in the table below (risk in % of EIF).

Table 8.9 Table and pie-chart with EIF results for the water column, upper 100 meter for discharge location 4, Winter.

Computed max. EIF:	**12016**				
Time averaged EIF:	885				
Components	Product	PNEC ppb	Contribution to risk %	Contribution max EIF	Contribution time averaged EIF
Total					
Soda Ash		200	0.03	3.6048	0.2654
Caustic Soda		20	0.37	44.4591	3.2728
Barazan D		420	0.08	9.6128	0.7076
Potassium Cloride		100	7.33	880.7700	64.8375
Sodium Chloride		1000000	0	0	0.0000
GEM GP		188	0.03	3.6048	0.2654
Clayseal Plus		562.3	0	0	0.0000
Clayseal Plus-2		0.45	1.51	181.4410	13.3567
Clay Grabber		9.8	0.33	39.6527	2.9190
Clay Grabber-2		1.31	0.42	50.4670	3.7151
Clay Sync II		1160	0.02	2.4032	0.1769
Bore HIB		146	0	0	0.0000
Dextrid E		1000	0.08	9.6128	0.7076
PAC-L		87.26	0.71	85.3133	6.2803
Cuttings		100000	0	0	0.0000
Barite-Bariumsulfat		115	83.23	10000.8855	736.2111
Barite-Silica		440	0.85	102.1357	7.5187
Baracarb 150		115	2.5	300.3991	22.1138
Baracarb 50		115	2.5	300.3991	22.1138



The results show that for the upper water column, effects caused by discharges of particle matter (essentially Barium sulfate 83%) are dominating the risk in the affected water volume. During the time of maximum EIF, the discharge is released from the rig 10 meters below sea-surface and sinks down in the water-column.

Figure 8.27 shows the time development for the EIF in water-column. It shows that the duration with high environmental risk diluted and disappears shortly after discharge.

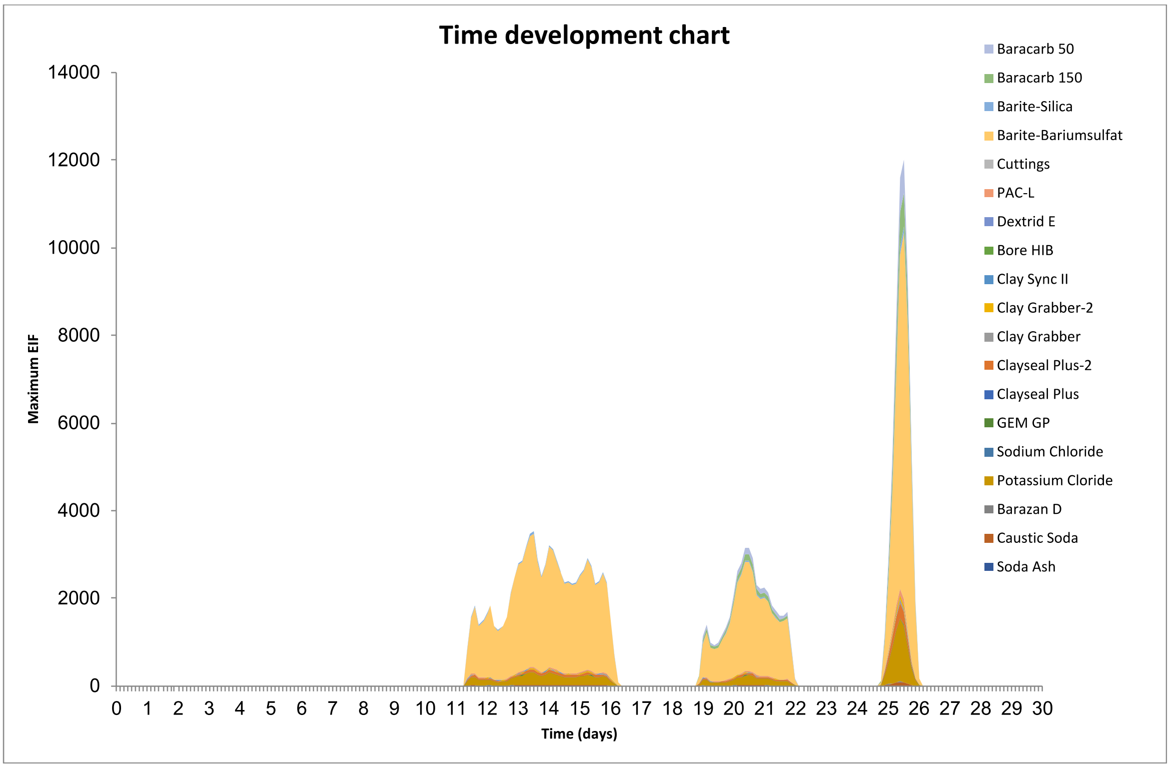


Figure 8.27 Time development of the EIF for the upper water column, for discharge location 4 Winter.

Figure 8.28 shows the time instant with maximum EIF for the upper water column due to discharges from rig 10 m below sea surface, while Figure 8.30 shows the maximum cumulative risk (foot-print) throughout the upper water column at any time during the drilling operation with discharges from the rig.